AMOS

NTNU – Trondheim
Norwegian University of
Science and Technology

AMOS

Centre for Autonomous Marine Operations and Systems

Annual Report 2014

Norwegian
Centre of
Excellence

The Research Council of Norway

OUR VISION

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

Editors: Annika Bremvåg and Thor I. Fossen
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DIRECTOR'S REPORT: LICENCE TO CREATE ...

AMOS has completed its second year of operation and has become a lively scientific centre of research on autonomous marine operations and systems with the licence to create – competence, knowledge and innovations. The organisation efficiently operates with strong support from NTNU, as the host institution, and committed partnerships with the Research Council of Norway, Statoil, DNV GL, MARINTEK, SINTEF Fisheries and Aquaculture and SINTEF ICT. In addition to the core activity of AMOS, several new associated research projects, which expand the capabilities of AMOS and the centre's impact, are established with national and international collaborators.

Licence to create competence

Currently, 65 young and talented PhD candidates, including ten females and four post-doctorates are employed at NTNU in AMOS research areas. 88 MSc students fulfilled their master's degree requirements in cooperation with AMOS in 2014, and five candidates received their PhD degrees in 2014.

In the past year, one new full professorship on sensor fusion was sponsored by DNV GL and three new professor-II positions on marine hydrodynamics and structural mechanics have been created to increase the expertise offered at different levels to students and to strengthen the in-depth research performed at the centre.

AMOS has been instrumental in the development of a joint PhD degree (Cotutelle agreement) between NTNU and the Technical University of Denmark (DTU). The first PhD candidate has been enrolled at AMOS. This degree program will strengthen the cooperation between AMOS and DTU researchers. Four DTU professors are currently employed in adjunct positions.

NTNU will coordinate a new Marie Skłodowska-Curie Innovative Training Network on Autonomous Marine Unmanned Aerial Systems for Marine and Coastal Monitoring with a grant provided by the EU to fund and train 15 doctoral students. The project initiative was initiated by AMOS and is completely aligned with the research strategies of AMOS and our partners.

Licence to create knowledge

AMOS is organised into nine research projects and nine associated projects. AMOS is creating new knowledge in the fields of hydrodynamics, structural mechanics, guidance, navigation, control and optimisation within the following research areas:

1. Autonomous offshore renewable energy
2. Offshore aquaculture
3. Autonomous unmanned vehicles and operations
4. Smarter, safer and greener marine vessels and operations

Cutting edge interdisciplinary research will provide the needed bridge to provide autonomy for ships, ocean structures, unmanned vehicles and marine operations.

Selected research highlights for 2014:

Guidance navigation, control and optimization

- A new method for integral line-of-sight (LOS) guidance, which includes its stability analysis, was developed by Lekkas and Fossen (2014). This method compensates for unknown environmental disturbances that occur during vehicle path-following control. A generic theoretical result, which proves that the well-celebrated proportional LOS guidance law for path following is uniformly semi-globally exponentially stable, was published in Automatica by Fossen and Pettersen (2014). Additionally, theoretical results on synchronisation of networked vehicles and agents was published in Automatica by Peymani et al. (2014).
- The research group also conducted important theoretical and experimental work on autonomous net-landing systems for UAVs using single-frequency carrier-phase differential GNSS for accurate positioning. The main results will appear in the IEEE Aerospace and Electronic Systems Magazine in 2015. Extensions of this work on autonomous landing onboard ships are in progress.
- Intervention AUVs is another topic of research, and new research results on robotic manipulator control that can increase the degree of autonomy for both remotely operated vehicle (ROV) operations and intervention AUVs have been developed. Furthermore, the research group developed significant new results for hyper-redundant underwater manipulators, i.e., swimming snake robots. These robots may constitute the next generation of intervention AUVs. In particular, these robots have the promising potential to improve the efficiency and manoeuvrability of next-generation AUVs.
- A new method for seafloor geometry approximation in a local region beneath an ROV for use in altitude control was developed by Dukan and Sørensen (2014). The ROV altitude and sea floor gradient, which are obtained from the sea floor approximation, are used in a guidance law for altitude control. The altitude observer and guidance law have been implemented in the control system of ROV Minerva and have successfully been used in several research campaigns.
- Unmanned oil and gas platforms are interesting for extracting resources from smaller oil and gas fields, and we have developed new methods for robot manipulators that are mounted on moving platforms. These developments include results for robot manipulators mounted on ships, underwater vehicles and ground vehicles. Singularity-free models were developed for the combined motion of the robot manipulator and platform and algorithms based on optimisation. A Springer textbook on the topic was published by From et al. (2014).
- Dynamic energy storage concepts, such as battery and capacitor banks, are currently being introduced as a way to increase the operational efficiency of ships, which allows temporary high power demands to be provided by these systems to reduce the number of installed or running generators and improve emissions or fuel economy. In a recent article, it was shown how the potential and kinetic energy of the ship hull itself can be effectively used as short-term dynamic energy storage that can be exploited on dynamically positioned (DP) ships.

Hydrodynamics

- Fish-farms operate in exposed areas, and thus, their behaviour must be assessed in waves and currents. A simplified model, which retains the main components of an aquaculture structure, was tested experimentally and numerically. Many parameters were varied to quantify their effects on the mooring-lines loads, which showed that mean loads are dominate over dynamic loads.
- Moonpools are expected to be widely used in lowering and lifting operations for subsea activities. The opening, which is well below the sea surface, leads to safer conditions unless the water inside the moonpool undergoes resonance, which in the worst case, will move up and down like a piston. Flow separation can mitigate this and must be modelled; however, there is an issue of computational costs. This is one example where two methods were combined to ensure efficiency and reliability.
- Control of CO_2 emission is a critical environmental issue and for ongoing study, becomes more challenging in heavy weather for maritime transport. This control is affected by the added resistance and loss of pro pulsion experienced by vessels in waves and also the decisions of the shipmaster.
- Sloshing is dangerous for membrane LNG tanks. An experimental-theoretical study confirmed the importance of coupling between structural and hydrodynamic problems, which showed that its structural stresses are much greater than that on a rigid tank.
- In severe waves, ships can become unstable and experience large roll motions (parametric roll); moreover, loss of freeboard can lead to compact masses of water invading the deck (water on deck). The performed investigation showed that these two phenomena affect and generally tend to worsen each other.

Structural mechanics

- The effect of the ship–platform interaction on the distribution of damage to offshore platforms subjected to ship collisions was investigated by means of nonlinear shell finite element analysis in a study by Storheim and Amdahl (2014). For floating platforms, penetration of bulbous bows or stern sections into cargo tanks or void spaces, which are essential for hydrostatic stability, may be critical. For high-energy collisions against fixed jacket platforms, it is essential that braces are capable of penetrating into the ship bow without significant plastic bending or local denting. The work will be used to revise NORSOK standard N-004. A method for reliable failure prediction of coarsely meshed shell structures was developed by Storheim et al. (2015).
- Offshore structures must resist rare ice loads with return periods of 1000 years. Large permanent deformations are accepted; however, cargo tanks and global integrity shall remain intact. Integrated analysis is required with a continuum mechanics model of the ice feature. To verify the material model, towing impact tests were performed in the Aalto's ice laboratory, and pilot tests were performed in SIMLab's pendulum accelerator rig in collaboration with SAMCoT. The test was presented on the Discovery Channel.
- Failures of drivetrain components are a primary challenge in connection with wind turbines and are a significant cost factor. It is therefore important to identify and repair the damage before it becomes critical. A prognostic method was established to detect faults in gears and bearings in wind turbine drivetrains. This method is based on angular velocity measurements of the gearbox input shaft and the output to the generator and a comparison between the faulty and fault-free conditions in the frequency domain. The method is shown to be simple yet accurate for detecting bearing faults at various locations in a gearbox model implemented in multibody dynamic simulation software.
- Structural reliability methods are used to make rational decisions in the various life cycle phases to ensure compliance of the implied safety level with the target level. This methodology is extended to cover mechanical equipment, such as gears and bearings. At the same time, it is demonstrated how the design, monitoring, inspection and repair of such equipment can be improved by introducing first principles to describe the ultimate and fatigue limit states as well as how the inherent uncertainties can be modelled.

Licence to create innovations

AMOS is targeting fundamental research and creating knowledge and competence that will contribute to improved international competitiveness of Norwegian industries and the safety and protection of the marine environment. A target is established to decrease the distance between fundamental research and value creation. Consequently, the AMOS School of Innovation is established to train AMOS researchers in innovation. The majority of the innovation will be achieved with partners and collaborators. Within selected areas, AMOS will create new companies based on the commercial potential. AMOS will contribute with its expertise by knowledge-based competence and innovations to strengthen the growth of the "blue economy" within the following areas: maritime transportation, offshore oil and gas, fisheries and aquaculture, offshore renewable energy, marine science and marine mining.

Celebration of two marine lighthouses

More than 250 former PhDs, colleagues and friends were invited to "The 70 years anniversary seminar and celebration of Professor Odd M. Faltinsen and Professor Torgeir Moan", which was held on May 19–20, 2014. A once-in-a-lifetime seminar was organised to tribute Moan's and Faltinsen's contribution to the field of marine technology, particularly to the disciplines of marine hydrodynamics and marine structures. Both professors have a remarkable career with world-class scientific merits. They have educated more than 100 PhD and hundreds of MSc students, have published more than 900 scientific papers and several textbooks, and have given numerous keynote presentations and plenary lectures. With more than 40 years of activity and relevant research and education, the industrial impact on maritime, oil and gas, fisheries and aquaculture and offshore renewable energy is tremendous. We are pleased and honoured that they are part of AMOS core group of scientific advisors to the centre.

I thank all colleagues, researchers, PhD and MSc students, partners and collaborators for their efforts in *creating competence, knowledge and innovations for a better world.*

Sincerely

Professor Asgeir J. Sørensen
Director AMOS

ORGANIZATION, COLLABORATORS, AND FACTS AND FIGURES 2014

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Torgeir Moan, Marine Structures

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Key Scientists
Jørgen Amdahl, Marine Structures

Thor I. Fossen, Guidance, Navigation and Control

Marilena Greco, Hydrodynamics

Tor A. Johansen, Optimization and Control

Kristin Y. Pettersen, Motion Control

Asgeir J. Sørensen, Marine Control Systems

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. AMOS researchers are currently co-operating with the following institutions:

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

National collaborators

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

- Ecotone AS, contact person: Ivar Erdal
- Kongsberg Maritime, contact persons: Dr Nils Albert Jenssen, Bjørn Gjeldstad, Arne Rinnan
- Maritime Robotics AS, contact person: Vegard E. Hovstein
- NORUT, contact person: Dr Rune Storvold
- Norwegian Defence Research Establishment (FFI), contact person: Nils-J. Størkersen, Stein Grinaker
- Rolls-Royce Marine, contact persons: Dr Jann Peter Strand Dr Ivar A. Ihle
- The University Centre in Kjeller (UNIK), contact person: Professor Oddvar Hallingstad
- The University Centre in Svalbard (UNIS), contact persons: Professor Geir Johnsen, Professor Jørgen Berge
- University of Tromsø - ARCTOS and Mare Incognitum, contact person: Professor Jørgen Berge

Facts and figures 2014

Personnel

- 6 keypersons
- 6 adjunct prof.
- 12 affiliated scientists
- 4 post-docs
- 65 PhD candidates
- 5 graduated PhD candidates
- 88 graduated MSc students
- 3 administrative staff
- 3 management
- 2 technical staff

Revenues

- Income: 44 852 KNOK
- Costs: 40 703 KNOK
- Year-end allocation:4 149 KNOK

Publications

- 2 books
- 2 book chapters
- 61 refereed journal articles
- 120 refereed conference papers
- 12 international keynote lectures

Dissemination

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

Innovation

- 1 company start-up
- 1 patent

PRESENTATION OF NEW AFFILIATED SCIENTISTS

Jo Arve Alfredsen

Associate professor, Department of Engineering Cybernetics, NTNU

Associate professor Jo Arve Alfredsen received his Master's degree (Siv. Ing.) in Engineering Cybernetics in 1992 and worked for several years in the maritime industry developing ship automation and propulsion control systems. Alfredsen later joined the research group of the legendary Prof. Jens G. Balchen, where he was engaged in the research and development of novel technologies for the fisheries and aquaculture sector, where his work ranged from large-scale robotic production of lobster juveniles to novel methods for controlling the behaviour of free-range fish. Subsequently, he received his PhD in Engineering Cybernetics in 2000.

After three years as a postdoctoral fellow at NTNU, Alfredsen became a permanent member of the faculty at the Department of Engineering Cybernetics, where he is currently teaching embedded and industrial computer design as well as heading the department's educational program and research activity on fisheries and aquaculture cybernetics. Over the last 10 years, Alfredsen has participated in and led several national and international research projects in the intersection between engineering cybernetics and fisheries and aquaculture production and biology, leading to more than 50 master students and 5 PhD candidates completed or currently under his supervision. His research interest is currently focused on sensors, instrumentation and remote monitoring technology for observing processes and life in the sea as well as automation and control systems for aquaculture production.

Edmund Brekke

Associate professor, Department of Engineering Cybernetics, NTNU

Associate professor Edmund Brekke earned a Master's degree in 2005 in Industrial Mathematics (Statistics) and a PhD degree in Engineering Cybernetics in 2010, which were both awarded by NTNU. His PhD research covered methods for target tracking using active sonar. This research was conducted at the University Graduate Center at Kjeller in close collaboration with Kongsberg Maritime.

After his PhD studies, Brekke worked as a postdoctoral research fellow at the Acoustic Research Lab at NUS in Singapore before becoming an associate professor in Sensor Fusion at NTNU in 2014. This professorship was awarded by DNV GL. Brekke's main research interests lie in Bayesian estimation with applications in parameter estimation, target tracking and autonomous navigation. Brekke is currently putting together a new KMB project on collision avoidance for autonomous surface vehicles. Application areas of his research are robotic navigation and automatic surveillance and monitoring.

Jørgen Juncher Jensen

Adjunct professor, Department of Marine Technology, NTNU, and professor at the Technical University of Denmark

Adjunct professor Jørgen Juncher Jensen received his PhD degree in Solid Mechanics from the Technical University of Denmark (DTU) in 1975. In 1974, he had joined the Department of Ocean Engineering at DTU as an assistant professor and later, in 1998, as a professor in Maritime Hydrodynamics. He became adjunct professor at NTNU in 2014. His research interests are primarily wave loads on ships and offshore structures with a focus on statistical methods for non-linear systems. He received the Dr. Techn. degree for this work in 1995. His main focus today is on wave-induced hydro-elastic responses of ships, and much of the research is done using the theory of conditional stochastic processes. Application areas include site specific assessment of jack-up units and tools for decision-support systems on ships.

He has been involved in several EU-sponsored projects as well as national projects and IMO work on probabilistic damage stability of ships.

Geir Johnsen

Professor, Department of Biology, NTNU

Professor Geir Johnsen works at the department of biology at NTNU and as an adjunct professor, at the University Centre on Svalbard (UNIS). He is one of the founding partners in the NTNU spin-off company Ecotone, which uses new optical techniques for mapping and monitoring the marine environment. He has had 1-year research stays at the University of California at Santa Barbara from 1992 to 1993 and at Curtin University in Perth, Australia from 2010 to 2011. He has supervised 33 master students and has graduated 12 PhD candidates. Currently, he supervises eight master students and four PhD candidates. He has published more than 100 papers in international journals and has been a co-editor for the books "Ecosystem Barents Sea" (Tapir Academic Press, 2009) and "Phytoplankton pigments: Updates on Characterization, Chemotaxonomy and Applications in Oceanography" (Cambridge University Press, 2011). His research areas include bio-optics, photosynthesis, pigment chemotaxonomy, underwater robotics and sensor development for in situ identification, mapping and monitoring of bio-geochemical objects of interest in the marine environment.

Martin Ludvigsen

Professor, Department of Marine Technology, NTNU

Professor Martin Ludvigsen's interest for the underwater environment began in his early teens when he started SCUBA diving, which has followed him until now. During his studies, his interest was strengthened and directed towards underwater robotics at Florida Atlantic University where he worked with autonomous underwater vehicles (AUVs). He followed this path and began working at the Danish AUR provider Maridan AS. His research focus became the application of underwater robotics, cameras and acoustical instruments that provide quantitative scientific information. Then, he worked with Sperre AS, which provides ROVs to the industry inshore and offshore. He became involved in the field of inspection maintenance and repair (IMR) and led the development and delivery of an IMR module handling system for the Åsgård field in AXTech AS.

Parallel to his industry activities, Ludvigsen participated in the start-up of the Applied Underwater Laboratory (AUR-Lab) at NTNU in 2009. The AUR-Lab provides possibilities for testing engineering trails and for the scientific collection of samples using underwater vehicles. Running a common pool of advanced under water equipment and maintaining an interdisciplinary research group has proven useful for both engineers and scientists. Today, the AUR-Lab is considered an essential asset for multidisciplinary marine research at NTNU, which facilitates a large body of research.

Ludvigsen's main research areas today are underwater robotics, underwater imaging, seabed mapping, complex marine operations, navigation, and new concepts for underwater vehicles.

Claudio Lugni

Adjunct professor, Department of Marine Technology, NTNU, and researcher at CNR-INSEAN, Italy

Adjunct professor Claudio Lugni received his Master's degree in Aeronautical Engineering in 1996 and his PhD Degree in Theoretical and Applied Mechanics in 1999 at the University of Rome. He was awarded with the Landrini Award in 2006.

Lugni was the director of the INSEAN scientific unit 3.0 "Seakeeping and Maneuverability" from 2007 to 2010 and affiliated researcher at the Centre of Excellence CeSOS (Centre for Ship and Ocean Structures) from 2003. He was scientifically responsible and manager of the research project '6DOF-RANSE- Phase I (2003-2005) and Phase II (2006-2009)", which was funded by the Italian Minister of Defence for the development, verification, and validation of numerical solvers for violent fluid-structure interaction. The research project was framed within a Memorandum of Understanding with the US Navy, including INSEAN, David Taylor Model Basin, ONR and the University of Iowa.

He was a member of the ITTC Committee 'Ocean engineering' from 2002 to 2003. Furthermore, he was co-founder and project manager of the CNR Spin-Off REMOCEAN.

Ulrik Dam Nielsen

Adjunct professor, Department of Marine Technology, NTNU, and associate professor at the Technical University of Denmark

In 2005, adjunct professor Ulrik Dam Nielsen obtained his PhD degree from the Section of Coastal, Maritime and Structural Engineering at DTU Mechanical Engineering. After four years as a post-doc and assistant professor at DTU, in 2009, Nielsen joined the staff of DTU Mechanical Engineering as an associate professor. His research and teaching is primarily about wave-ship interactions with a main focus on onboard monitoring and decision-support systems for operational guidance and performance. In his research, several topics are addressed, including analysis of full-scale measurements, in-situ estimation of the sea state at the location of an advancing vessel, fatigue damage accumulation in the hull girder and numerical models for the prediction of ship responses.

Nielsen is a board member of the Danish Society of Naval Architecture and Marine Engineering and serves as a member of the Royal Institution of Naval Architects (RINA) and the Society of Naval Architects and Marine Engineers (SNAME). He acts as chairman of the standing committee of the International Symposium of Practical Design of Ships and Other Floating Structures (PRADS) and is organising the next symposium to be held in Copenhagen in September 2016.

Nadezda Sokolova

Adjunct associate professor, Department of Engineering Cybernetics, NTNU, and researcher at SINTEF ICT

Adjunct associate professor Nadezda Sokolova received her PhD degree in 2011 from the Norwegian University of Science and Technology (NTNU), where she worked on weak GNSS signal tracking and the use of GNSS for precise velocity and acceleration determination. She holds an MSc degree in Geomatics Engineering from the University of Calgary in Canada and an MSc degree in Space and Aeronautical Engineering from the Narvik University College in Norway. Her primary research interests are in the areas of global navigation satellite systems and their augmentation via inertial and other secondary data sources.

Currently, she works as a research scientist at the Communication Systems department at SINTEF ICT, where she is involved in several research projects dealing with navigation and positioning technology. Highlight projects include work for the Norwegian Space Centre on ionospheric effects on satellite navigation, design of multi-frequency, multi-constellation GBAS for precision landing operations within the SESAR program project 15.3.7, design of GPS L1 C/A based GBAS within projects funded by the Norwegian Research Council (NORGAL) and Norwegian Space Centre (Arctic GBAS) as well as numerous smaller projects.

Rune Storvold

Adjunct associate professor, Department of Engineering Cybernetics, NTNU, and senior researcher at the Northern Research Institute (Norut)

In 2001, adjunct associate professor Rune Storvold obtained his PhD degree in Atmospheric Science from the Department of Physics at the University of Alaska Fairbanks. After two years as a research professional at the Geophysical Institute at the University of Alaska Fairbanks, Storvold joined the Department of Earth Observation at Norut. Research topics included remote sensing of snow and glacier properties using radar satellite data. The research was based on the use of radiative transfer and modelling of scattering properties. In 2005, he initiated the unmanned aircraft group at Norut and has lead this group since focusing on developing sensors, products and services based on unmanned aircrafts. Activities range from counting penguins in Antarctica to search-and-rescue activities in the North Sea. Storvold is co-chairing the Arctic Council, AMAP UAS expert group on airspace access in the Arctic for unmanned aircrafts. He is the director for the Arctic Center for Unmanned Aircraft (ASUF) and is a board member of UAS Norway. Storvold is on the scientific committees of the ISARRA and UAV conferences.

Alexander Timokha

Professor, Department of Marine Technology, NTNU, and professor at the Institute of Mathematics of National Academy of Sciences of Ukraine

Professor Alexander Timokha obtained his PhD degree in fluid dynamics from Kiev University in 1988 and later, earned the full doctor of science degree in physics and mathematics (habilitation) in 1993 at the Institute of Mathematics of the National Academy of Sciences of Ukraine (NASU). He is now a leading researcher and professor of Applied Mathematics at the Institute of Mathematics at NASU.

Timokha has been an Alexander von Humboldt-Fellow (2003-2004) as well as a visiting professor at Leipzig (1998-2001) and Jena (2004-2012) Universities. From 2004 to 2010, he has been a visiting professor at the Centre for Ships and Ocean Structures (CeSOS) in Trondheim, Norway. Since 2013, he is the honorary Visiting Professor at the University of Surrey, UK.

His scientific awards list includes the Golden Medal for the best young scientist of NASU (1993), President Early-Career Awards (twice from the Ukraine in 1994 and 1996), Petryshyn Award for the best work in nonlinear analysis (USA, 1994), Personal Scientific Award after M. Krylov (2000), State Award in Science and Technology of Ukraine (2012) and others. Timokha is an associated editor of the Journal of Applied Mathematics as well as the journal "Mathematical Problems in Engineering". In the 1980's, he was involved as a consultant for hydrodynamic aspects of spacecraft applications for the famous design offices Yuzhnoye and Salut.

His current research interests lie in mathematical aspects of hydromechanics with an emphasis on free-surface problems in general and on sloshing in particular. He has authored more than 170 publications and 4 books.

BOARD OF DIRECTORS

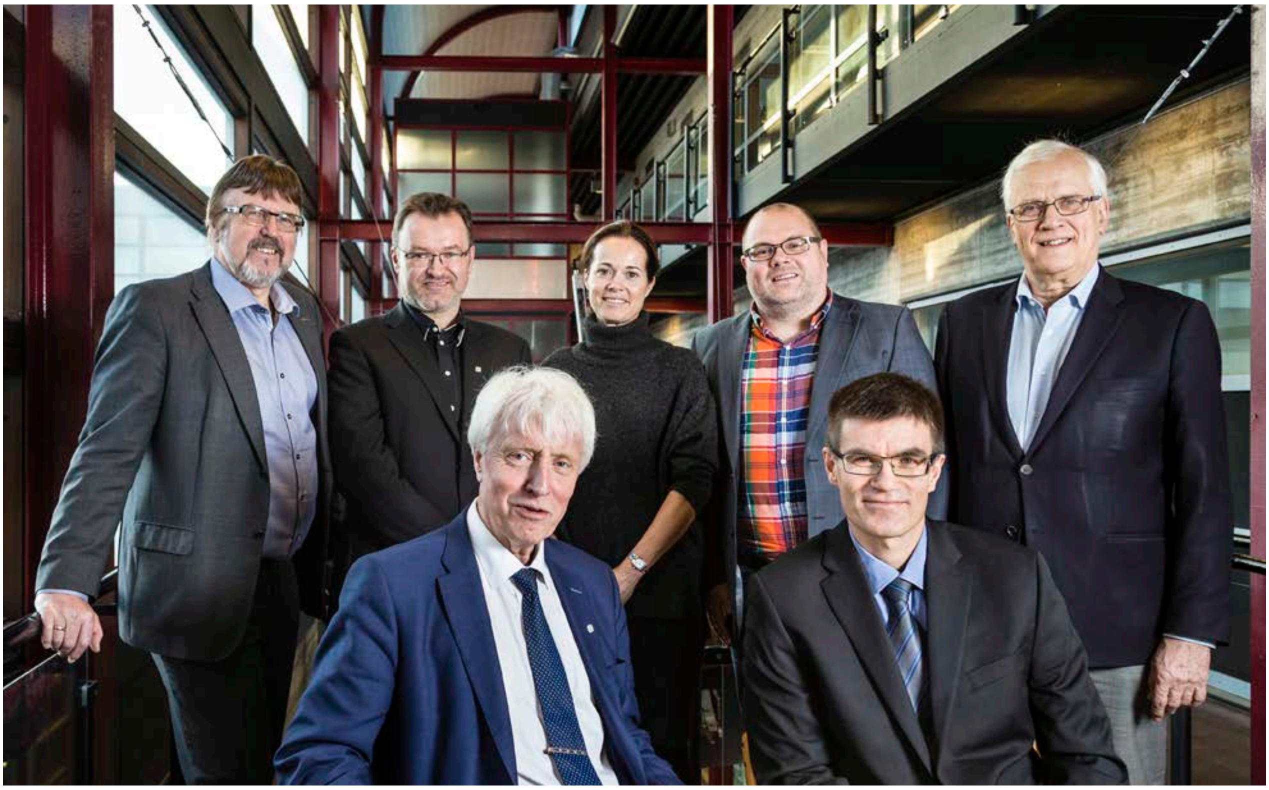

Figure 1: *From the left: Oddvar I. Eide (President, MARINTEK), Geir Egil Øien (Dean, Faculty of Information Technology, Mathematics and Electrical Engineering, NTNU), Ingvald Strømmen (Chair, Dean, Faculty of Engineering Science and Technology, NTNU), Liv A. Hovem (Director of Operations, DNV GL), Kjetil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

Fundamental results in all AMOS knowledge fields have been achieved. The Board is particularly satisfied with the strengthened scientific profile with the publication of 61 high-impact journal papers in 2014.

The number of recruited PhD candidates reached 65, which is impressive after only two years of operations. Several of the PhD candidates are funded by the nine associated projects which have been initiated by AMOS scientists. The target of graduating 100 PhDs within ten years seems highly realistic.

Even more PhDs and post-docs will be recruited through two new Centres for Research Based Innovation in which AMOS is a collaborator. AMOS was granted a Marie Skłodowska-Curie Innovative Training Network on Marine Unmanned Aerial Systems by the EU Commission. 15 PhD candidates and several research institutes and universities in Europe will cooperate.

AMOS School of Innovation is proceeding well with assistance from NTNU Technology Transfer. The PhD candidates have undertaken innovation training through seminars and meetings. One patent has been filed and one new spin-off company has been established.

The Board looks forward to a productive year in 2015, with excellent research and innovation providing outstanding competence and knowledge for the society.

The Board's endorsement of the annual report

The main responsibility of the Board of Directors is to ensure that 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 this annual report and endorsed it.

Ingvald Strømmen

Chair of AMOS' Board of Directors
Dean of the Faculty of Engineering Science and Technology at NTNU

A scheme of excellence

I have served as the Dean of the Faculty of Engineering Science and Technology (IVT) at NTNU since 2005. The Faculty is responsible for the education of 40% of the MSc students in engineering in Norway and is a partner in 19 Excellence Centres: Centre of Excellence (SFF AMOS), Centres of Environmentally Friendly Energy (FME) and Centres of Research-Based Innovation (SFI). Every year, the Faculty recruits 800 master's students to engineering studies, of which 44% of these students are female. Annually, the Faculty contributes 90 new PhDs to the Norwegian and international communities.

I am a professor in the field of energy and process engineering with a focus on the application of heat pumps for industrial purposes. Contributing to innovation and new industrial processes is both satisfying and stimulating. I received a Master's degree in Physics from the Norwegian Institute of Technology (NTH) in 1974 and a PhD in Refrigeration Engineering in 1980.

A culture of high-quality research and innovation

The Chairman of the Board of AMOS is an important and interesting position. The Faculty of Engineering Science and Technology has a focus on excellence, and a Centre of Excellence such as AMOS is a strong mechanism for developing a culture of high-quality research with considerable contribution to academic deliverables, such as high-quality publications and new PhDs. In addition, AMOS has an innovation focus, which can serve as the basis for new start-up companies.

From my position as the Chairman of the Board, I would like to contribute to the success of AMOS. The high level of academic deliverables is positive and influential to the research culture of the entire Faculty. The role of the Faculty is to develop technology for sustainability and innovation in society. AMOS is and will continue to be a very important mechanism for the fulfilment of this role.

Connecting excellent master's degree students to the Centre

The role of the Faculty of Engineering Science and Technology in AMOS is to contribute resources and infrastructure to ensure the success of the Centre. Key personnel are professors at the IVT- and IME-Faculty. In addition, the Faculty is paying substantial attention to the recruitment of master's degree students and PhD candidates. The Faculty has successfully recruited excellent students to all study programmes. Students from the Department of Marine Technology and the Department of Engineering Cybernetics can have their thesis work connected to AMOS. This connection is important for a successful centre. AMOS is also a considerable force for recruitment purposes. We have observed that excellence attracts excellence.

Ideas for the future

The continual focus on the main deliverables and improvements in international relations and networking with industry are important. The Centre has been successful in these areas. We look forward to an exciting future.

Liv A. Hovem

Member of AMOS' Board of Directors
Director Europe and Africa DNV GL Oil & Gas

My background story

I joined DNV in 1988 directly after earning my Master's degree in structural engineering at the Norwegian University of Science and Technology (NTNU). I searched for a place to work where I could pursue my technical interest which was structures in waves. I was eager to practice the skills I had learned at university; I wanted to be useful and was curious if I had chosen a profession that I would enjoy. I did, and a few years into my career, I was granted a scholarship and went to study hydrodynamics and structural reliability at UC Berkeley. I have worked in DNV (now DNV GL) ever since, and I am very happy with my choice.

AMOS' research areas are the way to go for the future

Challenges in the marine industry are currently more and more related to control and IT systems. Moreover, marine operations are more remote, and at the same time, tolerance for accidents and environmental implications are virtually zero. Taking this into effect, I truly believe that the field that AMOS is investigating is extremely relevant for the future. Systems will need to be optimised in terms of fuel consumption, emissions, safety and operational efficiency and cost. Autonomous systems are definitely a road to explore, which we have been seeing more recently with Google's autonomous cars and the use of drones.

For DNV GL as a company, it is important to follow the development in research and to ensure that we have the knowledge and competence to support the industry once the systems and technology are mature enough to be used. Personally, I also take great interest in watching closely how a Centre of Excellence, such as AMOS, is built and maintained over time.

A strong collaboration between AMOS, DNV GL and partner industries

DNV GL has had a long-term collaboration with NTNU over many years. We recruit many of our employees from NTNU, and in addition, there is a well-developed research collaboration between NTNU and DNV GL.

When NTNU hosts a Centre of Excellence, such as AMOS, which has an exciting and forward-looking theme, it is natural that we wish to follow it closely and contribute to its success. DNV GL's objective is to safeguard life, property and the environment. Thus, our role in AMOS is to ensure that these goals are being taken into consideration in the Centre's research and that it will be possible to monitor and control risks that autonomous systems introduce. Furthermore, we enjoy advising researchers based on our experience and acting as a bridge between the Centre and several of our partner industries. In our position, we can also indicate current research needs in the industry, as we did with unmanned gas production in remote areas and unmanned operation of wind farms.

The timing of AMOS is right and important

Looking at how rapidly AMOS has developed and grown with exceptional people engaged, I only see that my expectations to the centre have grown. I see that technology development and shifts in the industry have developed even faster than many of us foresaw and that the timing of AMOS is right and important. It is the right direction to develop, and regardless of how the autonomous systems will end up being used, be it in food production, energy production, maritime industry, mining or other areas we have not even thought of yet, it is important to stay focused and true to the original question AMOS set to answer.

RESEARCH PROJECTS

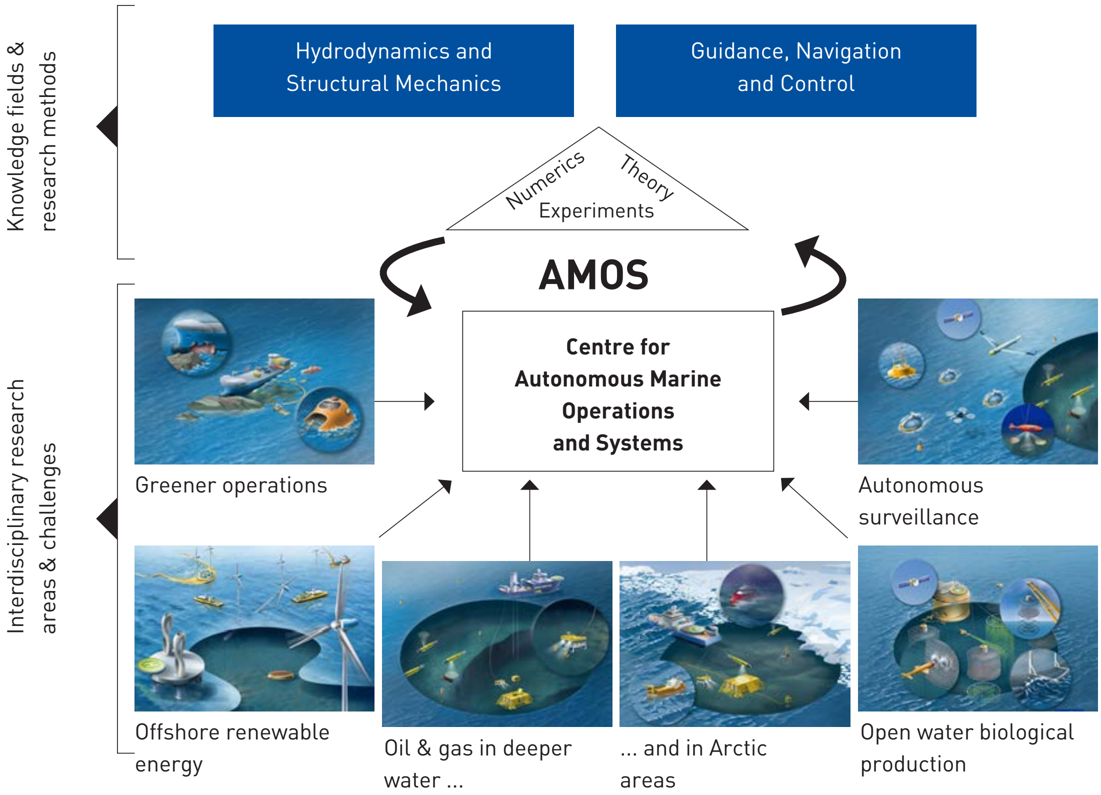

Figure 2: *AMOS research areas and knowledge fields.*

Optimization and fault-tolerant control of offshore renewable energy systems

Project manager: Professor Jørgen Amdahl
Research associates: Professors Asgeir J. Sørensen, Torgeir Moan, Martin Otto Laver Hansen, adjunct professor Jørgen R. Krokstad
PhD candidates: Emil Smilden, Jan-Tore Haugan Horn

The goal of the project is to develop integrated mathematical models for design, analysis, control and optimisation of jacket-supported or monopole offshore wind turbines (Figure 3) that considers the fluid-structure and soil-structure interaction effect on the structural response.

Novel turbine control strategies will be developed, which will also enable the inclusion of structural response monitoring, to reduce fatigue loads in operating conditions and prevent the exceedance of the ultimate strength during extreme loads or fault conditions. Modelling of nonlinear wave kinematics for hydrodynamic load calculation in extreme seas will be considered. Fast and reliable methods for nonlinear time-domain simulation of the aero-hydro-servo-elastic system will be evaluated. The project will commence in January 2015 with the recruitment of two PhD candidates.

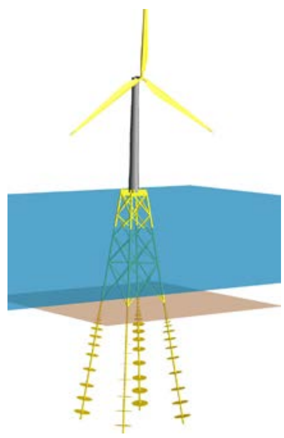

Figure 3: *Model of jacket-supported wind turbine with pile-soil modelling.*

Intelligent offshore aquaculture structures

Project manager: Professor Marilena Greco
Research associates: Professors Asgeir J. Sørensen, Jørgen Amdahl, Odd M. Faltinsen, Torgeir Moan
PhD candidates: Yugao Shen, Ida M. Strand, Stefan Vilsen

The potential for increasing marine food production is substantial due to the trend of relocating marine fish farms to more exposed areas. The fish farms will be subject to more energetic waves and stronger currents. The dimensions of the fish farms are expected to increase and new designs will appear. The importance of marine technology will consequently increase. The damage and collapse of floating fish farms have caused the escape of fish and significant economic loss. Damages may be caused by operational failures, breaking of mooring lines, anchor pull out or contact between chains or ropes and nets. Escaped farmed salmon may breed with wild salmon and produce genetic pollution of wild fish. Salmon lice is another concern, which has initiated investigations at AMOS in cooperation with SINTEF Fisheries and Aquaculture and industry partners in which a membrane structure is employed as the cover material for a cage; this cage is referred to as a closed flexible cage. The membrane structure can be considerably deformed in a current. Another issue is wave-induced sloshing inside the cage. Mathematical models that combine hydrodynamics, structural mechanics and automatic control of the inner fluid (hydraulics) are under development. Circular net cages with elastic floaters can also significantly deform in a current and their netting may contain 10 million meshes, which limits CFD and complete structural modelling. Recently, AMOS and its partners have begun the development of hybrid methods to analyse complex marine applications by integrating different numerical and physical systems to facilitate real-time communication between numerical systems and physical models.

Relevant research activities of the project for this year are as follows:

- Wave and current loads on fish farms
- Closed and flexible fish cages: Experimental study of current forces and deformations
- Hybrid model testing of cases that are relevant for fisheries and aquaculture

Wave and current loads on fish-farms

Using dedicated model tests and numerical simulations, Kristiansen and Faltinsen investigated the mooring loads on an aquaculture net cage in currents and waves. Compared with a realistic aquaculture plant, the total system is simplified and composed of a bottomless, flexible and circular net cage with an elastic floater, sixteen sinker weights and four crow feet mooring lines. The main purpose was to investigate the dominant physical effects for mooring loads. The mean loads dominate over the dynamic part of the loads in combined currents and waves and they significantly increase in long and steep waves, relative to the current. A sensitivity study indicated that a rigid floater significantly alters the loads in the mooring lines compared with a realistic, elastic floater and that the theoretical wave model is important. These loads are insensitive to the frequency-dependent added mass of the floater and the nonlinear restoring loads. The net cage with a very fine numerical mesh does not have to be represented. However, additional studies are required to investigate which parameters are essential in the analysis of the contact between chain/ropes and the subsequent rupture of the netting.

The wave-induced accelerations in elastic circular collars of floating fish farms have been numerically and experimentally investigated (refer to Figure 4). The experimental and numerical investigations examine a floater without a netting structure, with nearly horizontal moorings and in regular deep-water waves with different steepness values and periods without current.

The experiments highlighted the importance of higher-order harmonics of the accelerations. One reason may be over-topping of the waves, which was evident by the wave steepnesses $H/\lambda=1/30$ and $H/\lambda=1/15$ in the front part and aft part, respectively. Another reason may be that higher-harmonic wave loads produce excited resonant oscillations. A 3D weak-scatterer model with partly nonlinear effects and a 3D linear frequency-domain method, which are both based on potential flow, are numerically employed. The comparison with the measurements indicate a significant 3D and frequency dependency effect and flexible floater motions. The weak-scatterer model can only partly explain the nonlinearities in the measured accelerations.

Research to develop a simulation model for a well boat at a fish farm is underway.

Related publications:

- **Li, Peng; Faltinsen, Odd Magnus; Greco, Marilena.** Wave-Induced Accelerations of a Fish-Farm Elastic Floater: Experimental and Numerical Studies. I: 33rd International Conference on Ocean, Offshore and Arctic Engineering Volume 7: Ocean Space Utilization; Professor Emeritus J. Randolph Paulling Honoring Symposium on Ocean Technology. ASME Press 2014 ISBN 978-0-7918-4549-3. NTNU
- **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, NTNU

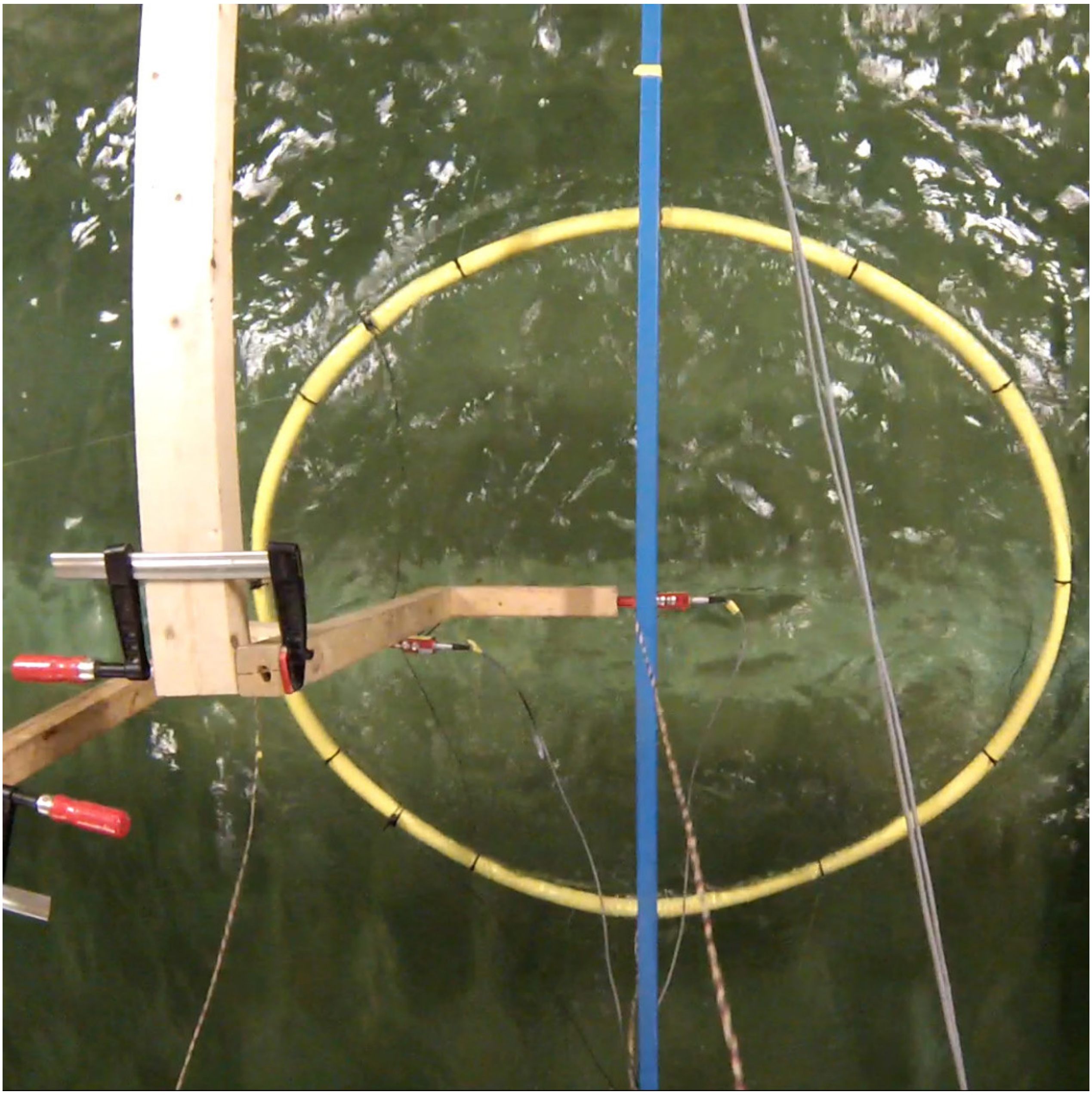

Figure 4: *Top view of the model tests with an elastic circular floater in regular waves.*

Autonomous unmanned vehicle systems

Project manager: Professor Tor Arne Johansen
Research associates: Professors Kristin Y. Pettersen, Asgeir J. Sørensen, Thor I. Fossen, Lars S. Imsland, associate professor Edmund Brekke
PhD candidates: Frederik S. Leira, Claudio Paliotta, Artur Zolich, Albert Sans Muntadas, Krzysztof Cisek, Anders Albert, Sigurd M. Albrektsen, Siri H. Mathisen

This project is dedicated to the analysis of fundamental challenges that need to be solved to enable fully autonomous vehicle systems to support marine operations. The study 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 mobile sensor networks.

The target outcomes of the project are robust communication and networking between heterogeneous vehicle systems and sensor networks, autonomous launch, recovery and docking systems, improved and efficient algorithms for sensor fusion, better methods for multi-vehicle mission and path planning, including obstacle avoidance and re-configurable control.

Automatic detection, classification and tracking of objects on the ocean surface using a thermal camera

Autonomous monitoring of the ocean surface from observation platforms to detect, recognise and track interesting objects, such as people, mammals, ships, and icebergs, is of significant interest in a number of applications. This project includes search and rescue, ice surveillance, security and collision avoidance.

AMOS researchers have examined how machine vision techniques can be used to process thermal images in real time onboard small mobile unmanned platforms to recognise the features of objects in the ocean and track and predict their motion from observations over time.

Related pulication:

- **Leira, Fredrik S.; Johansen, Tor Arne; Fossen, Thor I.** Automatic detection, classification and tracking of objective in the ocean surface from UAVs using a thermal camera, IEEE Aerospace Conference, Big Sky, 2015, NTNU

Unmanned aerial vehicle as communication relay for autonomous underwater vehicle

By combining the complementary features of autonomous underwater vehicles (AUVs) and unmanned aerial vehicles (UAVs) and coordinating their operation, AUV missions can be performed more efficiently.

AMOS has developed and field-tested communication relaying functionality that enables a small UAV to be deployed to travel to an AUV that goes to the ocean surface to download its data to the UAV and upload updated mission plans. In this manner, the ground control can maintain radio communication with the AUV at large distances due to the fast travel of the UAV and its superior radio communication quality, which is effective due to an elevated antenna for the AUV.

Related publication:

- **Johansen, Tor Arne; Zolich, A.; Hansen, T.; Sørensen, Asgeir J.** Unmanned Aerial Vehicle as Communication Relay for Autonomous Underwater Vehicle – Field Tests, IEEE Globecom Workshop – Wireless Networking and Control for Unmanned Autonomous Vehicles, Austin, TX, 2014, NTNU

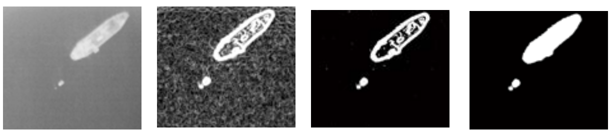

Figure 5a-d: *The figure shows a ship, RIB and buoy using a thermal camera mounted on an unmanned aerial vehicle at various stages of the machine vision recognition process. The images are taken from a field experiment with the University Porto in collaboration with AMOS.*

Figure 6a-b: *The figure shows the X8 UAV equipped with five antennas to support the different radio communication needs of AUV Remus 100's Wi-Fi link, ground station link, and telemetry.*

Autonomous underwater robotics for mapping, monitoring and intervention

Project manager: Professor Kristin Y. Pettersen

Research associates: Professors Mogens Blanke, Odd M. Faltinsen, Marilena Greco, Geir Johnsen, Martin Ludvigsen, Roger Skjetne, Asgeir J. Sørensen

PhD candidates: Inga Aamodt, Dennis J.W. Belleter, Mauro Candeloro, Daniel de A. Fernandes, Anna Kohl, Signe Moe, Mikkel C. Nielsen, Ingunn Nilssen, Petter Norgren, Stein M. Nornes, Martin Syre Wiig, Øyvind Ødegaard

Ocean space research using underwater robotics is important for mapping, characterisation and monitoring of the climate and the environment, exploration and exploitation of hydrocarbons and other minerals and resources in demanding areas, such as deep water and under ice. The main challenge is to increase the level of autonomy and robustness of underwater platforms for automatic mapping, monitoring and intervention considering both spatial and temporal coverage and resolution, high-level planning/re-planning and reconfiguration of single and multiple vehicles that are subject to the particular mission, environmental condition, available energy, communication constraints, and failure conditions. Methodology for integrated environmental mapping and monitoring using multiple sensor platforms and sensors to optimize knowledge gathering and sampling strategy is developed.

The project focuses on increasing the autonomy of remotely operated vehicles (ROVs) and autonomous underwater vehicles (AUVs). In addition, autonomous surface vessels (ASVs) are considered to support underwater operations. 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 and methods such as numerical optimisation, sensor fusion, guidance and nonlinear control and estimation.

Methods for coordinated and cooperative control of marine multi-agent systems are developed. Multi-agent operations have several advantages over conventional single agent operations. Using multiple agents enables tasks for single agents to be performed in parallel, which results in more time-efficient operations. Multiple simpler agents can take over the tasks of a more complex and costly single agent. The majority of existing research on multi-agent systems assume that the agents are fully actuated, whereas marine agents, such as ASVs and AUVs, are generally underactuated as they do not have independent sideway thrusters that are efficient during transit. In addition, environmental disturbances are generally not considered for most multi-agent systems, whereas this factor cannot be disregarded for marine multi-agent systems. The project has developed methods for straight-line path following for inhomogeneous formations of underactuated agents. The formation can consist of agents with different dynamics that are individually affected by a different unknown environmental disturbance. Formation path following is achieved using a two-fold strategy that consists of a guidance law to steer each vessel to a predefined path and a decentralised nonlinear formation control law that utilises local information only to synchronise the agents position along the path to achieve the desired formation. The resulting closed-loop error dynamics, which consists of path-following error dynamics and formation error dynamics, is analysed using the theory of feedback-interconnected systems, and the origin of the closed-loop error dynamics is shown to be uniformly globally asymptotically stable. The control objectives of the multi-agent system are achieved.

AUVs and ASVs are generally underactuated. As they have no side thruster or heave thruster, they have fewer independent control inputs than degrees of freedom to be controlled. The associated control challenges constitute an active area of research. In 2014, two journal papers were published with new results on this topic: "On uniform semiglobal exponential stability (USGES) of proportional line-of-sight guidance laws" by Thor I. Fossen and Kristin Y. Pettersen, which was published in Automatica, and "Line-of-Sight Path Following for Dubins Paths with Adaptive Sideslip Compensation of Drift Forces" by Thor I. Fossen, Kristin Y. Pettersen and Roberto Galeazzi, which was published in IEEE Trans. on Control Systems Technology. The articles present new results on handling unknown disturbances, especially the problems of handling disturbances that act in the direction in which no control force exists. Uniform semiglobal exponential stability is achieved, which is a stronger stability property than achieved in any previous literature on the control of underactuated marine vessels. In addition to guaranteeing fast convergence, important robustness properties are also provided.

Integral line-of-sight guidance is furthermore experimentally verified in two full-scale experiments. The first validates the guidance scheme for ASVs using the CART Unmanned Semi-Submersible Vehicle in sea trials off the coast of the Murter island in Croatia in a research cooperation with ISSIA-CNR, Genova, Italy. The other validates the guidance scheme for AUVs using the LAUV as a test platform outside Porto in Portugal.

Another essential feature of autonomous systems is the system´s capability of prioritising different tasks and handling unknown and dynamic environments. A promising approach is the null-space-based (NSB) behavioural control approach. An important research challenge addressed by this project is extending the NSB framework to handle set-based constraints, which will create an efficient framework for handling collision avoidance in an autonomous manner.

Fault-tolerance is essential for safe and reliable underwater operations, in which the working environment may not allow for emergency resurfacing. These environments may encompass under-ice operations or structural inspection and intervention inside subsea installations. 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 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 on fault diagnosis and robust navigation of underwater robots was presented in the article "Particle Filter for Fault Diagnosis and Robust Navigation of Underwater Robot" by Bo Zhao, Roger Skjetne, Mogens Blanke, and Fredrik Dukan, which was presented in IEEE Trans. on Control Systems Technology in November 2014. 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, can effectively diagnose faults, and can provide good state estimation even in cases where

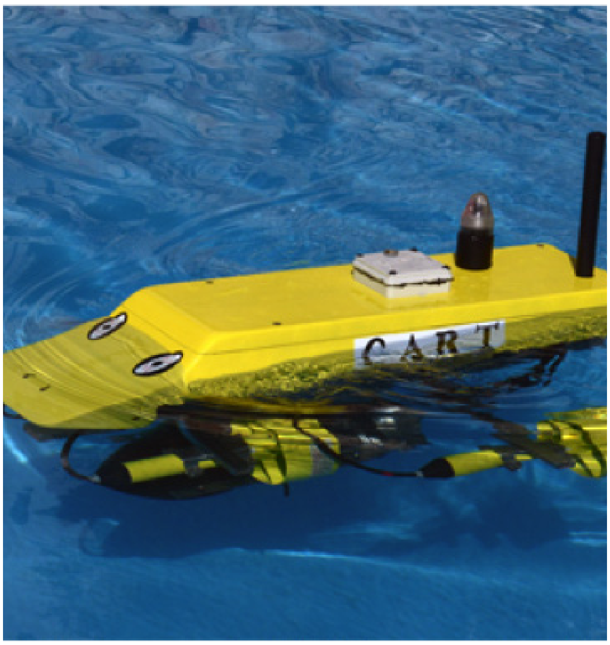

Figure 7: *The CART USSV (left) and the LAUV vehicle (right).*

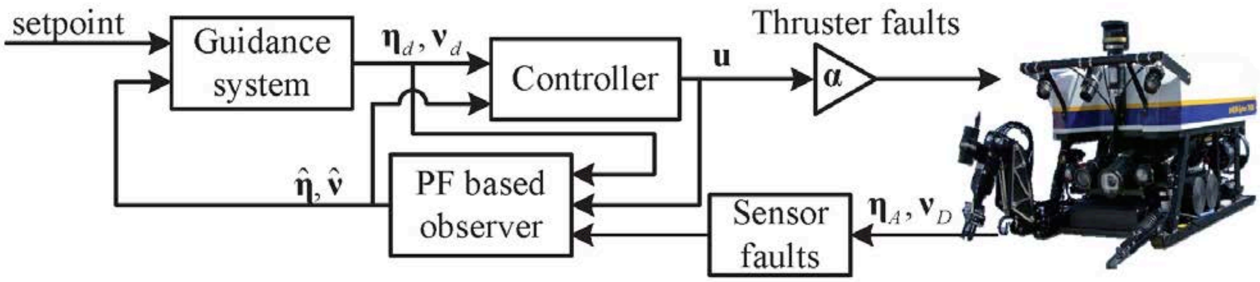

Figure 8: *Fault-tolerant control system of underwater robot.*

multiple faults occur. The comparison with other methods indicates that the proposed method can diagnose all faults within a single structure, can diagnose simultaneous faults, and is easily implemented.

Related publications:

- **Fossen, Thor I.; Pettersen, Kristin Ytterstad.** On uniform semiglobal exponential stability (USGES) of proportional line-of-sight guidance laws. Automatica 2014; Volum 50.(11) s. 2912-2917, NTNU
- **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 2014, NTNU
- **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; Volum 22.(6) s. 2399-2407, NTNU

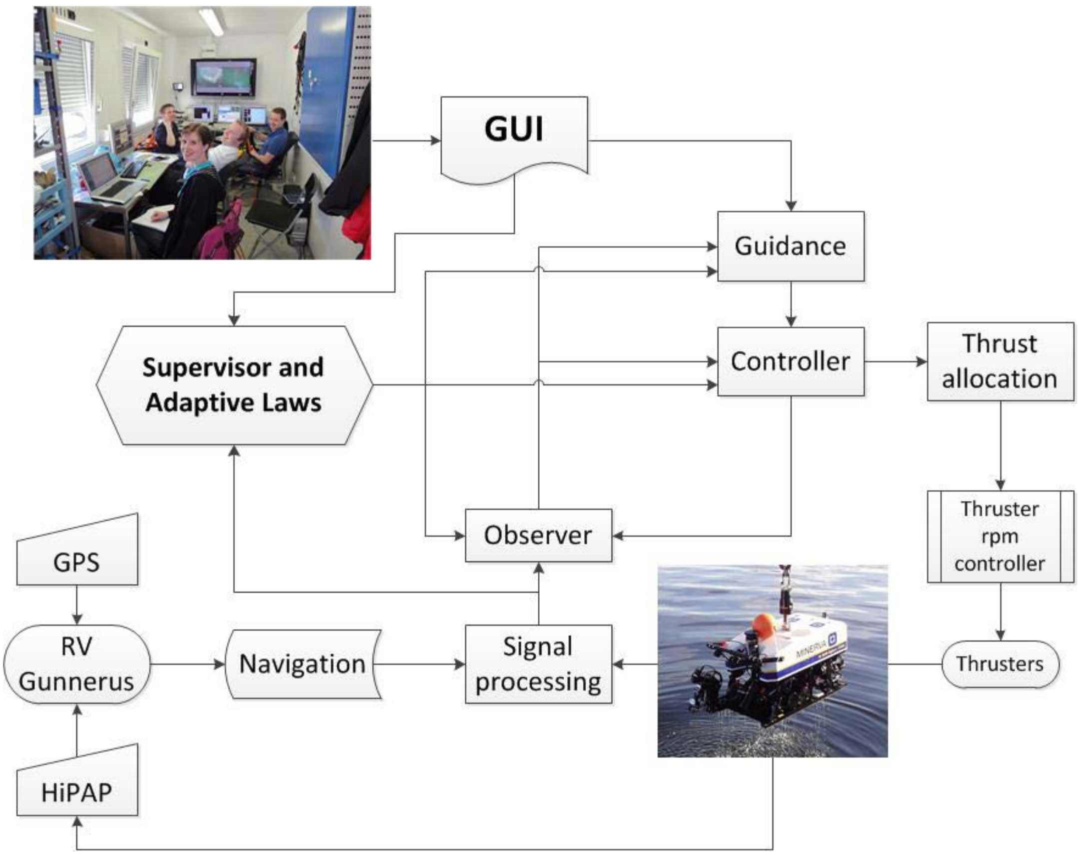

Figure 9: *ROV motion control architecture.*

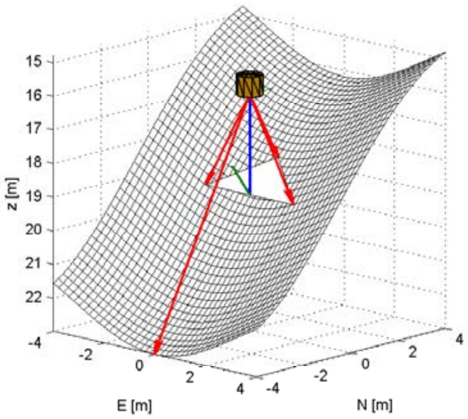

Figure 10: *DVL beams (red) and linear sea floor (white) approximation using 3 of 4 beams in addition to estimation of altitude (blue) and gradient vector (green).*

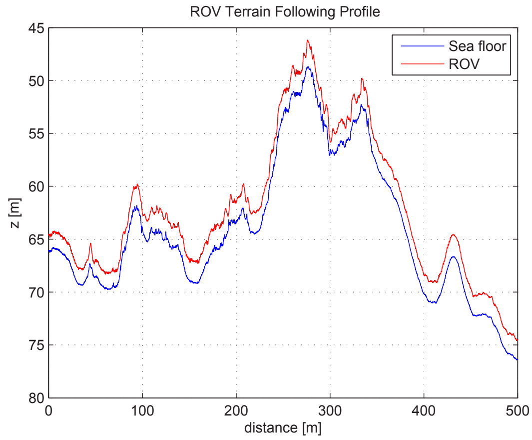

Figure 11: *Research campaign Tautra: ROV depth trace and the estimated terrain profile from DVL measurements.*

Sea floor geometry approximation and altitude control of ROVs

A new method for sea floor geometry approximation in a local region beneath a remotely operated vehicle (ROV) for use in altitude control is developed by Dukan and Sørensen and published in the IFAC Journal Control Engineering Practice. The method is based on Doppler velocity log (DVL) altitude measurements and ROV state estimates. The ROV altitude and sea floor gradient, which are obtained from the sea floor approximations, are employed in a guidance law for altitude control. The altitude observer and guidance law have been implemented in the control system of NTNU's ROV Minerva.

The results from the simulations and sea trials demonstrate the performance of the proposed altitude. The estimation and guidance system are shown in Figures 9-12.

Remotely operated vehicles (ROVs) are employed for various inspection and intervention missions in various industries, e.g., the oil and gas industry, ocean science research, and the aquaculture industry. Automation of additional motion control functions is gaining interest to improve the positioning accuracy and enabling the pilot to supervise the operation. Additional improvement in the DP system is the inclusion of automated control functions for altitude control and terrain following. During survey operations for seabed mapping and monitoring in varying terrain, this functionality is needed and has been successfully employed in several missions for marine biology and archaeology at the NTNU AUR-Lab.

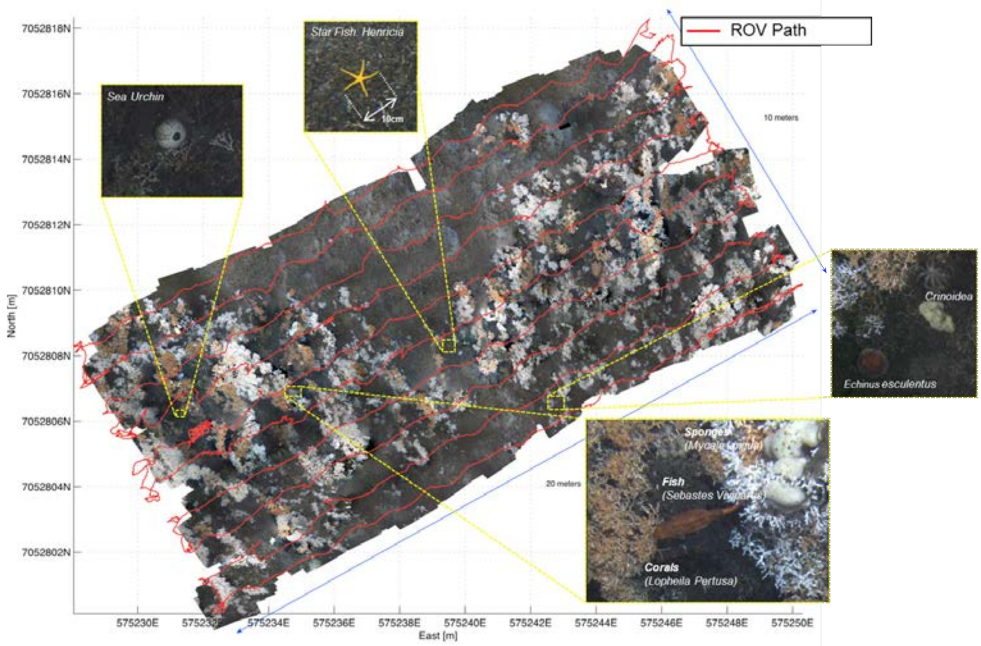

Figure 12: *Research campaign Tautra: Photomosaic of coral reef in the Trondheimsfjord using ROV with combined path following and altitude control.*

Autonomous aerial systems for marine monitoring and data collection

Project manager: Professor Thor I. Fossen
Research associate: Professor Tor Arne Johansen
PhD candidates: Mariann Merz, Kim Lynge Sørensen, Kristian Klausen, Lorenzo Fusini, João Fortuna, Mikkel Eske Nørgaard Sørensen

Figure 13: *A system for autonomous precision recovery of fixed-wing unmanned aerial vehicles (UAVs) using a low-cost GPS L1 C/A-based real-time kinematic (RTK) solution, which utilises locally generated corrections, is described and field-tested. Proof-of-concept field tests have been successfully completed.*

The importance of autonomous systems for monitoring and data collection is increasing. We use autonomous aerial vehicles in marine operations to improve operational safety and to collect data for a large number of applications. Each vehicle has a dedicated payload system for autonomous guidance and navigation and mission specific sensors for perception and data collection. The UAV payload systems can support a variety of operations, for instance, ice management in the Arctic, the monitoring of resources and environmental parameters, such as oil spills, and the monitoring of traffic and operations at sea. The project will focus on the following activities:

- Autonomous launching and net recovery of UAV using single-frequency RTK GPS and radio navigation
- Deployment, search, and recovery of marine sensors using a fixed-wing UAV
- Deployment, search, and recovery of marine sensors using multiple rotary-wing UAVs
- Robust UAV attitude and navigation systems for marine operations using nonlinear observers, MEMS sensors and camera measurements
- Autonomous anti-icing of UAVs
- Nonlinear and adaptive control of unmanned aerial vehicles

The research focuses on operations with UAVs that are capable of handling 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, the management of communication quality of service, and the 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, to update estimates of the distributed parameter phenomena that are being observed.

The short-term research outcomes comprise payload systems and software for use in UAV systems, whereas the long-term objective is the operation of fully autonomous UAV systems in restricted airspace. Experimental demonstrations will include autonomous maritime launch and recovery from ships, autonomy in ice-monitoring applications, research and rescue missions, and environmental monitoring.

Net recovery of UAV with single-frequency RTK GPS

The launch and recovery phases pose significant challenges to the operation of UAVs, particularly for fixed-wing UAVs that are operated from smaller ships or other geographically or operationally constrained sites without a proper runway. Although UAV missions can be frequently and autonomously operated under pilot supervision via

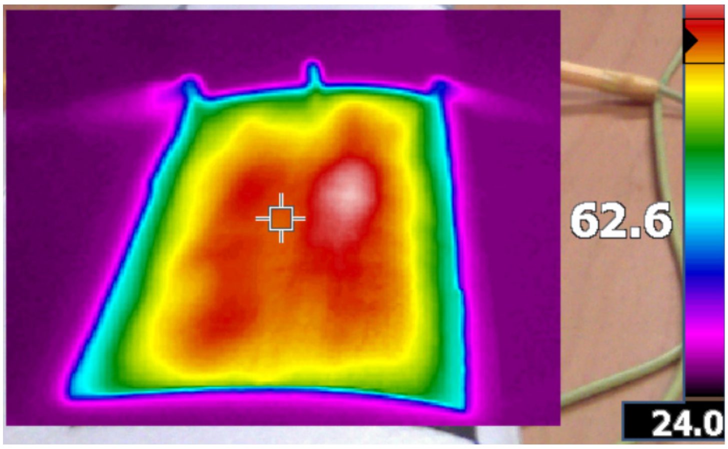

Figure 14: *Thermal image of the effect of heating on the leading edge of a UAV wing section with carbon nanotube coating.*

telemetry, the launch and recovery phases frequently require piloting using manual remote control (RC) and the pilot's visual feedback. The availability of reliable automatic recovery functionality with predictable performance is an important step towards increased autonomy, which can potentially produce reduced operating costs (a skilled RC pilot is not needed) and improved safety records and enable an increased use of UAVs.

Related publication:

- **Skulstad, R.; Syversen, C. K.; Merz, M.; Sokolova, N.; Fossen, T. I.; Johansen, T. A.** Net Recovery of UAV with Single-Frequency RTK GPS, IEEE Aerospace Conference, Big Sky, 2015, NTNU

Carbon nanotube-based airfoil heating system for in-flight UAV ice protection

Structural changes due to ice accretion are common causes for unmanned aerial vehicle (UAV) incidents in cold and humid weather. Icing causes an increase in mass and drag and a reduction in lift, which contribute to reduced performance and loss of control of the UAV. Conventional solutions cannot be scaled down and used in small UAVs due to substantial weight, cost and space requirements.

AMOS is investigating the use of electrically conducting carbon nanotube coatings on exposed UAV surfaces, such as the leading edge on wings. Autonomous inflight anti-icing and de-icing strategies employ autonomous aerodynamic performance monitoring of the UAV in combination with intelligent electric power management control to minimise energy consumption.

Related publication:

- **Sørensen, K. L.; Helland, A. S.; Johansen, T. A.** Carbon Nanotube Based Airfoil Heating System for In-Flight Anti-Icing and De-Icing of UAVs, IEEE Aerospace Conference, Big Sky, 2015; NTNU

Nonlinear observer for GNSS- and camera-aided inertial navigation

A nonlinear observer for the estimation of position, velocity, acceleration, attitude and gyro bias for UAV has been derived. The sensor suite consists of an inertial measurement unit (IMU), a GNSS receiver, a video camera, an altimeter, and an inclinometer. The camera and machine vision systems can track features from the environment and calculate the optical flow. These data and data from other sensors are fed to the observer, which is proven to be uniformly semiglobally exponentially stable (USGES). Exponential stability is important for systems that are exposed to environmental disturbances and uncertain initialisation as it guarantees strong convergence and robustness properties. In addition to a small computational footprint, these features constitute an advantage over other popular algorithms, such as the extended Kalman filter. The performance of the observer is tested on simulated and experimental data using the Penguin fixed-wing UAV system. The system is an important step towards greater fault-tolerance, as the camera may be used to replace faulty sensors in a critical situation to recover the UAV.

Related publicatons:

- **Fusini, L.; Fossen, Thor I.; Johansen, Tor Arne.** A Uniformly Semiglobally Exponentially Stable Nonlinear Observer for GNSS- and Camera-Aided Inertial Navigation. Proc. of the 22nd IEEE Mediterranean Conference on Control and Automation (MED'14), 16-19 June, 2014, Palermo, Italy, NTNU

- **Grip, H. F.; Fossen, Thor I.; Johansen, Tor Arne; Saberi, A.** Globally Exponentially Stable Attitude and Gyro Bias Estimation with Application to GNSS/INS Integration. Automatica. Volume 51, January 2015, Pages 158–166, NTNU

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

Project manager: Professor Tor Arne Johansen

Research associates: Professors Marilena Greco, Asgeir J. Sørensen, Roger Skjetne, Ingrid B. Utne, Odd M. Faltinsen

PhD candidates: Shaojun Ma

Power and energy management on future vessels with hybrid electric power plants utilizing diesel, LNG, fuel cells, and novel power concepts, will be 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.

Target outcomes of this project are 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. This project is closely linked to the D2V project.

CO_2 emission of ships in a seaway

Environmental concerns have caused the International Maritime Organization (IMO) to introduce an energy-efficiency design index in terms of grams of CO_2 emissions per nautical mile divided by the deadweight tonnage that applies to oil tankers, bulk carriers, gas carriers, general cargo, container ships, refrigerated cargo and combination carriers. The additional resistance and loss of propulsion in waves affects CO_2 emissions. The coupling between hydrodynamic loads, propulsion engine and ship dynamics must be considered. Six main North Atlantic trans-oceanic routes (refer to Figure 15) were investigated by applying weather statistics for a container vessel with a length of 175 m, a speed of 21.9 knots and CO_2 emissions of 331.21 kg/km in calm water conditions.

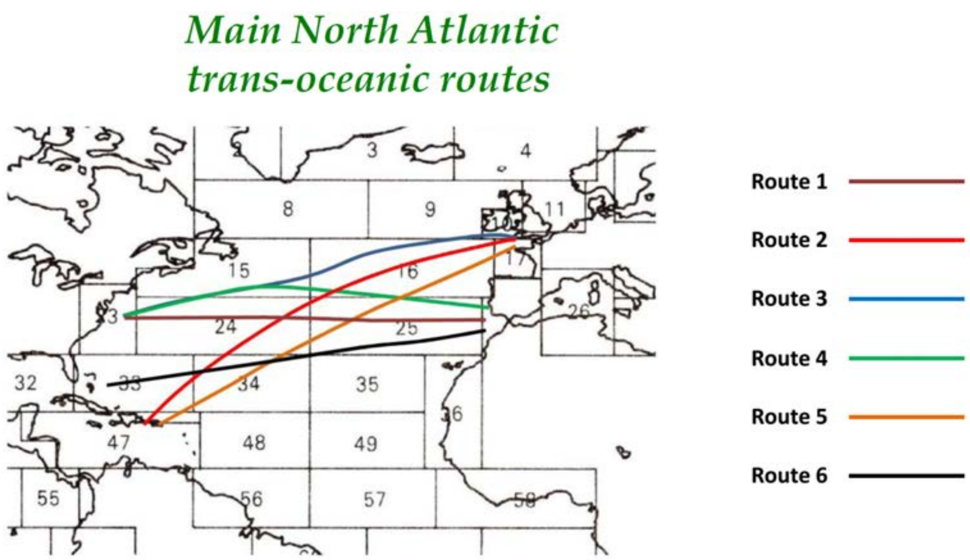

Figure 15: *Examined routes.*

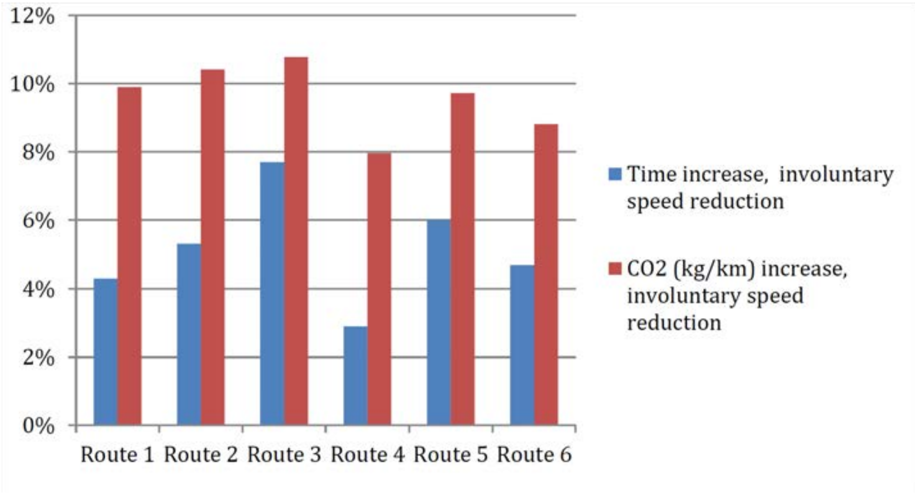

Figure 16: *CO_2 emission and time increase with involuntary speed reduction.*

The results for the increase in CO_2 emissions and time are presented in Figure 16 for the case with no voluntary speed reduction. However, the ship will reduce its speed in heavy weather. If we rely on empirical criteria to determine how an average shipmaster will react, we obtain the results presented in Figure 17.

Related publications:

- **Prpić-Oršić, J.; Faltinsen, O.M.; Mrakov, T.** A methodology for estimating the ship fuel consumption at sea waves, Simpozij SORTA 2014, (ISBN: 978-953-6326-90-7), 237-245, Baška, 2014, NTNU
- **Prpić-Oršić, J.; Faltinsen, O.M.; Valčic, M.** Development strategies for greener shipping Proceedings of the 56th International Symposium ELMAR-2014, str. 83-87, (ISBN: 978-953-1 84-1 99-3) Zadar, Croatia, 2014, NTNU
- **Prpić-Oršić, J.; Faltinsen, O.M.; Valčic, M.; Vučinic, D.** Energy efficiency approach to ship design and route planning Proceedings of the VIII AIGE National Congress, str. 192-196, (ISBN: 978-88-940011-0-5) Reggio Emilia, Italia, 2014, NTNU
- **Prpić-Oršić, J.; Vettor, R.; Faltinsen, O.M.; Guedes Soares, C.** Influence of ship routes on fuel consumption and CO2 emission, MARITIME TECHNOLOGY AND ENGINEERING - MARTECH 2014, (ISBN: 978-1-138-02727-5), 857-864, Lisabon, 2014, NTNU

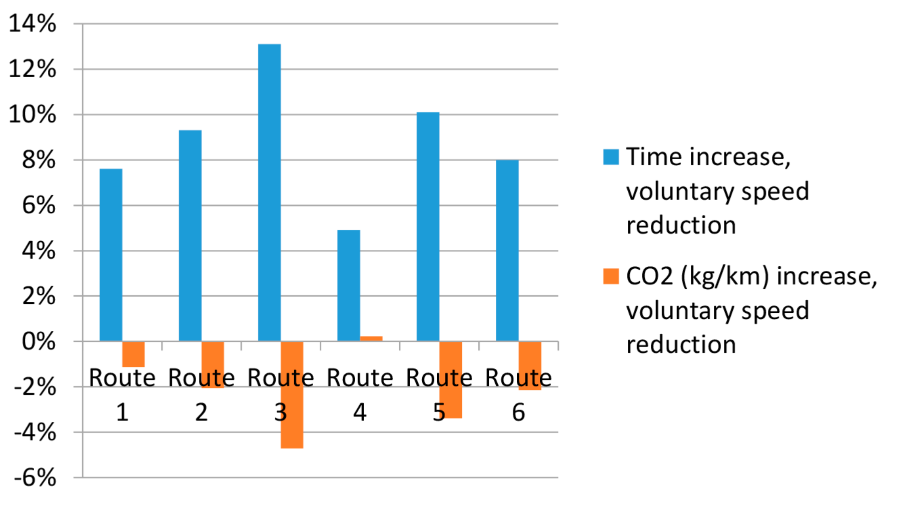

Figure 17: *CO_2 emission and time increase with voluntary speed reduction.*

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

Project manager: Professor Asgeir J. Sørensen
Research associates: Professors Jørgen Amdahl, Mogens Blanke, Odd M. Faltinsen, Thor I. Fossen, Marilena Greco, Torgeir Moan, Roger Skjetne, adjunct professors Claudio Lugni, Ulrik Dam Nielsen, Dr Vahid Hassani
PhD candidates: Leif Erik Andersson, Astrid H. Brodtkorb, Finn-Christian W. Hanssen, Martin Hassel, Ulrik Jørgensen, Hans-Martin Heyn, Svenn Are Tutturen

The interdisciplinary research on hydrodynamics, automatic control and marine structures addresses marine operations in extreme sea conditions, deep and shallow waters, and ice. Violent water-structure interactions are examined. Fault-tolerant control systems for dynamically positioned (DP) operated ships and rigs are investigated. Multi-objective control in DP and thruster-assisted position mooring are developed using the framework of hybrid control. Calculations of motion and load effects for slender structures and an assessment of fatigue, wear and ultimate strength of composite materials are important for safe operation. This analysis includes characterisation of the wave-current-wind environment in extreme weather conditions and a reliability assessment of existing sea models and their improvements.

Main research activities

In terms of the development of investigation tools and knowledge enhancement of relevant physical phenomena, the major contributions in this project are as follows:

- 2D sloshing experiments in depressurised conditions with shallow-water filling depths
- 2D-3D coupled technique for free-surface waves from deep to shallow water depths
- 2D-3D domain-decomposition strategy for violent wave-ship interactions
- Multi-block with dynamic local refinement for a 1D-3D domain-decomposition strategy for two-phase compressible flows
- Occurrence and mutual influence of parametric roll and water on deck for a FPSO and roll-yaw coupling relevance on an FPSO instability
- Impact phenomena and hydroelasticity excitation during sloshing in onboard tanks
- Preliminary application of a full fluid-structure interaction
- Hybrid control for dynamic positioning in extreme seas and ice
- Fault-tolerant control and parameter estimation for thruster-assisted position mooring in arctic offshore conditions
- Sea state estimation techniques using stochastic theory, hydrodynamic models and sensor fusion methods

Important aspects of these studies are described in the following sections and documented by the provided references:

Wave propagation from deep- to shallow-water depth

For offshore structures that operate in shallow-water depths, such as bottom-fixed wind turbines, the interaction with steep waves is a recognised problem. The ongoing analysis focuses on the definition of a novel hybrid model that can efficiently and accurately describe the wave dynamics from intermediate/deep- to shallow-water depths and consider the flow rotation and turbulence, which is relevant near the seabed. The method involves the strong coupling in time between a 2D shallow-water approximation in the horizontal plane (A) with the 3D Poisson equation for the vertical component of the fluid velocity (B). (B) provides correction terms for (A), which are related to the deviations of the 3D stream, whereas A furnishes the boundary conditions along the free surface and the seabed, which are required by (B). In the previous year, model A has been developed and assessed. This research was devoted to the study of the accuracy and robustness of model B with specific attention to the sensitivity of the boundary conditions. Both the Dirichlet condition and Neumann condition have been implemented and checked in test cases with complex computational domains.

Harmonic Polynomial Cell (HPC) method

Shao and Faltinsen proposed a new, efficient and accurate numerical method, which is based on harmonic polynomials, to solve boundary value problems governed by the 3D Laplace equation. The computational domain is discretised by overlapping cells. Within each cell, the velocity potential is represented by the linear superposition of

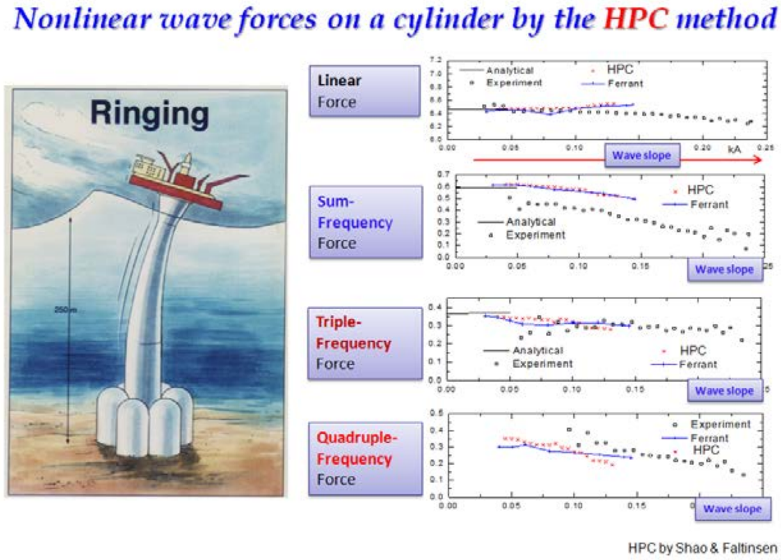

Figure 18: *Verification and validation of ringing loads.*

a complete set of harmonic polynomials, which are the elementary solutions of Laplace equation. The characteristics of the accuracy and efficiency of the HPC method are demonstrated by the analytical cases. Comparisons with other existing boundary element-based methods, e.g., the Boundary Element Method, the Fast Multipole Accelerated QBEM and a fourth-order Finite Difference Method. To demonstrate the applications of the method, it is applied to some studies that are relevant for marine hydrodynamics. Sloshing in 3D rectangular tanks, a fully nonlinear numerical wave tank, a fully nonlinear wave focused on a semi-circular shoal, and the nonlinear wave diffraction of a bottom-mounted cylinder in regular waves are explored. The comparison with the experimental results and other numerical results reveals satisfactory agreement, which indicates that this HPC method is a promising method for solving potential-flow problems. A fully nonlinear numerical with real-time speed and without wave breaking is possible.

Figure 18 illustrates the verification and validation of first to fourth-harmonic horizontal wave forces on a vertical free-surface piercing and bottom-mounted circular cylinder in regular deep-water waves in steady-state conditions. The results are relevant for a ringing and springing analysis of monotowers, such as the Draugen platform in extreme weather conditions without breaking waves.

Moored offshore structures in harsh locations may be exposed to severe waves and currents. To design mooring systems that are capable of withstanding induced loads, nonlinear loading and response of the offshore floater must be handled. To achieve an accurate and efficient prediction method, a numerical hybrid strategy that combines a fully nonlinear potential flow method with a Navier-Stokes solver in regions with significant viscous effects, is proposed. The potential-flow part is under development. It is based on the HPC method. Significant effort has been devoted to its combination with an efficient and robust immersed boundary method that enables structures to move without regenerating the grid at every time step and to ensure HPC accuracy. To enforce the boundary condition on a generic body, three layers of ghost nodes inside the body and corresponding interpolation points (three for each ghost node) mirrored into the fluid domain along the direction of the local normal vector of the body are employed to interpolate the normal velocity of the fluid at the immersed body boundary. The application on a fixed cylinder in a harmonically oscillating flow revealed accuracy between the third- and fourth-order convergence, which is similar the HPC method for a body-fitted grid.

Related publications:

- **Shao, Y.L.; Faltinsen, O.M.** A Harmonic Polynomial Cell (HPC) method for 3D Laplace equation with application in marine Hydrodynamics. Journal of Computational Physics, v.274, pp.312-332, 2014, NTNU

- **Shao, Y.L.; Faltinsen, O.M.** Fully nonlinear wave-current-body interaction analysis by a Harmonic Polynomial Cell (HPC) method, J. Offshore Mech. Arct. Eng., 136(3), 031301 – 031306, 2014, NTNU

Parametric roll and water on deck for an FPSO

The study of an FPSO has been pursued using model tests that were previously conducted at CNR-INSEAN and a numerical domain-decomposition (DD) strategy. The DD couples a weakly nonlinear potential-flow seakeeping solver with a shallow-water approximation of the water on the deck (WOD). Head sea-regular waves were investigated in the region of the parametric roll (PR) and WOD occurrence for the ship without bilge keels and mooring lines. For the steepness range of $0.1<kA<0.25$, PR occurs

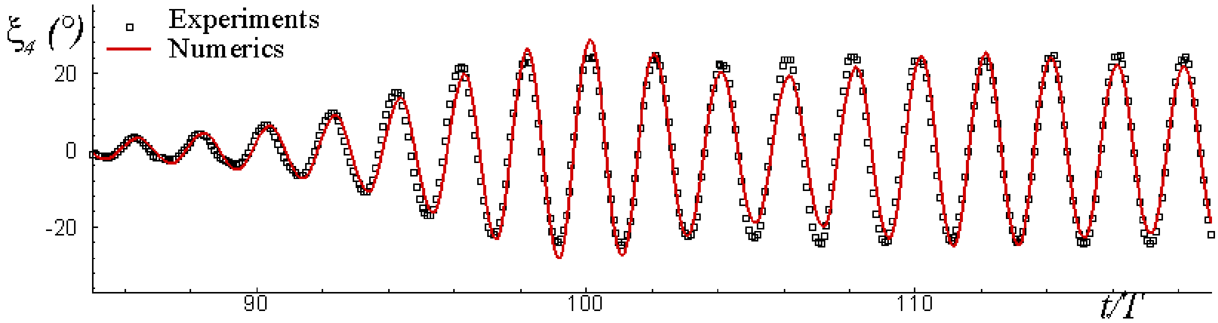

Figure 19: *Parametric roll for ω_{4n0}/ω =0.402 and kA=0.25.*

for the calm-water roll natural frequency–to-incident-wave frequency ratio ω_{4n0}/ω =0.402 and 0.464, which indicates that the change of roll natural period that tunes is twice the incident-wave period T. Interaction with steeper waves brings the instability for lower ω_{4n0}/ω and works against otherwise. This finding implies a wider region of parametric roll towards shorter waves. The phenomenon typically requires a considerable amount of time to develop, and the steady-state roll amplitude exceeded 20°° in the worst cases (refer to Figure 19). PR creates asymmetric water shipping, increases its severity (refer to the left plot of Figure 21) and may cause WOD. The latter affects PR and generally tends to increase the roll amplitude. For this variation, the scaling law ϒ1=f(d1) was identified (refer to right plot of Figure 21). The results of this study emphasise the importance of the modified steepness ε= (2A-f)/λ (where λ is the incident wavelength l and f is the ship freeboard) as parameter.

A setup inconvenience occurred during bow-sea regular wave tests. In run 44 (left plot of Figure 22) the FPSO experienced no PR and severe WOD caused water leakage in the vessel. The model was made waterproof and tested using the same conditions in run 46 (right plot of Figure 22), in which the FPSO experienced PR and WOD. The difference was due to a slack in the shaft that should avoid the yaw which was then partially allowed. This finding highlighted the importance of yaw-roll coupling in the occurrence of instability and motivated a more in-depth investigation, which is underway.

Related publications:

- **Greco, M.; Lugni, C.; Faltinsen, O.M**. Can the water on deck influence the parametric roll of a FPSO? A numerical and experimental investigation, European Journal of Mechanics - B/Fluids, 47, 2014, NTNU

- **Greco, M.; Lugni, C.; Faltinsen, O.M**. Roll-yaw Coupling Effects on Parametric Resonance for a Ship in Regular Waves, 29th Int. Workshop on Water Waves and Floating Bodies, Japan, 2014, NTNU

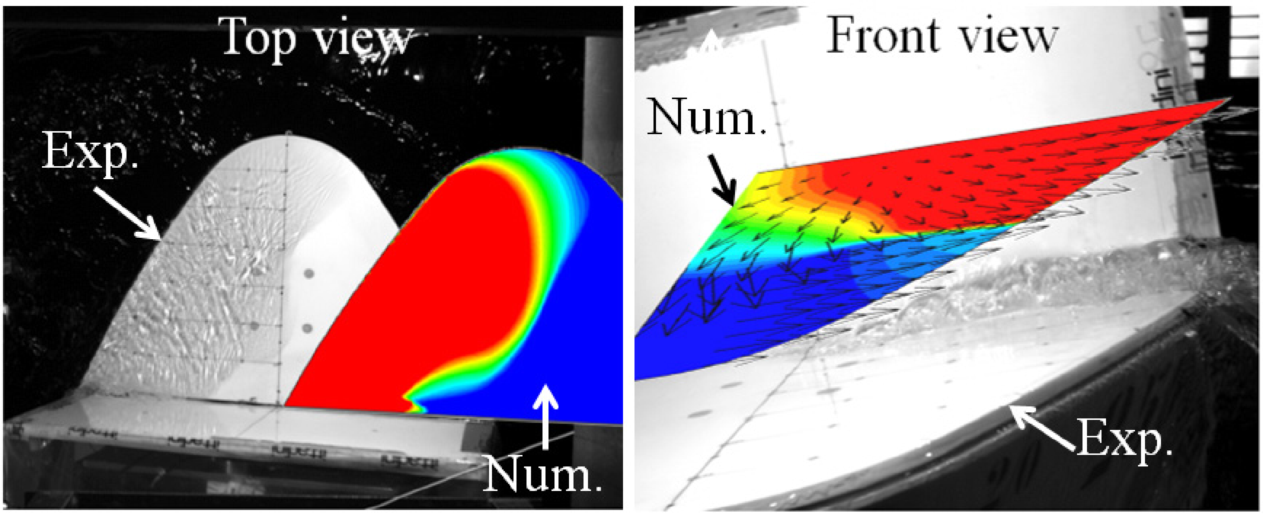

Figure 20: *Phases of water on (left) and off (right) deck for ω_{4n0}/ω=0.402 and kA=0.25. For the numerics: the contour levels indicate the water height and the vectors indicate the water speed.*

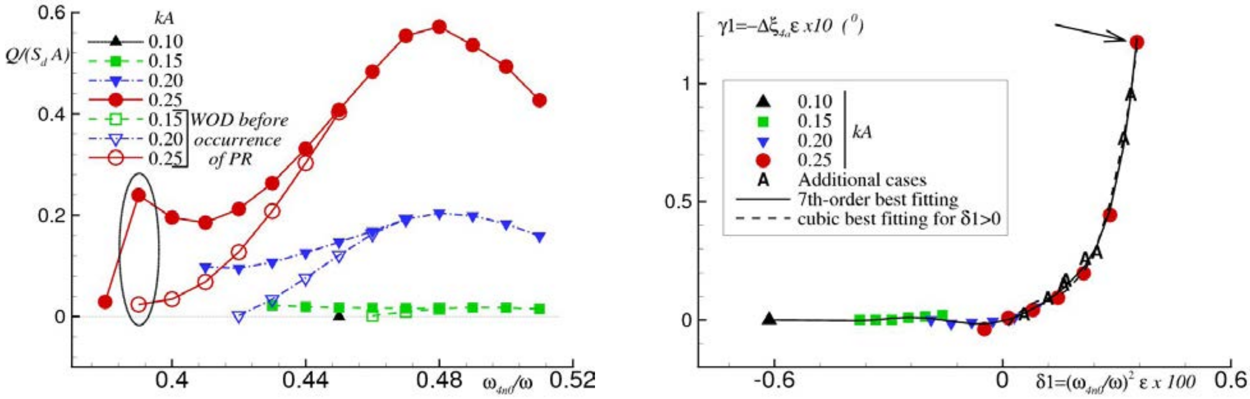

Figure 21: *Maximum volume of shipped water Q in steady-state conditions before and after PR. S_d is the deck area. Right: Scaling law for the variation of the steady-state roll amplitude $D\zeta_4$ caused by WOD loads.*

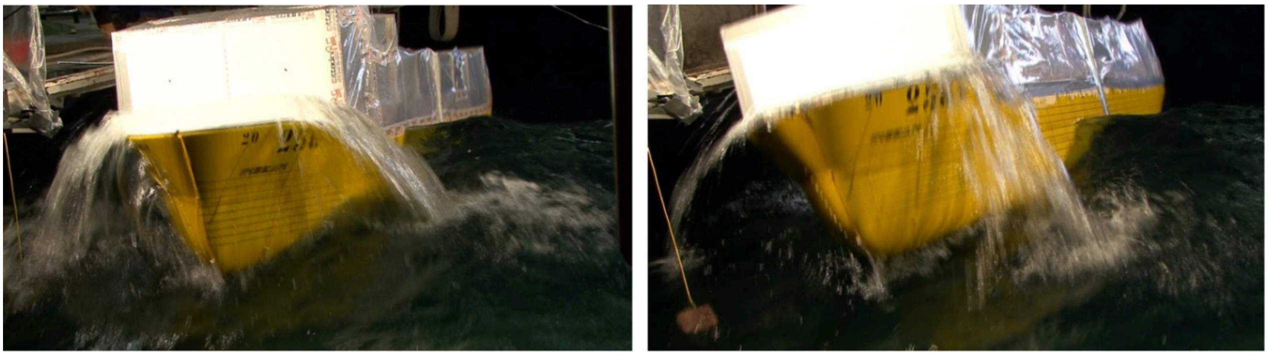

Figure 22: *Run 44 (left) and run 46 (right) at the time instant as a wave crest at mid-ship.*

Sloshing in onboard tanks

Large free-surface motions in a sloshing tank occur when the wave-induced horizontal ship velocities, in roll and/or pitch have sufficient energy in the frequency range that is near the lowest sloshing frequency of the tank. Depending on the forcing excitation, violent free-surface events may occur, which induce large global and local loads on the tank walls and increase the risk for the integrity of the structure.

Analytical approaches to nonlinear and linear sloshing problems need to know approximate natural sloshing modes based on potential-flow theory. At an early design stage, the lowest natural sloshing frequency (ies) is critical. Faltinsen and Timokha proposed a new method for constructing these approximate modes and for rapid computing of the corresponding natural sloshing frequencies in the two-dimensional case. The method was employed to perform a parametric study of the natural sloshing frequencies in a prismatic tank associated with liquefied natural gas (LNG) containers. The results are extensively compared with other approximate analytical solutions.

A simple, robust and efficient sloshing model that considers the breaking phenomena in a 2D rectangular tank in shallow water conditions has been developed by applying a Fourier decomposition to the Boussinesq equation and using an approximate analytic solution for the vorticity field that is induced by the wave breaking. A Boussinesq closure has been employed for the turbulent terms and the turbulent viscosity has been assumed to be constant on the liquid domain. The boundary conditions for the vorticity are directly assigned along the actual free surface. Ad-hoc experiments have been performed at CNR-INSEAN to validate the theoretical model proposed.

A comprehensive experimental investigation has been performed at CNR-INSEAN to explore and quantify the role of hydroelasticity during the evolution of a flip-through event inside a sloshing tank in a low-filling depth condition. A deformable aluminium plate, whose dimensions ensure the Froude scaling of the first natural vibration frequency of a Mark III structural panel, has been clamped in a stiff stainless steel wall. Strain gauges along the deformable plate measured the structural load. To characterise the hydroelastic effects, similar

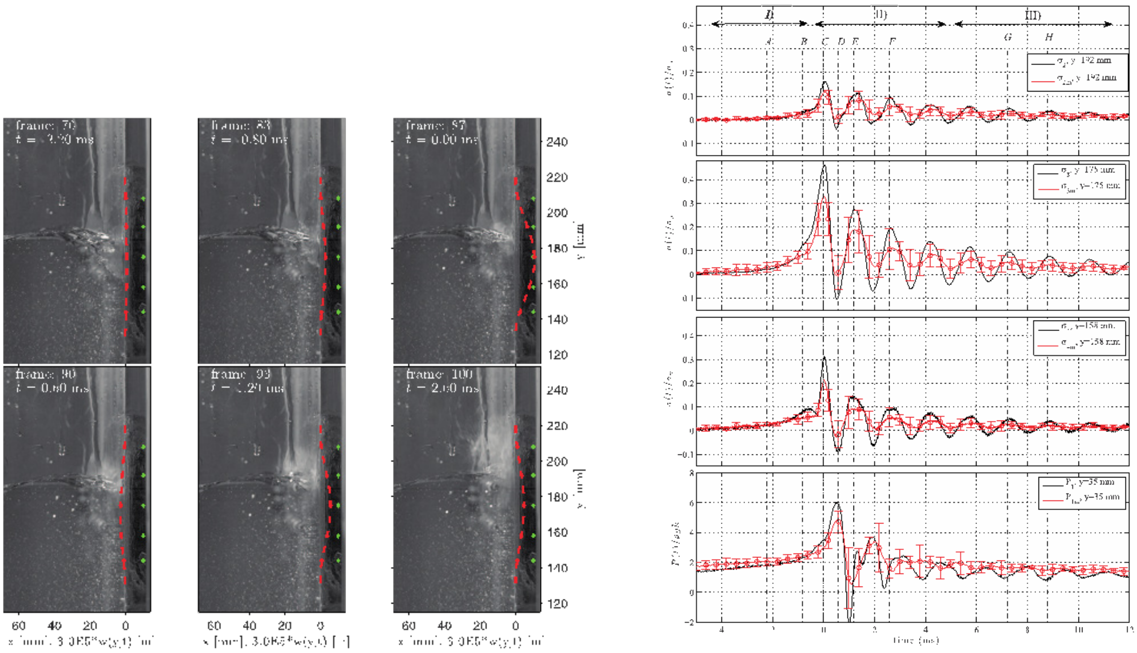

Figure 23: *Left: A flip-through event at six different times. The red dashed line represents the interpolation of the beam deformation (red symbols) as recorded by five gauges, which are installed on the elastic wall at the location indicated by the green diamond. Right: The first three panels report the time history of the strain gauges along the elastic wall at the positions reported in the legend. The fourth panel reports the time history of the pressure transducer at a point 35 mm above the tank bottom, along the rigid wall where the elastic plate is clamped. The red dashed line with symbols represents the mean value, which is calculated with five repetitions of the same run; the related standard deviation is indicated by the error bar. The black line represents the run of the left images.*

experiments have been performed in a completely rigid tank, i.e., by substituting the deformable plate with a stiff plate and using pressure transducers to measure the dynamic load along the wall. The study emphasised that the hydroelastic evolution is characterised by three different regimes (refer to Figure 23). During regime I, the quasi-static hydrodynamic load induces a small and quasi-static deformation of the beam. A strong and completely coupled hydroelastic behaviour occurs in regime II, in which the rapid increase of the hydrodynamic load originates the maximum strain. Due to the structural reaction, the hydrodynamic pressure increases. The varying wetted length of the beam causes a variation in the added-mass term and the natural vibration frequency of the deformable plate. When the elastic plate is completely wetted, the natural frequency remains constant, which characterises the free-vibration regime III.

A complete understanding of the physical phenomenon ensured its proper modelling. The numerical-experimental model named the hybrid model has been proposed for predicting the structural load. The unsteady Euler beam theory is employed; the forcing term given by the experimental pressure is measured in the rigid case. The added mass term, which is fundamental for proper prediction of the vibration frequency, is calculated using a potential flow model for incompressible liquid and assuming a quasi-static variation of the free surface. The instantaneous wetted length of the beam is determined by the experimental images (refer to the dashed line on the left panel of Figure 24).

The comparison with experimental data (refer to left panel of Figure 24) confirms the total satisfactory prediction of the model. However, differences appear in regime II, in which a more refined hydroelastic model is necessary. More simplified theoretical models, which are typically employed in the design stage and based on a quasi-static rigid approach, have shown an error similar to errors in the hybrid model for the prediction of the maximum structural stress, when dynamic hydroelastic effects are considered. However, they were unable to correctly predict the subsequent evolution of the plate deformation (refer to the right panel in Figure 24). The ratio between the maximum measured strain and the quasi-static value incorporates a dynamic amplification factor (DAF) equal to 1.84. However, the ratio between the experimental maximum strain and the numerical maximum strain of 1.33 is achieved with the hybrid model, which confirms the essential role of the added mass in the dynamic cal-

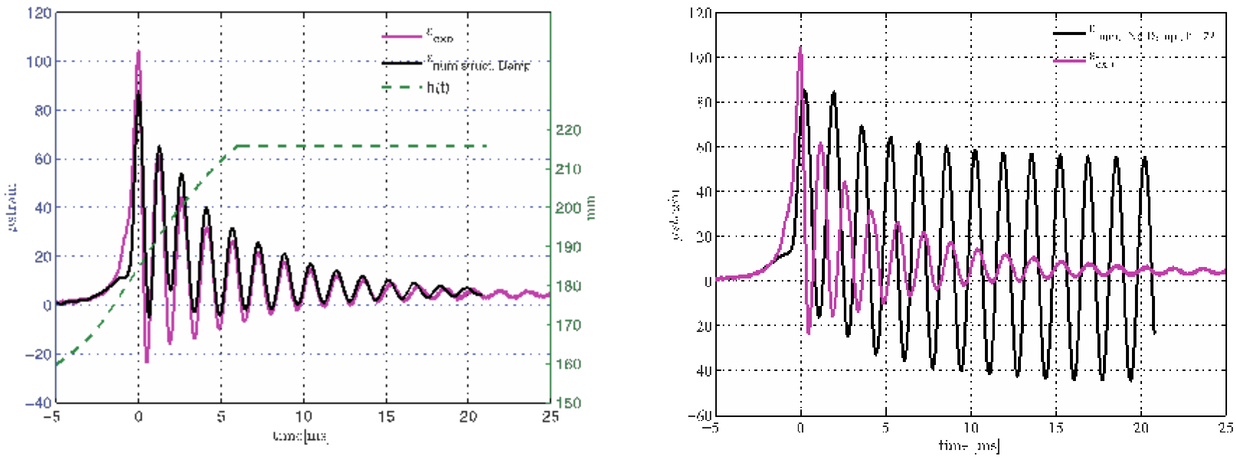

Figure 24: *Left: Hybrid model (black line) and experimental (magenta line) time histories of the strain at the centre of the beam. Dashed line represents the instantaneous variation of the wetted part of the wall. Right: Simplified model (black line) and experimental (magenta line) time histories of the strains at the centre of the beam.*

culation (refer to Figure 25). The latter fact implies that we must know the geometry of the impacting free surface, including which part of the structure is wetted.

The effect of a slatted screen on resonant sloshing is examined using new experimental results and numerical computations. The tank is narrow for two-dimensional flow, rectangular, and follows a sinusoidal forced horizontal motion. The screen is installed in the middle of the tank and the solidity ratio (ratio between the solid area of the screen and its total area) of the screen varies between 0.5 and 1. The forcing amplitude is small and the forcing frequencies address the first three natural frequencies of sloshing in the clean tank (tank without screen). An Open-source computational fluid dynamics (CFD) code named OpenFOAM is challenged against the experiments to assess its ability to capture nonlinear free-surface effects in shallow water in the presence of the screen. The numerical results are acceptable near the primary sloshing resonant frequencies. An important effect is the secondary resonance of the higher modes of sloshing, which are more pronounced due to the presence of the screen. These resonant effects that are far from the primary resonant frequencies are captured by the numerical simulations in terms of the resonant frequency and the amplitude of the sloshing wave responses at the vertical end-walls. In the numerical simulations, the screen's geometry is not simplified and all geometrical details are retained. The study is extended by experimentally investigating the impact pressures. However, the use of CFD surpasses state-of-the-art practices.

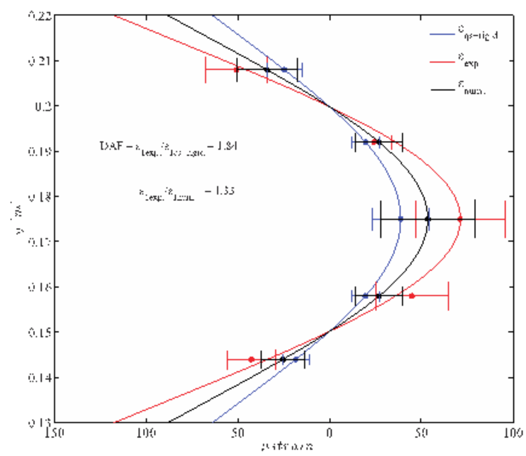

Figure 25: *Hybrid model (black symbol), quasi-static rigid model (blue symbol), and experimental (red symbol) mean values (with the error bar) of the maximum strain distribution along the elastic beam. The corresponding solid lines represent the strain reconstructions using the first vibration mode of the beam.*

Related publications:

- **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; Volum 26.(3), NTNU
- **Antuono, Matteo; Bardazzi, Andrea; Lugni, Claudio; Brocchini, Maurizio.** A shallow-water sloshing model for wave breaking in rectangular tanks. Journal of Fluid Mechanics 2014; Volum 746. s. 437-465, NTNU
- **Faltinsen, Odd Magnus; Timokha, Alexander.** Analytically approximate natural sloshing modes and frequencies in two-dimensional tanks. European journal of mechanics. B, Fluids 2014; Volum 47. s. 176-187, NTNU
- **Firoozkoohi, Reza; Faltinsen, Odd Magnus.** Experimental and numerical analysis of two-dimensional steady-state sloshing in a rectangular tank equipped with a slatted screen. I: Proceedings of the 11th International Conference on Hydrodynamics (ICHD 2014). : International Conference on Hydrodynamics 2014 ISBN 978-981-09-2175-0. s. 1015-1022, MARINTEK NTNU

Resonant water motion in moonpools

A significant increase in the use of moonpools to perform marine operations is expected. One reason is the rapid rise in the development of subsea factories. Operators have defined objectives such as all-year availability for maintenance and repair, which requires operability in, for example, the significant wave height Hs =4.5 m in the North Sea. Specialised offshore vessels with moonpools are regarded as one of the main elements for achieving this objective, which requires careful design of the moonpool to avoid excessive resonant piston-mode motion. Here, the piston-mode resonance is defined as the resonant liquid motion in the moonpool, which causes a net liquid flux through the lower entrance of the moonpool. The resonant flow is nearly vertical and one-dimensional in the majority of the moonpool. The word piston is associated with that observation that the liquid motion appears as the motion of a piston.

Regular wave-induced behaviours of a floating stationary two-dimensional body with a moonpool is investigated. The focus is the resonant piston-mode motion in the moonpool and rigid-body motions. Dedicated two-dimensional experiments have been performed. Flow separation at the vessel is required to theoretically explain the flow. A numerical hybrid method that couples viscous flow near the vessel with potential flow at a distance from the vessel has been developed. The latter procedure significantly reduces the computational time relative to use of the state-of-the art CFD in the complete computational domain. The use of a completely nonlinear free surface and body-boundary conditions are essential. The harmonic polynomial cell method solves the Laplace equation in the potential flow domain, whereas the finite volume method solves the Navier–Stokes equations in the viscous flow domain near the body. The numerical data are consistent with the experimental data. The moonpool substantially affects heave motions in the frequency range near the piston-mode resonance frequency of the moonpool. No resonant water motions occur in the moonpool at the piston-mode resonance frequency. Instead, large moonpool motions occur at the heave natural frequency associated with small damping near the piston-mode resonance frequency.

Related publication:

- **Fredriksen, Arnt Gunvald; Kristiansen, Trygve; Faltinsen, Odd Magnus.** Experimental and numerical investigation of wave resonance in moonpools at low forward speed. Applied Ocean Research 2014 ;Volum 47. s. 28-46, NTNU

Robust Multiple Model Adaptive Dynamic Positioning (RMMA-DP) system

The majority of current DP systems are designed to operate within a certain limit of weather conditions. In practice, the sea state may undergo large variations; therefore, the controller should adapt to the sea state. The observer in charge of reconstructing the low frequency (LF) motion should also adapt to a sea state. To satisfy this challenge, different techniques have been proposed, such as hybrid DP controllers and supervisory control techniques, with promising results. Supervisory control consists of a family (bank) of off-the-shelf candidate controllers that are designed to enable each controller can control the system during a special sea state and a supervisor to select the controller. The supervisor uses real-time input and output data and previous information about the system and generates a switching signal, which determines the time at which a controller should be selected. The most promising type of supervisors are the estimator-based supervisors, which have been frequently exploited by our research group in AMOS. We model the uncertainty in the system as a parameter uncertainty. In multi-estimator supervisors, the uncertain parameter set is divided into smaller subsets; a nominal parameter is selected for each subset. A separate estimator is developed for each selected parameter. The resulting set of estimators forms a bank which runs in parallel. At each sampling instant, a nonlinear function of the measurement residuals is employed to compute a performance signal for each estimator. The rationale is that the most accurate estimator will have the largest performance signal. At each sampling time, the performance signals are assessed to determine which controller should be selected from the bank of controllers. Figure 26 shows the

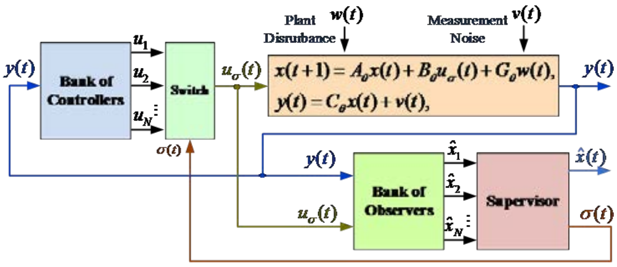

Figure 26: *Supervisory control architecture.*

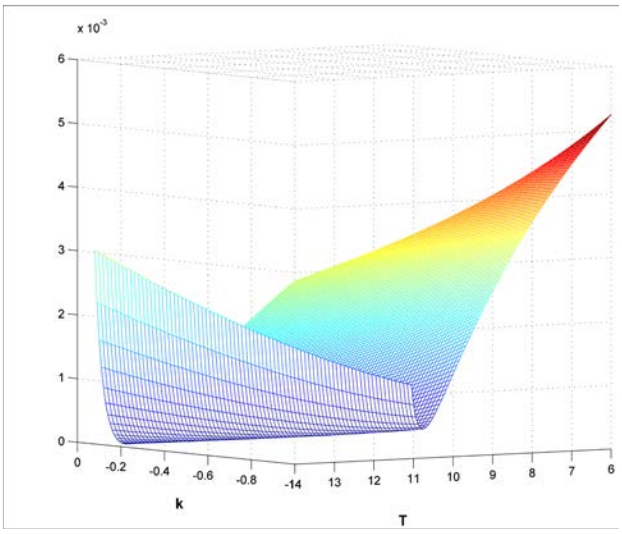

Figure 27: *Distance of the Nomoto systems with different k and T values from the Nomoto system with k = –0:15 and T = 8 as a function of k and T.*

architecture of the multi-estimator-based supervisory control.

Availing ourselves of previous results obtained by researchers in AMOS, we proposed a new type of DP control, which is named the Robust Multiple Model Adaptive Dynamic Positioning (RMMA-DP) system. A bank of individual robust DP controllers for different operational regimes (that address different sea conditions, such as calm, moderate, high and extreme) are designed using robust control theory. In the new structure, a bank of Kalman filters is designed based on a finite number of models of the vessel when it undergoes operations for different sea conditions. A multi-estimator supervisory tool is employed to identify the sea state and to select the appropriate robust DP controller from a pre-defined bank of controllers. The main objective of this method is to integrate a bank of appropriate robust DP controllers into a state of-the-art robust adaptive DP architecture that yields reasonable performance in varying operational conditions—from calm seas to extreme seas. The proposed structure extends the weather window operational availability of the DP system.

An important question regarding the multi-estimator supervisory tool is as follows, "what if the real system is not represented by any of the estimators?" To answer this question, we should analyse the situation in which the nominal values of uncertain parameters (selected for design of the multi-estimator) do not include the true parameter of the system. We have demonstrated that for a distinguishability condition, the supervisor will select the estimator that is closely resembles a real system. The problem of measuring the similarity between two dynamical systems based on their input\output data is addressed in, in which we define a (pseudo) metric topology on the space of stable discrete linear time-invariant (LTI) dynamic systems. Figure 27 graphically depicts how the distance of different first-order Nomoto models vary with variations in the time constant T and gain constant k.

The proposed metric is based on the idea of determining the distance of members of a set of discrete time LTI systems from a reference system; it has many applications in identification and model order reduction.

Related publications:

- **Hassani, V.; Sørensen, A. J.; Pascoal, A. M.** A novel methodology for robust dynamic positioning of marine vessels: Theory and experiments, In Proceedings of the American Control Conference (ACC), 560–565, 2013, NTNU

- **Hassani, V.; Sørensen, A. J.; Pascoal, A.M.** All Year Dynamic Positioning of Marine Vessels using Robust Adaptive Techniques: Theory and Experiments, submitted for Journal Publication, 2014, NTNU

- **Hassani, V.; Ross, A.** Defining a Pseudo-Metric Topology on Linear Dynamic Systems. In Proceedings of the 19th IFAC World Congress, 6890–6894, 2014, NTNU

Consequences of accidental and abnormal events on ships and offshore structures

Project manager: Professor Jørgen Amdahl
Research associates: Professors Asgeir J. Sørensen, Marilena Greco, Torgeir Moan, Odd M. Faltinsen, Dr Ekaterina Kim
PhD candidate: Martin Storheim

The goal of the project is to develop improved procedures for the analysis, design, and control in the case of accidental events, such as groundings and collisions of ships and offshore platforms. The main challenge is to incorporate the effect of hydrodynamics, such as external sea pressure and internal liquid cargo, in the assessment of structural resistance to the penetration of impacted panels. Although the nonlinear finite element method (ALE) is a viable tool, its computation time may be prohibitive. Three-dimensional (3D) domain decomposition is an alternative analysis strategy for a damaged ship that is subjected to sloshing. The influence of shallow water on wave actions is another research challenge in the simulation of the global motions of stranded vessels.

The project focuses on the following tasks:

- Behaviour of damaged ships
- Ship/platform and ship/ship collision identification of stranded ship conditions
- Stranded ships that are subjected to waves
- Drifting or powered ship grounding
- Reconfiguration control in faulty situations, and testing and verification
- Underwater explosions

Underwater explosions

The development of the proposed time-space domain-decomposition (DD) strategy for underwater explosions (UWEs) and their interaction with marine structures has continued. The DD applies a radial solver before the shock wave reaches the body and subsequently couples this solver with a compressible 3D method to investigate the fluid-structure interactions. This year, an effort to improve the method efficiency has been made. The hybrid solver employs a multi-block grid to allow small meshes

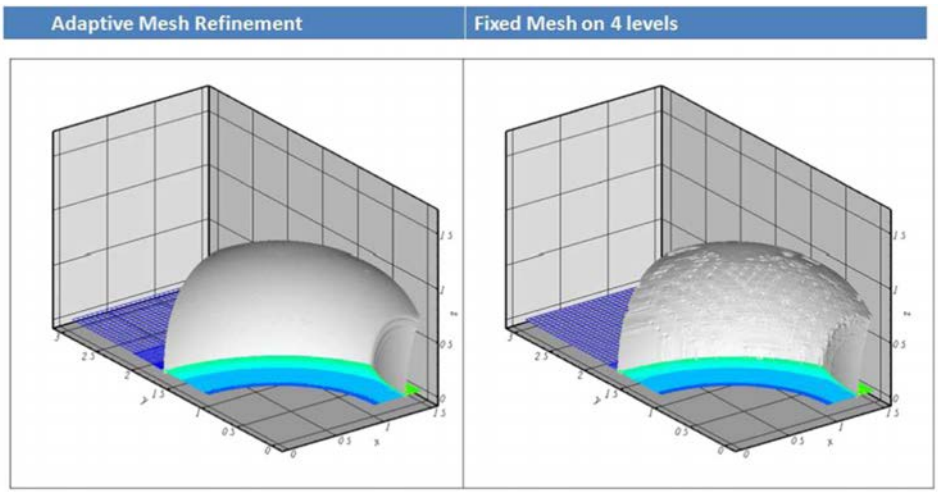

Figure 28: *Adaptive mesh versus fixed discretisation: snapshot of the surface with maximum pressure at the time of wave reflection from a wall.*

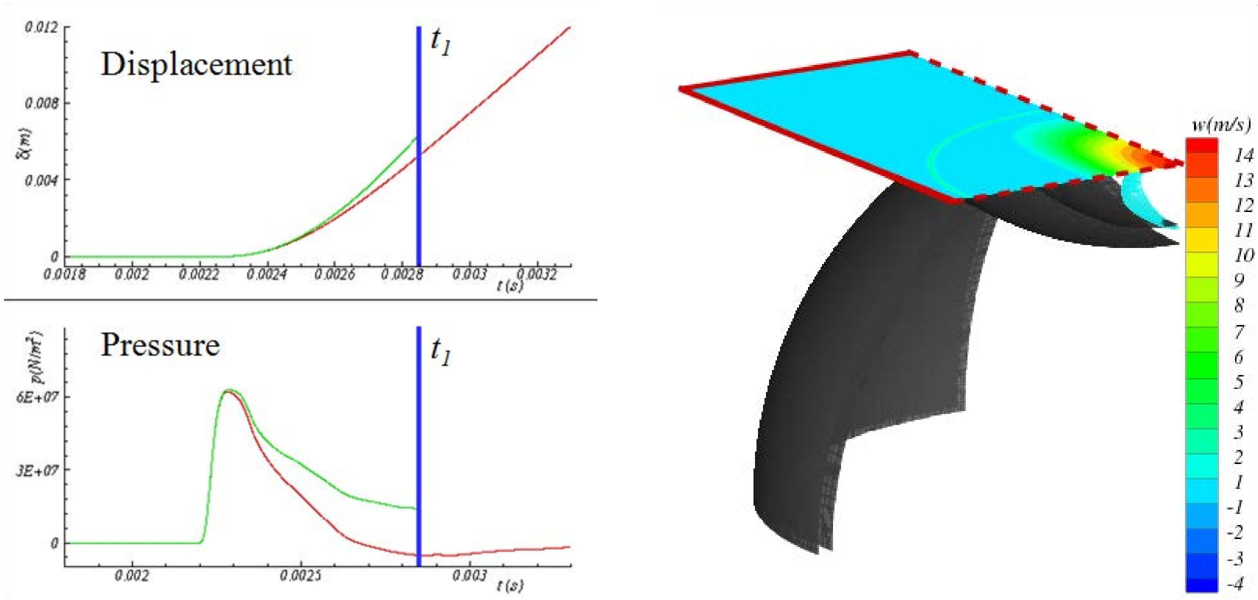

Figure 29: *Underwater explosion for an initial cavity with radius r_0=0.16 m and pressure p_0= 8.381 GPa. Left: displacement and pressure at the centre of the plate from approximate (green lines) and full (red lines) FSI. Right: Pressure isosurfaces p =2x10^7 N/m^2 (dark surfaces) and p = 0 N/m² (brighter surfaces) and contour lines of the plate vertical velocity w at time t_1. Here, the pressure is relative to the ambient pressure $p_0 \simeq$ 0.1 MPa.*

where needed and coarse cells where possible. To improve the efficiency of the solution with regards to time, an adaptive mesh refinement (AMR) is employed. The grid is halved either close to the interface between the two fluids or in close proximity of the high gradients of the fluid variables. The advantages of this process are shown in Figure 28, which shows the surface of maximum pressure during the wave (caused by an UWE) reflection stage from a wall. Two simulations have been performed with a similar local mesh size in the zones of large pressure: the first simulation contains AMR, whereas the second simulation is performed without AMR. The adaptive mesh increases the number of nodes as the simulation proceeds, whereas the fixed mesh has the same high loading cost for the entire simulation. As a result, the memory-space requirement is substantial with a factor of approximately 1.6 in terms of computational time for the same physical time interval. Another important advantage of the adaptive mesh algorithm is a smoother and more robust solution. The fixed mesh exhibits an unphysical smeared behaviour of the pressure when the mesh becomes too coarse as the discretisation in the fixed mesh does not change and may occasionally not be sufficiently fine during the evolution. The 3D solver with adaptive-mesh algorithm is capable of accurately capturing the wave reflection from the rigid wall and predicting a maximum wall pressure that is twice the incident wave pressure.

Another important ongoing development of the DD is the attempt of a 3D full fluid structure interaction (FSI) solution. It is motivated by the fact that the use of composite structures in offshore engineering has revamped the problem of FSI during underwater blasts as they enhance the FSI effect and increase the shock resistance of underwater structures. The practical applications of these materials range from warfare and offshore infrastructures to deep sea fuel transfer installations. The majority of the studies apply the hydrodynamic-pressure approximation proposed by Taylor for plates that interact with explosion waves. This application considers the reflected wave pressure and the damping effect due to the absorption of energy from the structure; however, it remains a simplified approach. Preliminary results for a TNT-charge explosion are shown on the left plot of Figure 29 in terms of displacement and pressure evolution at the centre of the structure that is modelled as an orthotropic plate. The displacement without a FSI is large; however, the reflection does not produce cavitation (negative value of the pressure) in the examined time interval. The fully coupled solution shows a distinct inception of cavitation (brighten pressure isosurface in the right side of the Figure).

Related publications:

- **Greco, M.; Colicchio, G.; Faltinsen, O.M.** A domain-decomposition strategy for a compressible multi-phase flow interacting with a structure, Int. J. for Numerical Methods in Engineering, 98, 2014, NTNU
- **Colicchio, G.; Greco, M.; Faltinsen, O.M.** Hydroelastic Response of a Submerged Structure to an Underwater Explosion, 29th Int. Workshop on Water Waves and Floating Bodies, Japan, 2014, NTNU

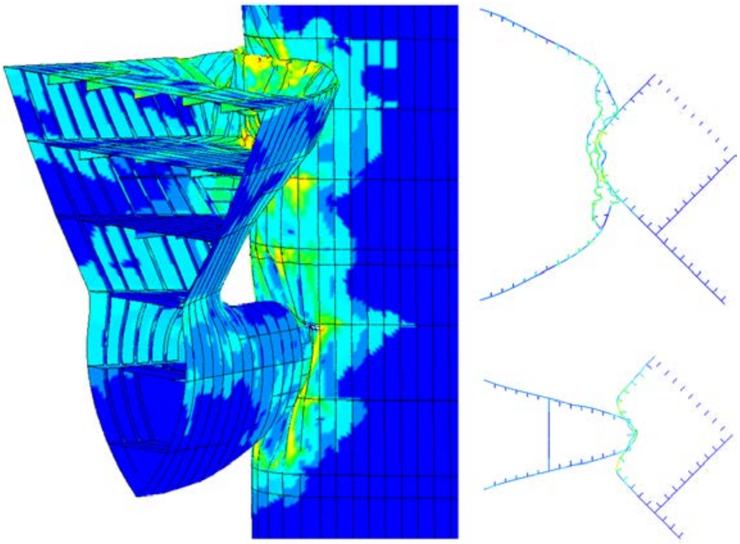

Figure 30: *Simulation of penetration and damage distribution in bow-platform column impact.*

Ship collisions

The damage to offshore platforms that are subjected to ship collisions has been investigated. The considered scenarios include bow and stern impacts against the column of a floating platform and stern impacts against the jacket legs and braces. The effect of the ship–platform interaction on the distribution of damage is examined by modelling both structures using nonlinear shell finite elements. The collision forces from the vessel are compared with the suggested force–deformation curves in the NORSOK code. For floating platforms, the crushing behaviour and potential penetration of bulbous bows or stern sections into the cargo tanks or void spaces, which are essential for hydrostatic stability, are analysed (refer to Figure 30). For high-energy collisions against fixed jacket platforms braces should be capable of penetrating the ship bow without being subjected to significant plastic bending or local denting.

Adequate treatment of the relative strength between the interacting bodies is especially relevant for impacts with high levels of available kinetic energy, for which shared energy or strength design is the target. This study is co-ordinated with Activities in DNV-GL JIP Determination of Structural capacity with Nonlinear Finite Element Methods. The outcome of the study will include proposals for revisions of the NORSOK standard N-004 Appendix A—Design against accidental actions.

In the assessment of the impact performance of offshore and ship structures using nonlinear finite element analysis, fractures in heavily deformed panels should be considered. Fracture is a localised phenomenon; to capture these effects, a mesh size in the range of the plate thickness is required. However, the sheer size of the structures makes detailed modelling computationally prohibitive. Thus, a method for reliable failure prediction of

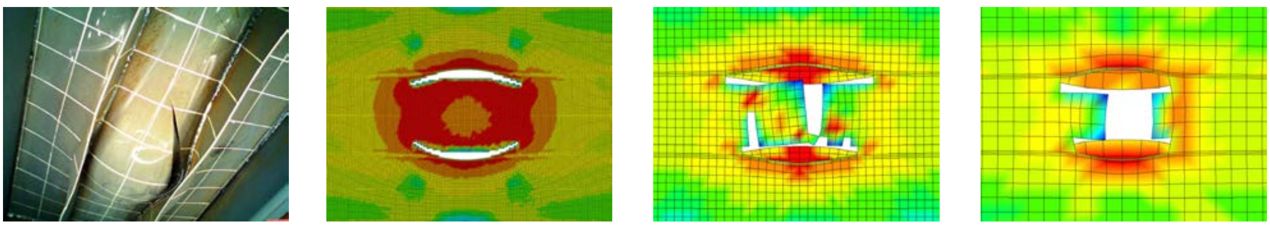

Figure 31: *Test and simulation of fractures in a plate with two flat bar stiffeners. The mesh size is 1, 5 and 10 times the plate thickness. The colours show the von Mises stress.*

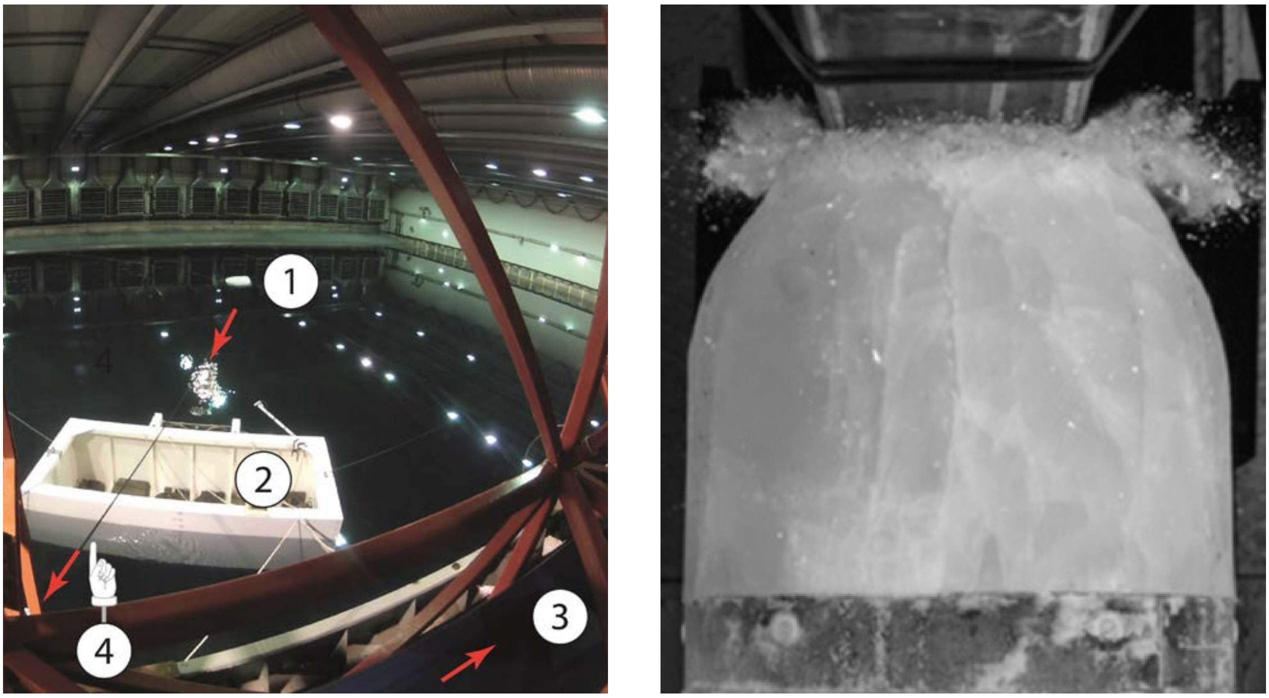

Figure 32: *a) Towing impact test, b) High-speed impact experiment.*

coarsely meshed shell structures has been developed. It combines a local necking instability criterion with a post-necking damage model. The failure model is based on the power law plasticity with the stress-based Bressan-Williams-Hill (BWH) instability criterion and a coupled damage model after incipient necking. The model is incorporated in the explicit finite element code LS-DYNA. It provides a robust prediction of material failure and energy dissipation with a low mesh size dependence in comparative simulations of experiments on several levels: from the formability tests with varying strain states to medium- and large-scale impact experiments. An example is given in Figure 31.

Abnormal level ice-structure interaction

Ships and offshore structures that operate in Arctic conditions have to be designed against ice loads with return periods of typically 100 years in the ultimate limit state (ULS) condition. Offshore structures must also resist rare (abnormal) ice loads with return periods in the range of 10,000 years. In some areas outside the ice edge, only abnormal ice loads actions may be expected; thus, the ULS resistance is not a design issue. Whereas the structure has to remain virtually undamaged in the ULS, large permanent deformations are accepted for abnormal ice impacts in the accidental limit state (ALS) provided that no penetration of cargo tanks with subsequent spills occur and global integrity is not jeopardised. The design in ULS is typically represented by empirical pressure-area relationships for crushing ice. Similar pressure-area relationships have been developed for ALS. These make less sense, however, as the capacity of the structure may limit the contact pressure; the energy dissipation in the structure may be sufficient to comply with the acceptance criteria. Unless a conservative design is desired, an integrated analysis in which the interaction between the deformation of the structure and the ice is considered should be conducted. This analysis requires continuum mechanics models of the ice feature and the structure. Material modelling of ice is challenging. An existing model, which is applicable for integrated analysis, has been further developed.

To verify the material model and ice-structure interaction behaviour, towing impact tests have been conducted in the ice laboratory of Aalto University in Finland; refer to Figure 32a. In collaboration with SAMCoT and SIMLab, plans for testing in SIMLab's pendulum accelerator rig are underway. Pilot tests conducted in 2014 were filmed and presented on the Discovery Channel's Daily Planet show in September. A photo that was taken by a high-speed video camera during one of the pilot tests is shown in Figure 32b.

Related publications:

- **Kim, Ekaterina.** Experimental and numerical studies related to the coupled behavior of ice mass and steel structures during accidental collisions. Trondheim: Doktoravhandlinger ved NTNU 2014 (ISBN 978-82-326-0192-9) 220 s., NTNU
- **Storheim, Martin; Amdahl, Jørgen.** Design of offshore structures against accidental ship collisions. Marine Structures 2014; Volum 37. s. 135-172, NTNU

Safety, risk and autonomy in subsea intervention

Project manager: Adjunct professor Ingrid Schjølberg
Research associates: Professors Ingrid B. Utne, Thor I. Fossen, Dr Anastasios Lekkas
PhD candidates: Jeevith Hegde, Bård B. Stovner, Erlend K. Jørgensen, Christopher Thieme, Eirik H. Henriksen

This project addresses the development of decision support methods for safer, smarter and more reliable autonomous subsea intervention. The project addresses topics in the entire decision support chain from operator situation awareness to local autonomous functionalities. Four main research topics are addressed to support the development of the decisions support tools: i) operator trust, perception and awareness, ii) risk models and analysis of risk during operation, iii) autonomous functions for subsea intervention and iv) design of systems and analysis of operational data.

The short-term outcomes will comprise methods for subsea intervention via limited bandwidth link, localisation for subsea intervention, mission and motion planning, guidelines for safe and reliable autonomous operations and improved situation awareness.

Highlights:

- Architecture for real-time risk management in the oil and gas industry with a focus on surface and subsea applications
- Establishment of NextGenIMR project
- Application of standards for autonomous IMR operations
- Human factors in autonomous operations
- Development of methods for obtaining more reliable acoustic position measurements
- Methods for underwater localisation and perception

Related publications:

- **Utne, Ingrid Bouwer; Schjølberg, Ingrid**. A Systematic Approach to Risk Assessment: Focusing on Autonomous Underwater Vehicles and Operations in Arctic Areas. I: ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering Volume 10: Polar and Arctic Science and Technology San Francisco, California, USA, June 8–13, 2014. ASME Press 2014 ISBN 978-0-7918-4556-1. NTNU
- **Schjølberg, Ingrid; Utne, Ingrid Bouwer; Vinnem, Jan Erik.** Risk Management. [Patent] Patentnr./Lisensnr.: 120737 Registrert 2014-06-30, NTNU

Figure 33: *AMOS Operations.*

ASSOCIATED RESEARCH PROJECTS

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

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

Rolls-Royce

The Fault-Tolerant Inertial Sensor Fusion for Marine Vessels (MarineINS) project for marine vessels is funded by the Norwegian Research Council via MAROFF and Rolls-Royce Marine. The project goal is to develop novel architectures and algorithms for integrating sensor data from various position reference systems and inertial sensors to provide motion and position measurements with better accuracy and reliability and less stringent requirements for each sensor. The solutions will improve redundancy and failure handling and will employ software algorithms to gain high-quality information from data obtained from low-grade sensors.

The main goal of the project is to test nonlinear strapdown inertial navigation systems onboard a supply vessel using new software architectures and nonlinear sensor fusion methods. The use of fault-tolerant design techniques with inertial measurements, such as accelerometers and gyros, will be emphasised to prevent the need for a mathematical model for the vessel.

Signal-based inertial navigation system for marine vessel aided by GNSS

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

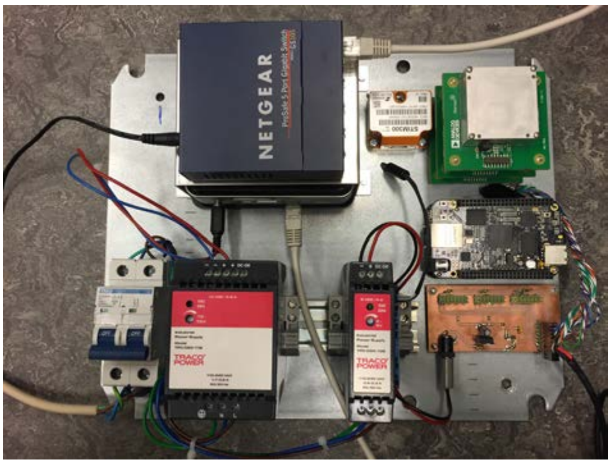

Figure 34: *Onboard computer for data logging that contains three ADIS 16485 IMUs from Analogue Devices.*

Related publications:

- **Bryne, T.H.; Fossen, T.I.; Johansen, T.A.** Nonlinear Observer with Time-Varying Gains for Inertial Navigation Aided by Satellite Reference Systems in Dynamic Positioning. Proc. of the IEEE Mediterranean Conference on Control and Automation (MED'14), 16-19 June, 2014, Palermo, Italy, NTNU

- **Rogne, R.H.; Johansen, T.A.; Fossen, T.A.** Observer and IMU-based Detection of Faults in Position Reference Systems and Gyrocompasses with Dual Redundancy in Dynamic Positioning. 2014 IEEE Multiconference on Systems and Control. October 8-10, 2014, Antibes, France, NTNU

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

Project manager: Professor Thor I. Fossen
Research associates: Professors Tor Arne Johansen, Oddvar Hallingstad, adjunct associate professor Håvard F. Grip
PhD candidates: Sigurd M. Albrektsen, Kasper Trolle Borup, Jakob M. Hansen
Project collaborators: AMOS, UNIK, Maritime Robotics, FFI
Project web page: https://www.itk.ntnu.no/english/research/lowcostnav/Hovedside

UNIK FFI Forsvarets forskningsinstitutt Norwegian Defence Research Establishment MARITIME ROBOTICS

The Low-cost integrated navigation systems using nonlinear observer theory (LowCostNav) project, which is funded by the Norwegian Research Council via FRIPRO, will develop nonlinear observers for attitude estimation and the integration of MEMS-based inertial sensors aided by position reference systems. The goal of the project is to replace the extended Kalman filter (EKF) with nonlinear observers for position, velocity and attitude (PVA) determination without performance degradation. This advancement will significantly reduce the computational footprint, and the software can be used in different applications, such as low-cost consumer electronics, cars, and navigation systems for AUVs, ships, and UAVs. MEMS technology and embedded systems enable technologies for the development of low-cost and compact PVA units. LowCostNav focuses on nonlinear observer design for the estimation of PVA by preventing traditional EKF designs, which facilitates the assessment of global exponential stability. Thus, performance and robustness can be guaranteed and quantified by mathematical methods. The development of effective computer algorithms that can be implemented using only a fraction of the source code footprint while representing computational complexity compared with a standard EKF implementation is also possible. These algorithms will simplify implementation, maintenance, and software verification, as well as documentation.

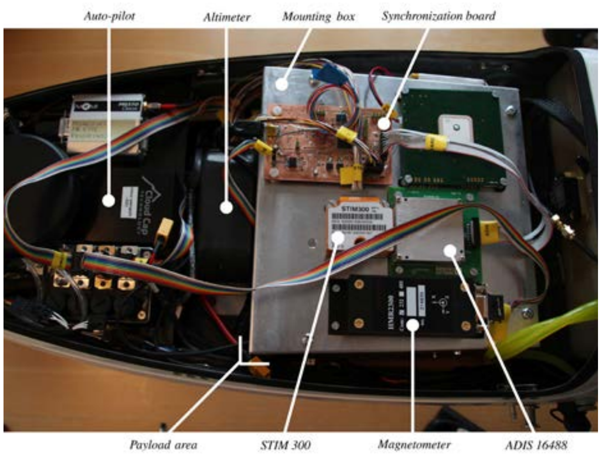

Figure 35: *A payload module for the Penguin B UAV has been designed with IMUs, GNSS-receiver, magnetometer, altimeter, camera and onboard computer. A custom PCB has been designed for data synchronisation.*

Highlights

A complete navigation solution for PVA determination has been developed using a nonlinear observer, which guarantees that the origin of the estimation error dynamics is globally and exponentially stable. This problem is a difficult mathematical problem as the attitude estimation problem is constrained to SO(3). This study has been extended to include time-delayed GNSS measurements. A payload module for the Penguin B UAV was constructed in 2014 (refer to Figure 35). The payload module is employed for experimental verification and testing of the strapdown navigation systems.

Related publication:

- **Grip, H.F.; Fossen, T.I.; Johansen, T.A.; Saberi,** A. Globally Exponentially Stable Attitude and Gyro Bias Estimation with Application to GNSS/INS Integration. Automatica. Volume 51, January 2015, Pages 158–166, NTNU

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

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

Dynamically positioned (DP) vessels with electric power plants in the range of 10-80 MW are employed in the offshore industry for several safety-critical operations, including drilling, supply, offloading, construction, anchor handling, and production.

Research areas:

- Design and verification of complex systems by system simulations
- Analysis of transient and stationary dynamics on fuel consumption and gas emissions
- Optimal and fault-tolerant control of hybrid power systems with AC and DC on ships and rigs with diesel- and LNG-driven gensets and energy storage using battery banks and flywheels

Optimisation-based control of diesel-electric ships in dynamic positioning
Dr Aleksander Veksler successfully defended his PhD thesis in November 2014. His thesis exploits recent advances in computer hardware and numerical algorithms to apply more computationally demanding control methods and enable more effective exploitation of the thruster system and power plant with less risk for power blackout.

Real-time numerical optimisation methods and feed-forward and predictive control strategies can be employed to control power generation and consumption in an integrated manner. The thesis shows how ship performance parameters, such as fuel consumption, power bus electric frequency variation and dynamic positioning accuracy, can be more effectively controlled in extreme

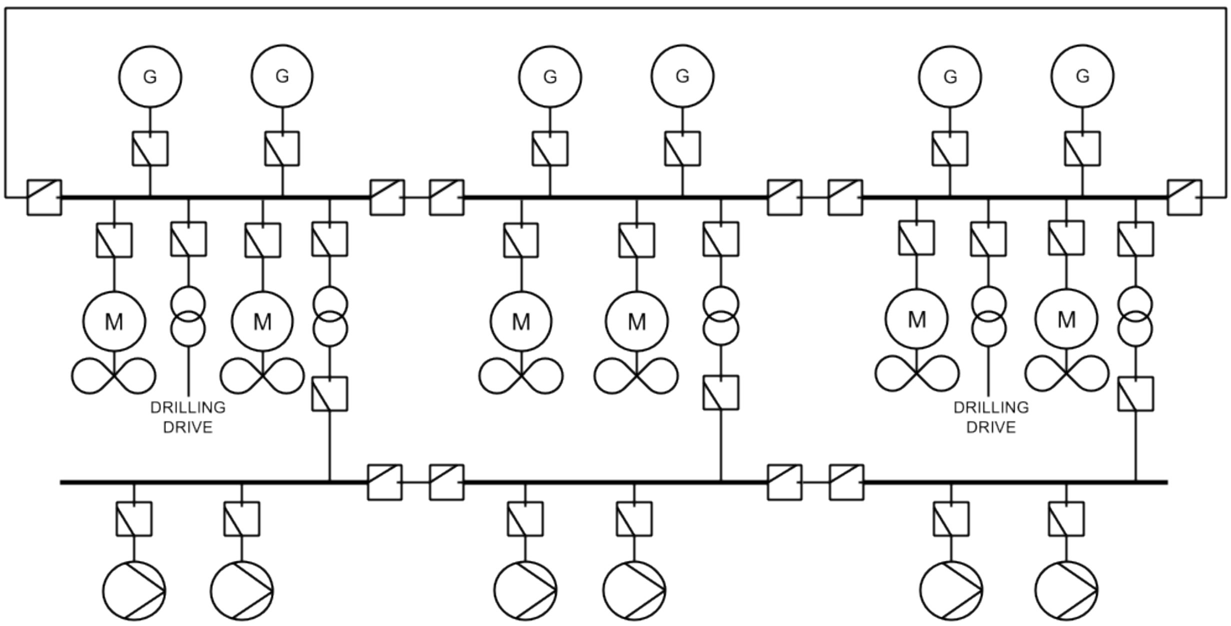

Figure 36: *Typical power plant configuration.*

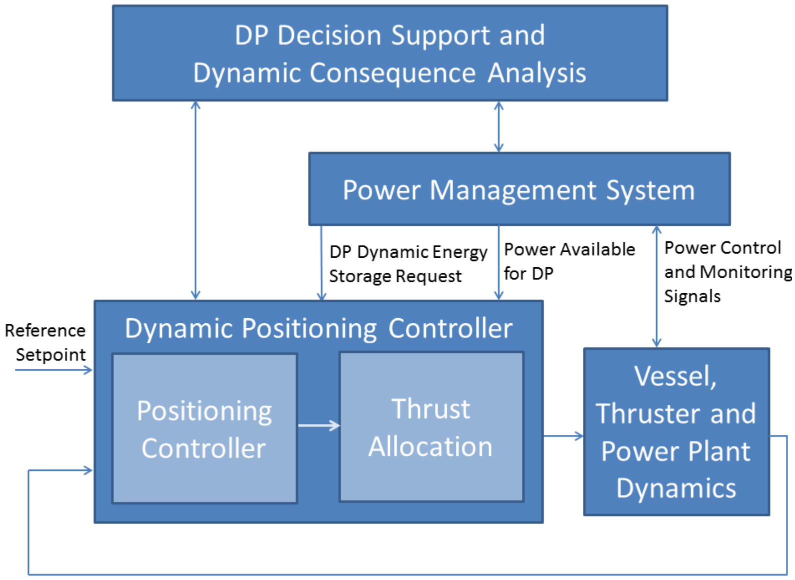

Figure 37: *Proposed control architecture.*

situations when operating near the capability limits. This study contributes to a reduction in the consequences of the failure of thrusters or generators and the risk for over/underfrequency protection trips.

Marine vessel power plant simulator developed under the D2V project

A multi-domain system simulator for electric power and propulsion on marine vessels is developed by a team of doctoral students in the D2V project as an extension to the extensively utilised Marine Systems Simulator at NTNU. The Simulink-based simulator enables an extensive range of thruster, propulsion and power systems to be configured and simulated as a total system. This system includes simulation of the vessel, environmental forces, machines, and control systems, such as dynamic positioning, thruster control, autopilots and power management systems.

By simulating the interactions between these systems in an integrated simulation system, system performance, integrated design, and fault tolerance can be examined. Examples of these systems are hybrid power plants, consequences of dynamic disturbances in dynamic positioning, DC distribution systems, emissions, fuel consumption and wear on rotating machinery.

Related publication:

- **Bø, T. I. et al.** Real-time marine vessel and power plant simulator, Proc. AMSE 34th International Conference on Ocean, Offshore and Engineering, (OMAE), St. John's, Canada, 2015, NTNU

Dynamic positioning system as dynamic energy storage on diesel-electric ships

Dynamic energy storage concepts, such as battery and capacitor banks, are currently being introduced to increase the operational efficiency of ships, which enables temporary high power demands to be provided by these systems to reduce the number of installed or running generators for the benefit of improved emissions or fuel economy.

A recent paper describes how the potential and kinetic energy of the ship hull can be effectively applied as a short-term dynamic energy storage that can be exploited on dynamically positioned ships that operate against an environmental force field. Significant power variations of approximately 10-s periods can be accommodated without significantly reducing the positioning accuracy. Surplus transient electric energy is consumed by the thrusters and stored as potential and kinetic energy of the ship hull, which moves against the force field. Using an intelligent control strategy integrated within the dynamic positioning system, the energy is recovered to the dynamic positioning system by reducing the consumption of the thrusters.

A benefit of the approach is that it does not require the installation of electric energy storage devices, as it only requires software functionality in the dynamic positioning or thruster control system.

Related publication:

- **Johansen, T. A.; Bø, T. I.; Mathiesen, E.; Veksler, A.; Sørensen, J.** Dynamic Positioning System as Dynamic Energy Storage on Diesel-Electric Ships, IEEE Transactions on Power Systems, Vol. 29, pp. 3086 - 3091, 2014, NTNU

Next generation subsea inspection, maintenance and repair (NextGenIMR)

Project manager: Adjunct Professor Ingrid Schjølberg
Research associates: Professor Ingrid B. Utne, adjunct professor Tor B. Gjersvik, Dr Anastasios Lekkas
PhD candidates: Jeevith Hegde, Bård B. Stovner, Eirik H. Henriksen
Project collaborators: AMOS, SINTEF, FMC Technologies, Statoil
Project web page: https://www.ntnu.edu/amos/project-9-amos-operation-centre

Maintaining high regularity with subsea facilities requires reliably installed equipment and efficient methods of inspection, condition monitoring and early detection of equipment fault. NextGenIMR will develop robust perception methods and collision-free motion planning algorithms for autonomous subsea inspection and light intervention operations.

The project has a strong focus on subsea factory design for autonomous intervention. Although the project especially addresses autonomous platforms, the results are applicable to cable connected ROVs that will shift from manual control to automatic control with autonomous functions. Advances in sensor technology, communication, ICT architecture design, localisation methods, robotics and task-planning open new possibilities to bridge the gap between manual control and autonomy. NextGenIMR results will be tested, verified and demonstrated in full-scale test beds, which are available at NTNU, and among industry partners. The technology will be highly relevant for IMR operations in fish farms and deep-sea mining.

Media coverage:

- «Derfor vil de lage garasjer på havbunnen», 21 November 2014, Teknisk Ukeblad: https://www.tu.no/petroleum/2014/11/21/derfor-vil-de-lage-garasjer-pa-havbunnen

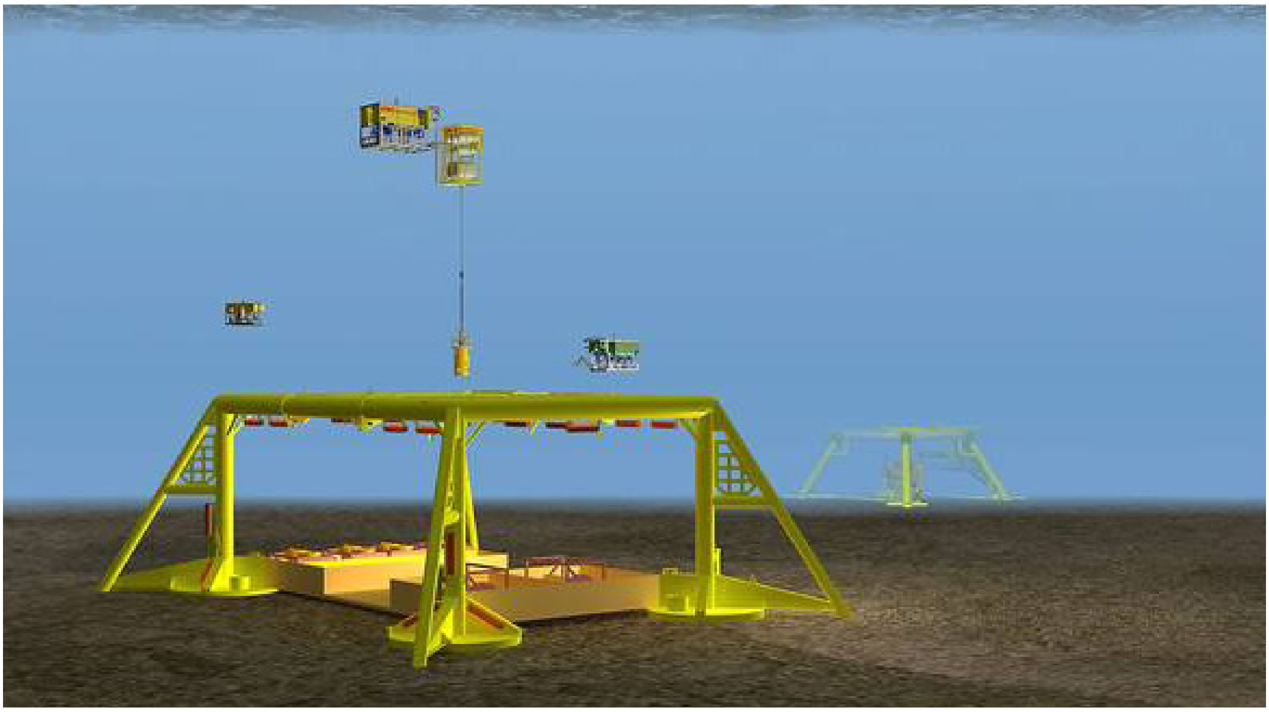

Figure 38 *(FMC Technologies): Subsea Installation.*

Control, information and communication systems for environmental and safety critical systems

Project manager: Professor Kristin Y. Pettersen

Research associates: Professors Thor I. Fossen, Jan Tommy Gravdahl, Lars S. Imsland, Tor Arne Johansen, Anton Shiriaev, Asgeir J. Sørensen, Ole Morten Aamo

PhD candidates: Walter Caharija, Pål J. From, Esten Grøtli, Daniel de A. Fernandes, Espen Hauge, Hessam Mahdianfar, Johannes Phillip Maree, Aleksander Veksler

Project collaborators: AMOS, Centre for Ships and Ocean Structures (CeSOS/NTNU)

Project web page: https://www.itk.ntnu.no/cics

The project Control, Information and Communication Systems for Environmental and Safety Critical Systems is a Strategic University Program funded by the Norwegian Research Council. The project goal is to develop advanced information and communication technology (ICT) for important applications, such as the marine and maritime industry, the oil and gas industry, and for sustainable energy production.

Unmanned oil and gas platforms are employed for the extraction of resources from smaller oil and gas fields. The project presents new research results for robot manipulators that are mounted on moving platforms. This includes results for robot manipulators mounted on ships, unmanned underwater vehicles and satellites. Singularity free models are developed for the combined motion of the robot manipulator and the platform, and algorithms based on optimisation utilises instead of counteracting the environmental forces, which significantly reduces the energy consumption. The results on this study have culminated in the book "Modeling for Simulation, Analysis, and Control of Vehicle-Manipulator Systems" by P.J. From, J.-T. Gravdahl and K.Y. Pettersen, which was published by Springer-Verlag in 2014 (see Figure 39).

Another research topic addressed by this project is communication within networks of mobile units. It is primarily motivated by an increased interest in Arctic areas, including the resources detected at Skrugard og Shtokman

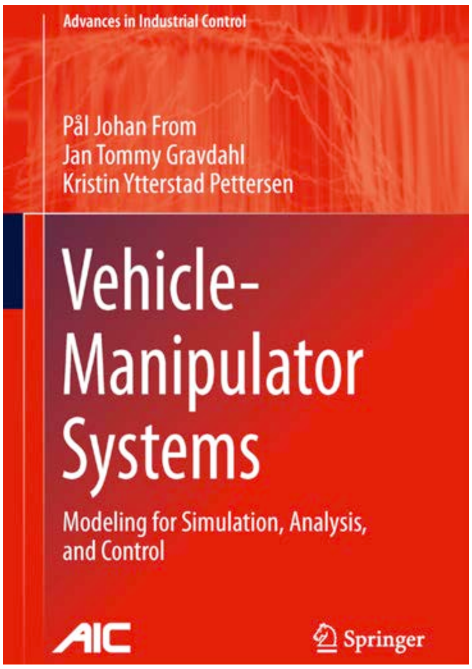

Figure 39: *Book "Modeling for Simulation, Analysis, and Control of Vehicle-Manipulator Systems" by P.J. From, J.-T. Gravdahl and K.Y. Pettersen, Springer-Verlag, 2014.*

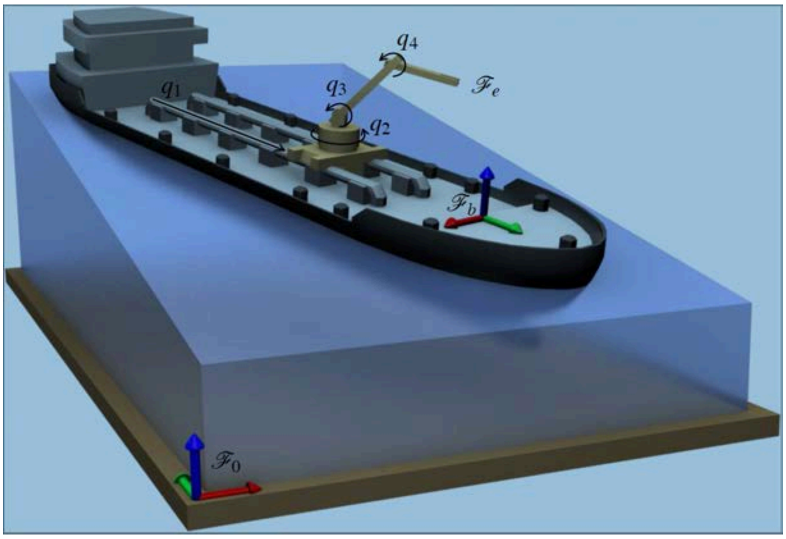

Figure 40: *A vehicle-manipulator system.*

field. Significant parts of the undiscovered oil and gas resources are located in the Arctic. Another important reason for this interest is the occurrence of ice melting in the polar regions, which may open up the northeast and northwest passage and significantly reduce the energy consumption for shipping between West Europe and East Asia and between Europe and the west coast of the USA. Communication is important for shipping and drilling and extraction operations. Large parts of the Arctic lack a permanent communication infrastructure. Unmanned planes and helicopters can serve as a supplement to the existing permanent infrastructure by working as communication nodes. The project has developed algorithms for path planning for these communication nodes, which satisfies 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. More than 200 papers have been published in international journals, books and conferences, and the project has educated five PhDs.

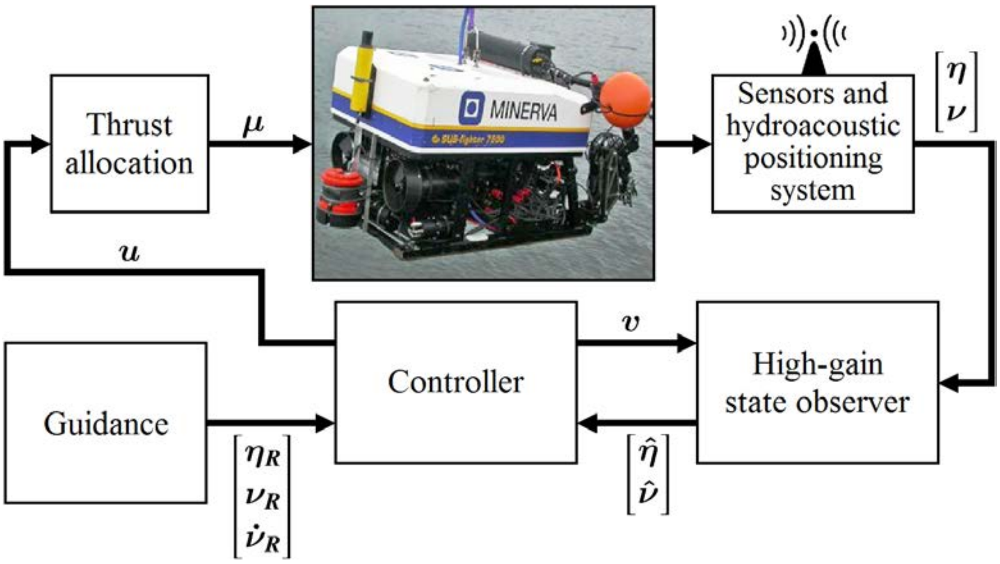

Figure 41: *Block diagram of the output feedback control system. The block corresponding to the controlled plant is illustrated here by the NTNU's ROV Minerva.*

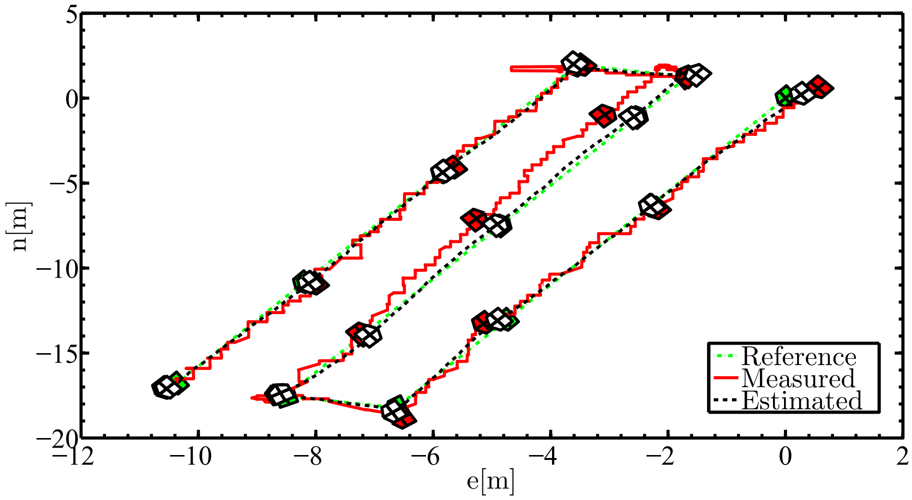

Figure 42: *Trajectory tracking test: Top view of the North-East plane.*

Output feedback motion control system for observation class ROVs based on a high-gain observer: theoretical and experimental results

An output feedback controller based on a high-gain observer is developed for a motion control system (MCS) for ROVs with station keeping—dynamic positioning (DP)—and trajectory tracking capabilities. Four degrees-of-freedom are controlled—surge, sway, heave, and yaw. The MCS consists of an output feedback control system that is composed of a high-gain state observer (HGSO) and a multiple-input-multiple-output (MIMO) proportional-integrative-derivative (PID) controller aided by reference feedforward. Feedback linearisation of the plant dynamics is also performed by the MCS. Stability and satisfactory performance for suitable and smooth reference trajectories are attained despite the presence of unmodelled dynamics, plant parameter variations, measurement noise, and environmental disturbances. The results obtained from full-scale trials based on the NTNU's ROV Minerva, which is navigated by the proposed MCS, are presented in Figures 41-43. The results are reported in the IFAC Control Engineering Practice paper of Fernandes, Grøtli, Sørensen, Pettersen and Donha (2015).

Related publication:

- **Fernandes, D. de A.; Sørensen, A. J.; Pettersen, K. Y.; Donha, D. C.** Output feedback motion control system for observation class ROVs based on a high-gain state observer: theoretical and experimental results. Control Engineering Practice; Vol. 39, 2015, pp. 90-102, NTNU

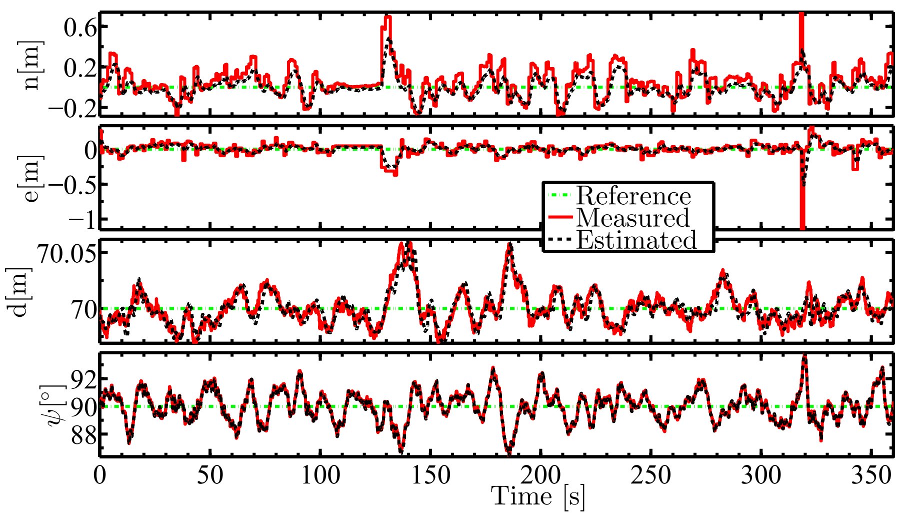

Figure 43: *DP test: Position and heading angle in the NED frame.*

Snake locomotion in challenging environments

Project manager: Professor Kristin Y. Pettersen
Research associates: Professors Odd M. Faltinsen, Jan Tommy Gravdahl, Marilena Greco, Asgeir J. Sørensen, associate professor Øyvind Stavdahl, Dr Christian Holden
PhD candidates: Eleni Kelasidi, Ehsan Rezapour
Project collaborators: AMOS, SINTEF ICT
Related website: http://robotnor.no/our-snake-robots-in-the-media/

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

The project develops new research results within control systems, information and communication technology for robotic locomotion in unknown and challenging environments. Inspired by biological snakes and eels, snake robots have long, slender and flexible bodies that can provide robust locomotion properties in any environment, both on land and in sea.

This project develops new mathematical models for snake robots, including the hydrodynamic models of swimming snake robots. New methods and tools for obstacle-aided locomotion are also developed, including mathematical models for the interaction between the snake robot and its environment and model-based control algorithms for obstacle-aided locomotion. New force sensing capabilities are introduced for snake robots, and the theoretical results are verified using numerical simulations and experiments with physical snake robots.

In addition, underwater snake robot locomotion is investigated. This introduces new challenges, as a swimming snake robot can move in three-dimensional space and the mathematical models that form the basis of the model-based analysis and control design should incorporate the hydrodynamic effects. This study provides the potential for improving the efficiency and manoeuvrability of next generation AUVs.

Related publication:

- **Rezapour, Ehsan; Pettersen, Kristin Ytterstad; Liljebäck, Pål; Gravdahl, Jan Tommy; Kelasidi, Eleni.** Path following control of planar snake robots using virtual holonomic constraints: theory and experiments. Robotics and Biomimetics 2014; Volum 1.(3) s. 1-15, NTNU SINTEF

Figure 44: *The snake robot Mamba in the NTNU Snake Robotics Laboratory.*

Dynamic response analysis of wind turbines under fault conditions

Project manager: Professor Torgeir Moan
Research associates: Adjunct associate professor Zhen Gao
PhD candidate: Zhiyu Jiang
Project collaborators: AMOS, Centre for Ships and Ocean Structures (CeSOS/NTNU)

Wind turbines are subjected to faults and failures during their lifetime. A vast number of sensors are installed on a modern wind turbine to detect and isolate faults. Faults, such as bearing wear or gear tooth wear, are difficult to detect at early stages, though they may result in a total breakdown of the drivetrain. According to international standards, such as the IEC 61400 series, wind turbine designs should consider the transient responses caused by faults, e.g., grid loss and blade blockage due to loss of pitch control. Figure 45 shows the response in a land-based turbine when a blade blockage occurs at 400 s. After a time delay of $T_d = 0.1$ s, an emergency shutdown occurs. The significant main-shaft bending moment shown in Figure 45 is caused by the imbalanced load acting on the rotor plane. During shutdown, if one blade is seized and hindered from normal pitch-to-feather activity, the transient responses can be large. Clearly, the response would also depend on the time instant when shutdown occurs and on the specific shutdown procedure. Figure 46 indicates that the strong resonant responses excited during shutdown can be largely eliminated if the pitch rate is reduced from 8 deg/s to 1 deg/s.

Related publications:

- **Moan, T.** Stochastic dynamic response analysis of offshore wind turbines in a reliability perspective. In Cunha A., Caetano E., Ribeiro P., and Muller G. (eds.), Proc. 9th EURODYN Conf. 2014, NTNU
- **Jiang, Z.** Long-term response analysis of wind turbines with an emphasis on fault and shutdown conditions. PhD thesis, Department of Marine Technology, Norwegian University of Science and Technology, Trondheim, Norway, 2014, NTNU
- **Jiang, Z.; Moan, T.; Gao, Z.** A comparative study of shutdown procedures on the dynamic responses of wind turbines. Journal of Offshore Mechanics and Arctic Engineering, Vol. 137, pp. 011904(1-15), NTNU

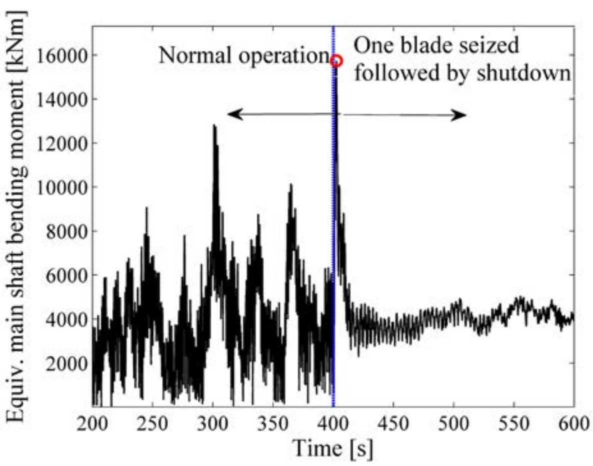

Figure 45: *Time series of the main-shaft bending moment in grid loss and blade seize followed by shutdown; land-based turbine; mean wind speed=17 m/s; turbulence intensity=0.2; time of fault occurrence=400 s; pitch rate=8 deg/s; HAWC2 simulation.*

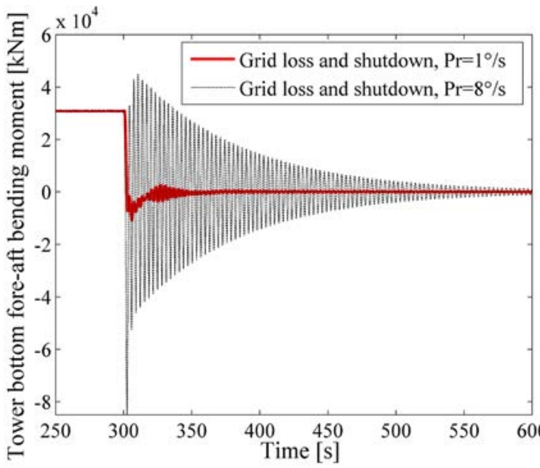

Figure 46: *Effect of pitch rate on the tower-bottom bending moment during shutdown; constant wind speed=20 m/s; land-based wind turbine; Simo-Riflex-AeroDyn simulation, Pr=pitch rate.*

Nonlinear wave loads on offshore wind turbines

Project manager: Professor Torgeir Moan
Research associates: Adjunct associate professor Erin E. Bachynski, Dr Ali Nematbakhsh
Project collaborators: AMOS, Statoil, MIT, MARINTEK

Tension leg platform wind turbines (TLPWTs, Figure 47) hold promise for capturing offshore wind energy in intermediate (45-150 m) and deep (>150 m) water. TLPWT designs with diameters in the range 5-18 m and pitch natural periods of 1.5-4.5 seconds have been presented in literature. Marine structures with structural periods in the range of 1-5 seconds are known to be susceptible to "ringing" responses in high, steep waves due to a transient response at flexural natural frequencies that are substantially higher than the incident wave frequencies.

A study on the effect of ringing loads computed using a bandwidth-limited, sum-frequency formulation on TLPWTs showed significant increases in the maximum loads in severe sea states compared with first-order hydrodynamic load models (Bachynski and Moan, 2014). Further work using CFD methods showed good agreement (Nematbakhsh et al., 2014).

These results are also of interest for bottom-fixed offshore wind turbines, which are the most commonly used turbines (Figure 48). Economies of scale are pushing for larger turbines (6-10 MW), which require larger support structures. For shallow and intermediate water depths, large mono-pile foundations are considered to be most promising with respect to the levelised cost of energy (LCOE). The largest natural period of such structures is 3-5 seconds, and nonlinear high-frequency wave loads in relatively shallow water (15-50 m) can also lead to ringing-type and other high-frequency responses.

Based on the mono-pile diameter and wave conditions, the calculation of the hydrodynamic loads may need to account for nonlinear kinematics, diffraction effects, viscous effects, and finite depth effects. While methods for deep water are based on perturbation methods and linear incoming waves, the incoming wave nonlinearity becomes more important in shallow water. New theoretical and computational methods are being developed.

Related publications:

- **Bachynski, E. E.; Moan, T.** Ringing Loads on Tension Leg Platform Wind Turbines, Ocean Engineering, 2014, 84, 237-248, NTNU
- **Nematbakhsh, A.; Bachynski, E. E.; Gao, Z.; Moan, T.** Comparison of Wave-induced Response of a TLP Wind Turbine Obtained by CFD Method and Potential Theory. In the Twenty-fourth International Ocean and Polar Engineering Conference, 2014, NTNU

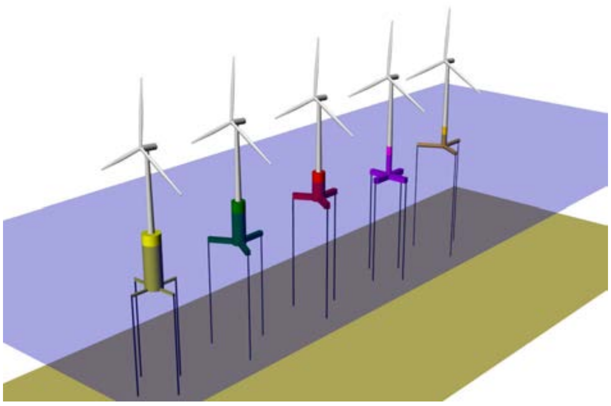

Figure 47: *Tension leg platform wind turbines (TLPWTs).*

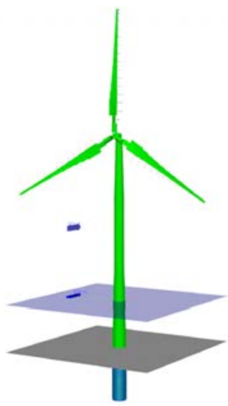

Figure 48: *Bottom-fixed monopile wind turbine.*

Numerical and experimental study of a combined wind and wave energy concept – STC (Spar-Torus-Combination)

Project manager: Professor Torgeir Moan
Research associates: Adjunct professor Claudio Lugni, adjunct associate professor Zhen Gao
PhD candidate: Ling Wan
Project collaborators: AMOS, Centre for Ships and Ocean Structures (CeSOS/NTNU)

Combined concepts of wind turbines and wave energy converters on one platform have been proposed and investigated in the EU FP7 Project – MARINA Platform. The STC concept, which was developed at NTNU, was one of the three combined concepts that were studied in detail both numerically and experimentally. It consists of a spar wind turbine and a torus-shaped heaving-body wave energy converter. The model tests were performed at a scale ratio of 1:50 in the towing tank at INSEAN through the MARINET project to investigate both the survivability and functionality of the wave energy converter in extreme and operational conditions.

Figure 49 shows the test model with two survival modes. In addition to the motions and mooring tension, the forces between the torus and the spar were also measured by three multi-axial load cells. The numerically and experimentally obtained RAOs of the vertical force are compared in Figure 50. The result indicates clearly that the vertical force is much larger for the MWL mode, and the RAO shows a peak at a wave period of 12 s, which is the natural period of heave motion when the torus is fixed to the spar at the mean water level. The numerical results based on linear wave theory agree well with the experimental results. The comparison between experimental and linear numerical results for the MWL mode in large waves (H=9 m) shows a discrepancy due to water exit and entry (slamming) of the torus and is being investigated in more detail.

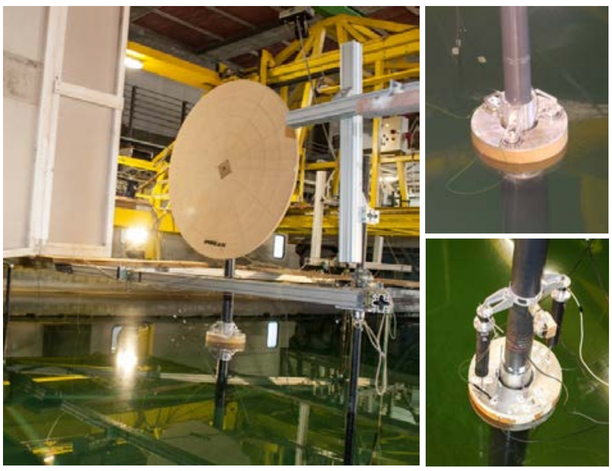

Figure 49: *The STC test model at INSEAN (right-top: MWL survival mode with the torus fixed to the spar at mean water level; right-bottom: operational mode with the torus connected to the spar by two pneumatic cylinders to model the PTO damping).*

Figure 49 also shows the STC model in the functionality test. In this configuration, the torus is connected to the spar via two pneumatic cylinders to model the damping effect on the power take-off (PTO) system in the wave energy converter. The power predicted by linear theory and the measured power are found to agree extremely well.

Related publications:

- **Wan, L.; Gao, Z.; Moan, T.** Model Test of the STC Concept in Survival Modes. In: Proceedings of the 33rd International Conference on Ocean, Offshore and Arctic Engineering, OMAE2014-23213, June 8-13, San Francisco, California, USA, 2014, NTNU
- **Wan, L.; Gao, Z.; Moan, T.** Power Performance of the Wave Energy Converter in a Combined Wind and Wave Concept and its Survivability. In: The 1st International Conference on Renewable Energies Offshore (RENEW), November 24-26, Lisbon, Portugal, 2014, NTNU

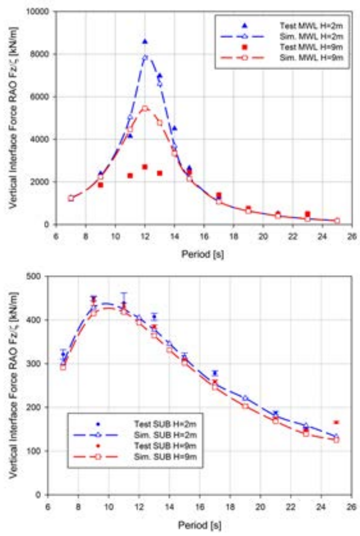

Figure 50: *Numerically and experimentally obtained RAOs of the vertical force between the torus and the spar for the MWL (left) and the SUB (right) survival modes.*

PHOTO GALLERY

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Prof. Thor I. Fossen, Co-director


Prof. Jørgen Amdahl


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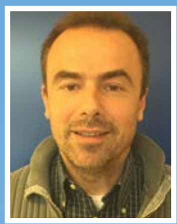
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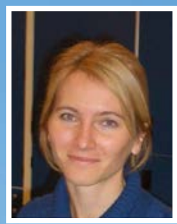
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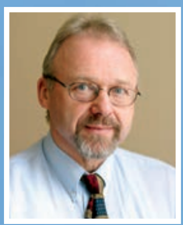
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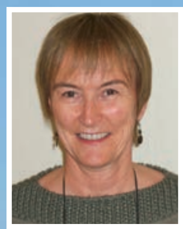
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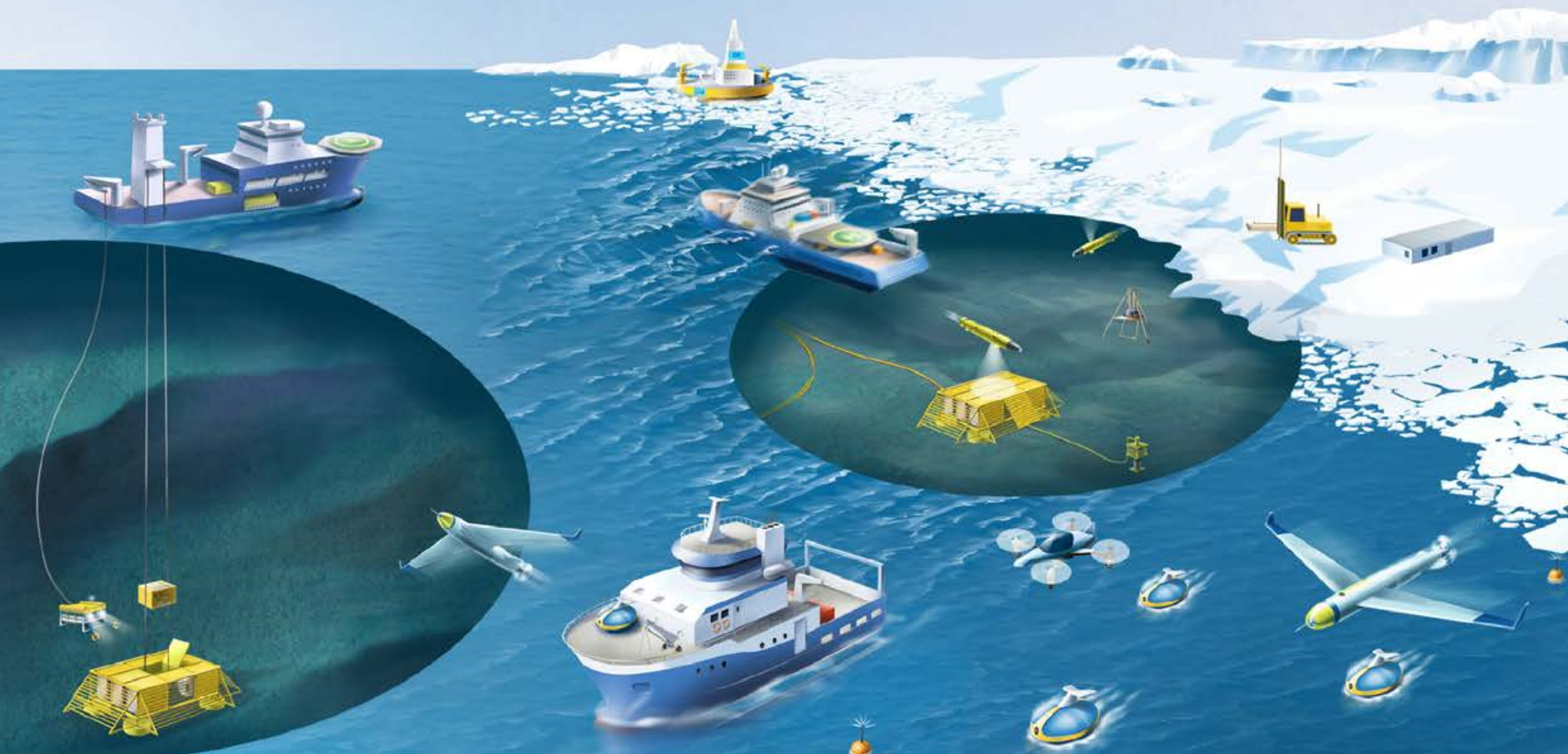

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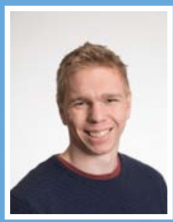
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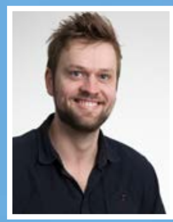
Sigurd M. Albrektsen


Leif Erik Andersson


Dennis Belleter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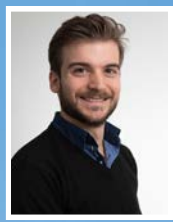
Torleiv H. Bryne


Torstein I. Bø


Walter Caharija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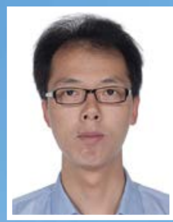
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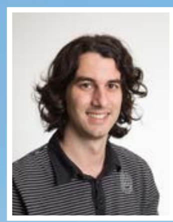
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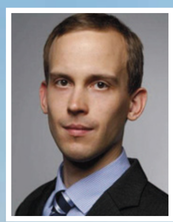
Mahdi Ghane


Jakob M. Hansen


Finn-Christian W. Hanssen


Martin Hassel


Jeevith Hegde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Eleni Kelasidi


Kristian Klausen


Anna Kohl

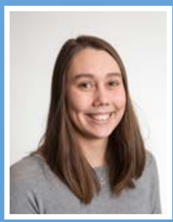

Fredrik S. Leira


Lin Li


Shaojun Ma


Siri H. Mathisen


Marianne Merz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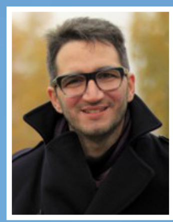
Claudio Paliotta


Michel Rejani Miyazaki


Robert Rogne


Børge Rokseth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Mohd A. Siddiqui


Espen Skjong


Martin Storheim


Bård B. Stovner


Ida M. Strand


Kim L. Sørensen


Mikkel E. N. Sørensen


Christoph A. Thieme


Svenn A. Tutturen


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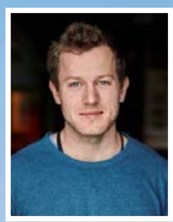
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Martin S. Wiig


Zhaolong Yu


Yuna Zhao


Artur Zolich


Øyvind Ødegård

LABORATORY HIGHLIGHTS AND RESEARCH CAMPAIGNS

Highlights of the Applied Underwater Vehicle Laboratory (AUR-Lab)

The AUR-lab's web page: https://www.ntnu.no/aur-lab

During 2014, AMOS was the most active user of AUR-Lab by its professors and PhD and MSc students. AUR-Lab has enabled AMOS to test code and algorithms in engineering trials and integrated operations, in which the successful operations have been important to our experienced end users. AUR-Lab is also engaged in the Horizon2020 project Blue Mining; the objective of this project is to localise, characterise and exploit seabed mineral resources. Our activity supports the research performed under SAMCoT and the Arctic DP project and Petromax projects.

In 2014, several academic staff, technical personnel and students contributed to the course "AB334/834 Underwater Robotics and Polar Night Biology" at UNIS in Longyearbyen with a large field campaign in Ny-Ålesund, Spitsbergen. During the operation, our REMUS AUV was employed to document the vertical diurnal migration of zooplankton. The results proved that these creatures followed a daily cycle, even during the polar night when only marginal amounts of light are present (not detected by the human eye)!

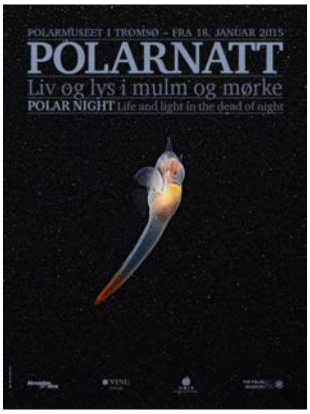

Figure 51: *Front page of polar night exhibition with contribution from AUR-Lab and AMOS. Photo by Geir Johnsen, NTNU/UNIS.*

Figure 52: *ROV under Arctic sea ice. Photo by Geir Johnsen, NTNU/UNIS.*

Figure 53: *ROV SF 30k deployed for test of fly-out ROV. Photo by Martin Ludvigsen, NTNU.*

Figure 54: *Remotely operated vehicle operation during polar night in Ny Ålesund. Photo by Geir Johnsen, NTNU/UNIS.*

Figure 55: *Underwater Hyperspectral Imager on crawler robot in Kongsfjorden mapping marine life in the polar night. Photo by Geir Johnsen, NTNU/UNIS.*

Figure 56: *Control room for ROV SF 30k. Photo by Martin Ludvigsen, NTNU.*

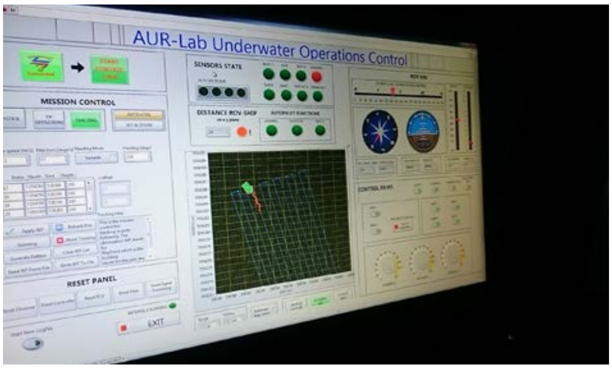

Figure 57: *ROV control system developed at AUR-Lab/ AMOS. Photo by Martin Ludvigsen, NTNU.*

Figure 58: *AUV Remus 100. Photo by Petter Norgren, NTNU.*

In April, the AUR-Lab completed a week-long cruise, during which AUV REMUS, ROV Minerva and RV Gunnerus collaborated to document the seabed and search for historical artefacts. During the cruise, the complementary properties of the three vehicles were exploited to maximise area coverage while documenting the targets in detail.

AUR-Lab has also been serving the MSc students and education with several cruises. In October, the wreck of an allied Halifax bomber aircraft was discovered at a depth of approximately 180 meters outside Vikhamar by a group of MSc students using ROV Minerva. The plane had significant damage from hitting the water during the crash 72 years ago, which was documented using underwater photogrammetry. The discovery of the aircraft made headlines in the media in Norway and the UK due to the historical interest in the wreck.

The combination of a geological erosion zone and the dumping of excess material from WWII was the focus of an operation in December in collaboration with the Norwegian Geological Survey (NGU), the Institute of Marine Research (Havforskningsinstituttet) and the NTNU spin-off Ecotone AS. The concern was that currents would remove sediments and leave the material exposed; the material contained a large amount of explosives and left-over material from the war. The potential for pollution and contamination was expected. These suspicions were confirmed. However, the area exhibited high diversity and abundance. Large occurrences of cold-water corals were detected on the dumped objects and nearby rock walls.

These operations have served as an arena to prove the relevance of the technology developed in AMOS in direct applications with demanding end users. Many engineering trials have been conducted to verify algorithms and code to provide experimental data for publications.

Media coverage

Theme	Publication	Date	URL
Life in the polar night. From under-water robotics and polar night biology course	National geographic	16.2.2014	http://voices.nationalgeographic.com/2014/02/16/the-vibrant-ecosystem-of-the-polar-night/
	Aftenposten	23.1.2014	http://www.aftenposten.no/viten/Pa-jakt-etter-havets-morke-mysterier-i-polarnatten--7443604.html
Halifax bomber discovered by students	NRK	24.10.2014	http://tv.nrk.no/serie/dagsrevyen/NNFA19102414/24-10-2014
		24.10.2014	http://www.nrk.no/trondelag/rare-british-ww2-airplane-found-in-norwegian-fjord-1.12005570
	Adresseavisa	25. 10.2014	http://www.adressa.no/nyheter/innenriks/article10272030.ece
		25.10.2014	http://www.adressa.no/nyheter/sortrondelag/article10472292.ece
	Aftenposten	25.10.2104	http://www.aftenposten.no/nyheter/iriks/NTNU-studenter-fant-britisk-bombefly-pa-havets-bunn-7759463.html
	VG	25.10.2104	http://www.vg.no/nyheter/innenriks/historie-og-arkeologi/se-det-sjeldne-krigsflyet/a/23322656/
	Daily mail, Express, Telegraph	10.12.2014	http://www.dailymail.co.uk/news/article-2868218/British-bomber-sunk-Nazis-raid-battleship-Tirpitz-WW2-Norwegian-fjord-72-years-crashed-bodies-crew-inside.html
	BBC Nottingham	12.12.2014	http://www.bbc.co.uk/programmes/p02cfjyr
Bombs from WWII, Agdenes	NRK	12.12.2014	http://www.nrk.no/trondelag/krigsmateriell-i-fjorden-kan-vaere-miljobombe-1.12098222
Underwater hyper-soectral imager	Teknisk Ukeblad	20.2.2014	http://www.tu.no/forskning/2014/02/20/kartlegger-havbunnen-i-barentshavet-med-nytt-superkamera
AUR-Lab	Gemini, Adresseavisa	19.2.2014	http://gemini.no/2014/02/rov-drift-pa-havbunnen/
Marine archeology	Adresseavisa	7.1.2014	http://www.adressa.no/nyheter/trondheim/article8913775.ece
Drones in marine research	Fiskeribladet fiskarn	20.2.2014	

Highlights of the Marine Cybernetics Laboratory (MC-Lab)

The MC-lab's web page: https://www.ntnu.no/imt/lab/cybernetics

The Marine Cybernetics Lab is a fully instrumented marine hydrodynamic model basin that is used to conduct marine cybernetic and hydrodynamic experiments in PhD research and MSc projects. For quality assurance prior to experimental testing in the MC-Lab, the Marine HIL Simulation Lab (HIL-Lab) has been established as an extension of MC-Lab. It is intended as a highly available lab where students and researchers can verify their HW/SW setups, signal communication, user interfaces, and test scenarios in real time for bugs and weaknesses prior to conducting actual time-limited experiments. Refer to http://www.ntnu.no/imt/lab/hil for details.

In 2014, the MC-lab was employed by several MSc students in their projects and by several PhD candidates in their research; a few activities are summarised here.

In spring 2014, MSc student Solveig Bjørneset conducted experiments on a control system for thruster-assisted position mooring of a semi-submersible using CyberRig I as part of her MSc thesis. The experiments included decay tests for the identification of six degrees-of-freedom hydrodynamic parameters, motion response tests in regular and irregular waves, and the verification of a roll-pitch damping control law in irregular waves.

In spring 2014, MSc student Andreas Orsten conducted a series of experiments on the automatic reliability-based control of iceberg towing in open waters, which comprise a challenging offshore operation in Arctic petroleum activities. The proposed control system setup involved the use of a Line-of-Sight method to determine the appropriate towline direction to tow an iceberg along a straight-line path (away from protected structures) in the presence of ocean currents. An online reliability index algorithm based on towline tension measurements was employed to compensate the velocity of the towing vessel to prevent towline failure modes. In MC-Lab, a water container was used to emulate the iceberg and the entire automatic towing operation was then set up and conceptually tested with the expected results.

As part of the Arctic DP project and CoE AMOS, PhD candidate Øivind K. Kjerstad performed experimental testing of a resetting DP observer for severe environmental disturbances on December 22, 2014 using CyberShip III. The objective was to test and compare a resetting law augmenting the nonlinear passive DP observer with triggered discrete state updates in a hybrid control architecture. The purpose of this law is to improve transient state tracking when a stationkeeping vessel is subjected to severe disturbances. CyberShip III was set in DP with respect to a fixed location and heading and subjected to a nominal sea state with regular waves. The vessel was perturbed by a stick to simulate severe transient disturbances. The resetting observer and its nominal "nonlinear passive DP observer" counterpart were run in parallel with equivalent tuning. The results showed that the resetting observer improved the transient state tracking performance compared with its continuous counterpart.

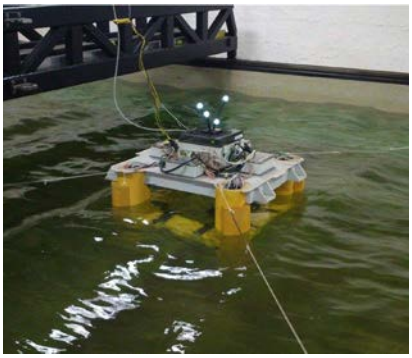

Figure 59: *CyberRig I moored and positioned in waves.*

Figure 60: *C/S Enterprise I set up as an iceberg towing vessel.*

Figure 61: *CyberShip III used in DP testing.*

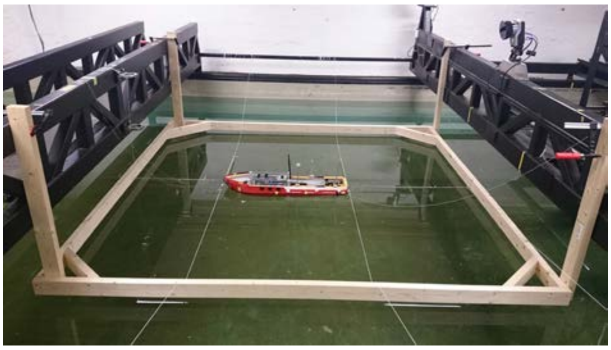

Figure 62: *Hydrodynamic parameter identification for C/S Enterprise I.*

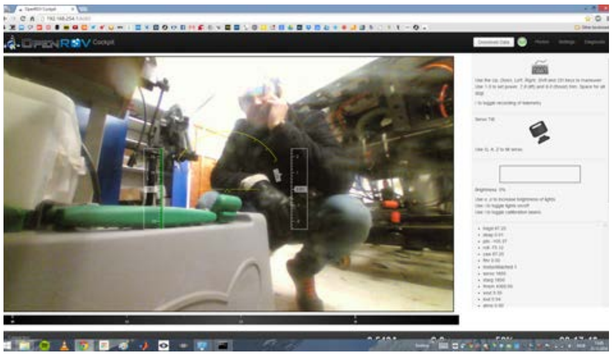

Figure 63: *MSc student Fredrik Sandved being filmed by the onboard camera of the OpenROV.*

The model ship C/S Enterprise I is actively employed for research and teaching in the MC-Lab. Recently, its control system has been modernised and robustified; the software and interface have been adapted to the National Instruments' VeriStand real-time control system platform. Extensive documentation is ongoing to make CSE1 more available. Thus, the identification of its hydrodynamic parameters is required for the simulation and control design. Figure 62 shows the parameter identification setup, where force measurements are performed for translational motions at varying speeds using the towing carriage.

In these days, MC-Lab is also being prepared for underwater robotics using small underwater vehicles. This activity is a prioritised AMOS activity, in which the MC-Lab can serve as a rapid prototyping and qualification lab for research prior to larger experimental campaigns conducted via AUR-Lab.

In the autumn of 2014, a group of MSc students assembled an OpenROV platform (http://www.openrov.com) and tested it in MC-Lab. This activity motivated the students for the design and manufacture of a new mini-ROV model, which the students named Neptunus. After testing in MC-Lab, the students brought the Neptunus ROV for testing on a real mission by AUR-Lab in the Trondheim Fjord. Here, they learned that all aspects of the design and intended operation must be verified and extensively tested before employed in a real operation. In sea, the rubber seal of the instrument container of the ROV began to leak, which damaged the electronics board. They are currently working on fixing these issues and creating a more robust design.

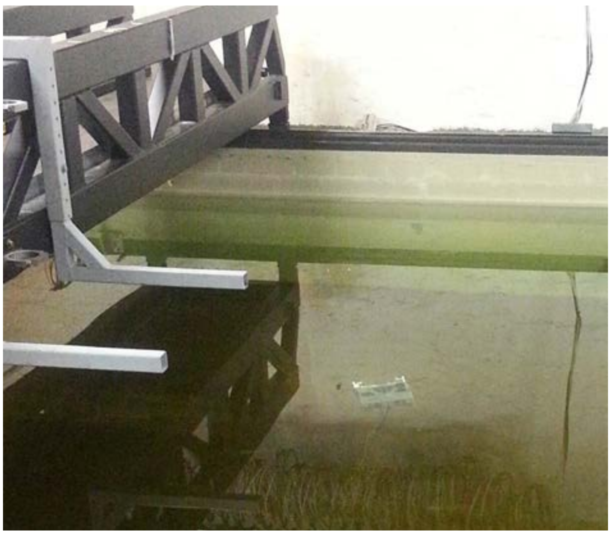

Figure 64: *The OpenROV tested in MC-Lab.*

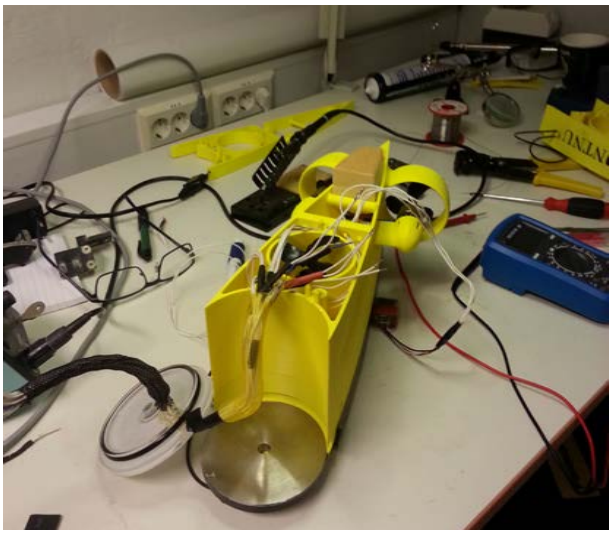

Figure 65: *ROV Neptunus being built in MC-Lab by students Jostein Follestad, Fredrik Sandved, and Eirik Valle.*

Highlights of the Unmanned Aerial Vehicle Laboratory (UAV-Lab)

Figure 66: *Flight tests at Breivika.*

The UAV-lab's web page: http://www.itk.ntnu.no/english/lab/unmanned

The UAV-Lab at NTNU boosted its activity in 2014 by supporting the research of 13 PhD projects and 15 master student projects, as well as some industry and research collaborations. By the end of 2014, approximately 20 unmanned aerial vehicles (UASs) of various size and capabilities are owned and operated by the UAV-Lab:

- Penguin B fixed-wing
- Skywalker X8 fixed-wing
- 3D Robotics hexa-rotor
- Microdrone quad-rotor

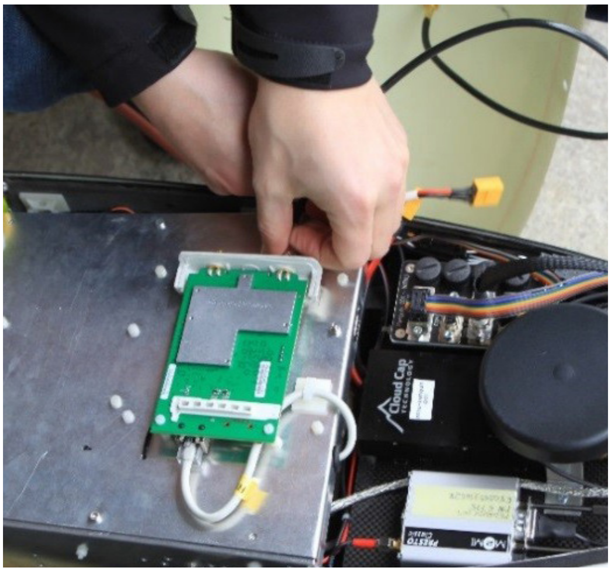

Figure 67: *Penguin UAV payload with thermal camera gimbal.*

The lab has operational procedures for UAVs approved by the Civil Aviation Authorities in Norway. The procedures entails the operation in visual line of sight (VLOS), extended visual line of sight (EVLOS), and beyond line of sight (BLOS).

Infrastructure

A laboratory/workshop at the Department of Engineering Cybernetics, which is one of the main hubs of the lab, provides space and equipment for developing and testing equipment prior to field work, including indoor and net-cage-protected outdoor flight areas for multi-rotor development and testing.

Field testing facilities and equipment are developed, established and operated in close collaboration with Maritime Robotics AS and the University of Porto. The UAV-Lab's main field experimental facility is Breivika Airfield at Agdenes. It enables us to operate in a maritime and coastal environment within shared airspace controlled by the air traffic control at Ørland Airport. The facilities contain an operation room and workshop.

The UAV-Lab has mobile operating centres and occasionally operates from other locations, such as Eggemoen Airport.

System integration and payloads

The research activities in AMOS require extensive development of custom payload systems and integration with customised avionics software and hardware.

In 2014, progress has focused on the following system development and integration activities:

- RTK GPS-based automatic precision recovery
- Radio communication
- Thermal cameras installed in pan-tilt gimbals
- Autonomous guidance and control
- Advanced navigation payloads with time-synchronised acquisition of data from GNSS, inertial sensors, magnetometers, laser altimeter, camera systems, and autopilots.
- Anti-icing and de-icing systems
- Payload delivery systems

Missions and results

The following tasks were successfully accomplished, which produced field-proven procedure or research results:

- Catapult launch systems for Penguin and X8
- Communication relayed by UAV over AUV and custom small buoys in the ocean surface
- Autonomous net recovery of X8
- Navigation payload flight testing
- Thermal camera payload flight testing
- Wind turbine inspection tests at Valsetneset Wind Park
- Navigation and control of multi-rotor for object pick-up
- Guidance and control of multi-rotor for search missions
- Sunfish tracking in Portugal

The majority of these field experiments are documented and analysed as parts of research papers or master thesis projects.

Highlights of the experiments at CNR-INSEAN

The close collaboration with CNR-INSEAN also provides access to additional advanced facilities. In 2014, their sloshing laboratory with the six-DOF mechanical system 'Hexapod' was utilised to continue the physical research on the hydroelastic effects connected with sloshing in depressurised conditions (refer to Figure 68), which are relevant for LNG tanks, and to begin a new investigation of water-oil-boom interactions and related failure mechanisms (refer to Figure 69).

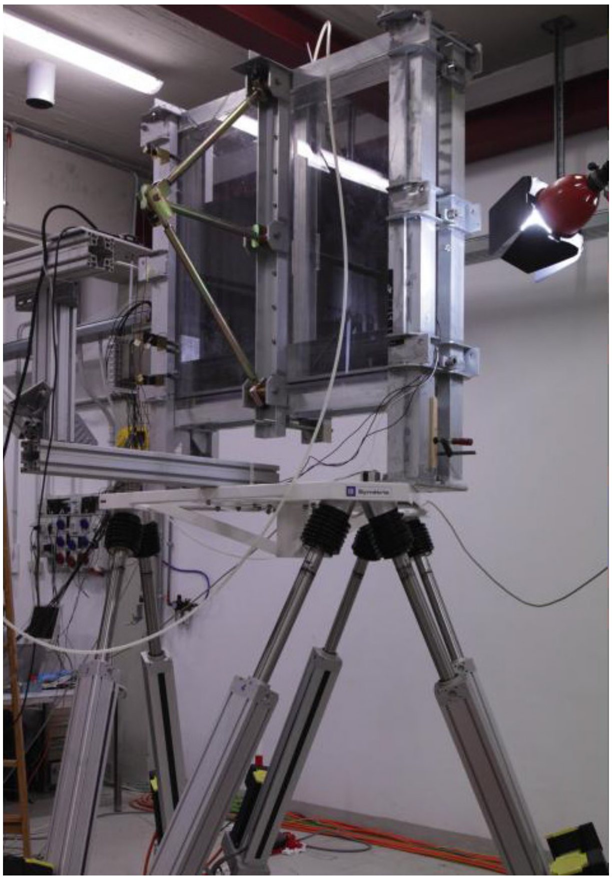

Figure 68: *Setup for 2D sloshing tests on a tank with a deformable plate on the left side wall.*

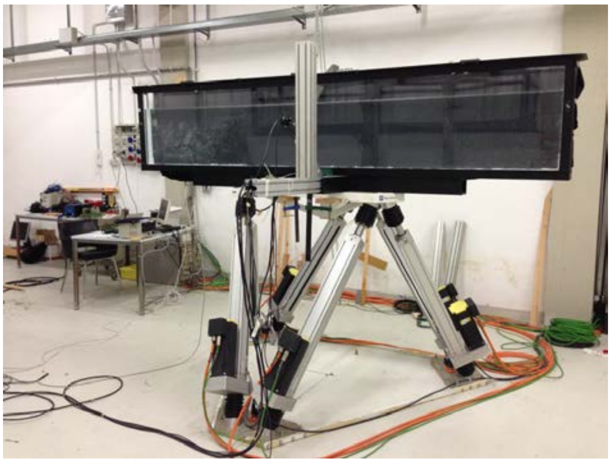

Figure 69: *Setup for 2D tests on water-oil-boom interactions.*

Research campaign: AMOS researchers investigate mysteries in the sea during the polar night

Figure 70 *(Geir Johnsen, NTNU): Professor Asgeir J. Sørensen inspects the pier below the marine laboratory in the moonshine.*

AMOS professor Asgeir J. Sørensen, professor Jørgen Berge (Arctic University of Norway and University Centre in Svalbard) and professor Geir Johnsen (NTNU and University Centre in Svalbard) led a team of marine technologists and marine biologists on a research campaign to find out what happens under sea-level during the polar night.

The professors went on a two-week research campaign in January 2014, where there were a total of 65 students and researchers involved. The expedition was the largest marine biological exploration ever during the Arctic polar night.

Before the expedition, it was a common assumption that underwater life during the polar night entered a kind of winter rest. The researchers found that this is not the case at all. On the contrary, the polar underwater ecosystem is also at full activity during wintertime. This knowledge is essential when administering arctic sea areas.

The researchers and students used new prototypes of light measurement instruments to determine how much light from the moon, stars and northern lights as well as diffuse light from the sun below the horizon influence marine organisms in terms of mass migration, reproduction, egg planting and day and night cycles. The researchers used three underwater robots around the clock: two remotely operated vehicles (ROVs) and one autonomous underwater vehicle (AUV).

Read more about the results of the research campaign at http://gemini.no/2014/02/avslorer-mysterier-i-polarnatta/ (in Norwegian).

HONOURS, AWARDS AND OTHER ACHIEVEMENTS

AMOS adviser Prof. Torgeir Moan was awarded **Honorary Professorship** at Aalto University in Finland.

Figure 71: *(Tuomas Saulиala, Aalto University): Prof. Torgeir Moan receives the diploma and hat from Aalto University for his honorary professorship on 10 October 2014.*

NTNU's "Universitetsavisa" reported: http://www.universitetsavisa.no/forskning/article42015.ece

AMOS adviser Prof. Odd M. Faltinsen was awarded the **SOBENA International Award 2014** for his "fundamental contributions for marine and ocean engineering on an international level".

AMOS adjunct professor Jørgen Juncher Jensen received the **SNAME Davison medal** for "outstanding scientific accomplishment in marine research". Furthermore, Juncher was selected as the **37th Georg P. Weinblum Memorial Lecturer.**

AMOS director and professor Asgeir J. Sørensen received the **Teacher of the Year 2014 Award** from the Master students of the Department of Marine Technology at NTNU.

Figure 72: *The Teacher of the Year 2014 Award that Prof. Asgeir J. Sørensen received from the Master students of the Department of Marine Technology at NTNU.*

Two papers co-authored by AMOS adjunct professor Claudio Lugni have been selected in June 2014 for **Best Paper Awards** for the 32nd International Conference on Offshore Mechanics and Arctic Engineering (OMAE'13) in Nantes:

Bouscasse, B.; Antuono, M.; Colagrossi, A.; Lugni, C. A classification of shallow water resonant sloshing in a rectangular tank, 32nd Int. Conference on Offshore Mechanics and Arctic Engineering (OMAE'13), Nantes, 2013, NTNU

Marino, E.; Nguyen, H.; Lugni, C.; Manuel, L.; Borri, C. Irregular nonlinear wave simulation and associated loads on offshore wind turbines, 32nd Int. Conference on Offshore Mechanics and Arctic Engineering (OMAE'13), Nantes, 2013, NTNU

AMOS PhD candidate Filippo Sanfilippo was awarded the **Best Student Paper Award** at the 2014 IEEE International Conference on Information and Automation for his paper "JOpenShowVar: an Open-Source Cross-Platform Communication Interface to Kuka Robots" by F. Sanfilippo, M. Fago, L.I. Hatledal, K.Y. Pettersen and H. Zhang.

AMOS professors Kristin Y. Pettersen and Tor Arne Johansen have been awarded **membership in the Norwegian Academy of Technological Sciences (NTVA)**.

AMOS adviser professor Odd M. Faltinsen became a **corresponding member at the Croatian Academy of Sciences and Arts.**

AMOS adjunct professors Jørgen Juncher Jensen and Ulrik Dam Nielsen became a **fellows of the International Community for Maritime and Ocean Professionals (SNAME).**

Figure 73: *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 pages, NTNU.*

The World Elite in Marine Technology Celebrated Their Veterans: 70 Years Anniversary Seminar and Celebration for Professors Faltinsen and Moan

Figure 74: *Speakers and participants listen to the presentations at the 70 Years Anniversary Seminar at the Marine Technology Centre. Front row from the left: Unni Steinsmo (CEO of SINTEF Group), Tore Ulstein (deputy CEO of Ulstein Group), Torbjørn Digernes (previous NTNU-rector), Professors Moan and Faltinsen, and Henrik Madsen (CEO of DNV GL).*

For the 70 Years Anniversary Seminar and Celebration for Professors Faltinsen and Moan on 19-20 May 2014, the Marine Technology Centre was packed with 300 national and international guests and prestigious speakers. Additionally, the seminar was video-streamed with 787 views in total.

Have a look at the programme, the presentations given at the conference as well as the pictures taken at the seminar and celebratory dinner: https://www.ntnu.edu/amos/newsandevents.

Teknisk Ukeblad interviewed the two professors for the occasion: https://www.ntnu.edu/documents/20587845/21897188/TU-marin+verdenselite+feiret+veteranene.pdf/f17c6c7f-d98f-4070-aa52-84580d80aeb1

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

INNOVATION AND TRAINING OF PHD CANDIDATES

Project manager: Adjunct professor Ingrid Schjølberg

The AMOS innovation model

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

AMOS has established a set of values to support the development of a culture for innovation: **excellence, generosity, and courage.** These values form the basis for the AMOS workplace culture: endorsing excellence in performance, promoting individuals' well-being, developing individuals' personal qualities and skills, encouraging openness in discussions, and generating research results for pioneering and original game-changing technology. This approach has the potential to create paradigm shifts in business opportunities.

Excellent research is business as usual for AMOS personnel. Over the last decade, six key scientists and a number of associated scientists have educated more than 100 PhD candidates and produced hundreds of highly ranked international journal and conference articles. AMOS' staff's academic innovation is pushing the frontiers of research and contributing to increased expertise in industry.

At AMOS, we create a **culture for innovation** by including innovation in the agenda.

We have a monthly innovation day where we invite industrial experts to participate in guest lectures on innovation (for a list with dates and topics, see Appendices in this annual report). In this way, all PhD candidates learn how

Figure 75: *AMOS poster from the stand at the TechInnovation in Singapore in September 2014.*

to pitch their research and gain knowledge in business development. The monthly innovation day is organised in close collaboration with the NTNU School of Entrepreneurship.

In addition, AMOS participated in TechInnovation in Singapore in September 2014. TechInnovation is a technology marketplace that brings together international seekers and providers of new technology. AMOS participated in a joint stand together with other partners from NTNU, which included spin-off companies. Interesting meetings were held with NTU, Rolls Royce Marine, NUS and MPA. This was followed up during the MTEC conference in November 2014. A number of joint research initiatives are currently under establishment.

Resources are about generating new associated projects in close collaboration with industry to create value through the results obtained by AMOS personnel. AMOS personnel work continuously to create new initiatives that bridge the gap between excellent research and industrial practice and push industry to be at the forefront of technology development to ensure business and opportunities. New and old associated projects are listed in the chapter "Associated Research Projects" in this annual report.

Knowledge on entrepreneurship and on how to raise capital is an important part of AMOS' innovation strategy. AMOS is working with NTNU Technology Transfer and the NTNU School of Entrepreneurship to develop ideas for spin-off companies and to contact venture capital firms to develop start-up companies. In 2014, AMOS PhD graduate Fredrik Dukan founded his own company Norwegian Subsea AS- see box below.

Well-being of people

Our personnel are located both at Gløshaugen and Tyholt campus, with Tyholt being the main hub. The modern locations form an excellent meeting and working environment for AMOS personnel. An open meeting area serves as a room for meet-ups and discussions.

In 2014, a number of social activities have contributed to a good working environment at AMOS:

"AMOS Day" took place 3-4 February, where AMOS staff met and discussed the centre's strategy, results and plans for the future.

On 21 August, the AMOS kick-off for autumn 2014 welcomed all new PhD candidates with a status update about AMOS, pizza lunch and speed dating between old and new

AMOS spin-off-company: Norwegian Subsea AS

Norwegian Subsea

Norwegian Subsea AS was founded based on Fredrik Dukan's PhD thesis on ROV motion control systems.

By using new theory and sensor technology, it is possible to make extremely compact, high-performance navigation systems with low power consumption. This is ideal for subsea and downhole navigation applications and for the use in smaller underwater vehicles. The technology is also applied to other subsea motion monitoring tasks.

The company works with clients in the oil & gas, drilling and subsea production industries, primarily in the North Sea region. With a particular focus on R&D and innovative product development, Norwegian Subsea aims to be at the forefront of the subsea navigation industry.

The company is based in Oslo and has received funding from Innovation Norway and the Research Council of Norway. Norwegian Subsea AS is owned and driven by its founders Fredrik Dukan, Håkon Baste and Lars Torgersen.

Figure 76 *(Norwegian Subsea AS): Illustrative picture.*

PhD candidates, post-docs and professors. In the evening, everyone had dinner at Graffi in Trondheim together with staff from the Department of Marine Technology at NTNU (refer to Figure 77).

AMOS had a seasonal lunch in winter together with staff from the Department of Marine Technology at NTNU as well as Christmas coffee (refer to Figure 78 and 79).

In addition, there were other seasonal meet-ups at AMOS, for example, during Halloween.

AMOS' PhD candidates had their own Christmas party together on 5 December at the Estenstadshytta with food and games.

Moreover, many AMOS' PhD candidates like to socialise in their free time. Some go out together in the evening. Some play soccer with staff from Marintek and the Department of Marine Technology. Others go climbing, swimming or jogging. Some even participate in marathons and similar activities together.

Figure 77: *One of the two rooms that AMOS and department staff shared at Graffi in Trondheim on 21 August 2014.*

Figure 78: *Staff from AMOS and the Department of Marine Technology enjoy a maritime view and relaxed atmosphere during a seasonal lunch on 20 November at the Scandic Nidelven hotel.*

Figure 79: *Some of the AMOS staff who met for Christmas coffee.*

INTERVIEWS WITH PHD CANDIDATES

Mikkel Cornelius Nielsen

Joint PhD candidate at AMOS and the Technical University of Denmark

Age: 26
Title of thesis: Fault-tolerance and reconfiguration for collaborating heterogeneous underwater robots
Time left in the programme: 2,5 years
Supervisor: Prof. Mogens Blanke
Co-supervisors: Adjunct prof. Ingrid Schjølberg, associate prof. David Johan Christensen
Where are you from: Copenhagen, Denmark

What distinguishes a joint PhD degree from a regular one?

I get supervision from both NTNU and the Technical University of Denmark, DTU. The respective institutions have different specializations and hence different perspectives on matters related to my project. This is naturally an asset when trying to come up with possible solutions. Furthermore, my PhD defence will be here in Trondheim since AMOS is funding my project, but I will get both NTNU and DTU on my diploma.

Why did you choose a joint PhD degree before a regular one?

When I applied, my focus was primarily on the project title. The aspect of a joint PhD was not really a factor for me especially since there was little information available on the conditions associated.

Why did you go for a Scandinavian joint PhD instead of an international one?

There are several reasons for why I applied for AMOS. Two of the most important reasons for me were the centre's focus on maritime technology and the ambitious vision of recruiting a vast amount of PhD candidates, which in turn has created a really good working environment.

How do you perceive the collaboration between AMOS/NTNU and DTU?

I think both institutions can gain much from each other and to me it seems like both agree on this. For me and my project however there is no doubt that the research facilities at NTNU are beyond anything I could get anywhere else.

How is it to be a PhD candidate at AMOS?

One of the unique perks with a centre like AMOS is the large number of international PhD candidates; this makes for a really good social environment with many different views on any given topic (pizza with pineapple is a perfectly fine meal, Claudio!).

What is the best thing about being a PhD candidate?

The best thing is the freedom to define my own project. This really allows me to explore subjects that I would not have had the opportunity to do elsewhere.

What is the worst thing about being a PhD candidate?

Freedom is a double-edged sword; while it is really cool to shape your own project, it is also really challenging and at times very frustrating. The problems do not end when the official workday does, and usually it can be hard to let them go for the night or the weekend. Luckily, there are supervisors to catch you and point you in appropriate directions.

Is it worth it?

No doubt! The possibilities in the project really inspire me and while I stated the endless project problems as a "bad thing" the reality is that I like the challenge and there is nothing better than finding a solution to the problem at hand.

What is your primary research field at AMOS?

My field is fault-tolerant control and the reconfiguration of cooperating multi-robot systems. The primary goals are to avoid catastrophic system failure and improve system reliability through clever heuristics.

What are your plans for the future?

Well, my primary focus right now is doing the PhD. In the future, I hope to find a position in R&D – best case in something related to underwater vehicles.

Astrid Helene Brodtkorb

PhD candidate at AMOS

Age: 25
Title of thesis: Dynamic positioning in extreme seas: increasing the operation window of dynamic positioned vessels using hybrid design methods
Time left in the programme: 2,5 years
Supervisor: Prof. Asgeir J. Sørensen
Co-supervisors: Prof. Andrew R. Teel, Dr Vahid Hassani, Prof. Marilena Greco, Dr Dong Trong Nguyen
Where are you from: Asker, Norway

Why did you choose to become a PhD candidate?

When I was in the third year of my master studies, I went to two professors, one in hydrodynamics and one in automatic control, and asked them about their research areas. I chose automatic control because it sparked my interest. Already then I played with the thought of taking a PhD degree.

After that, it was a matter of opportunity. I followed some lectures of Prof. Andrew Teel who gave a PhD course when I was in the 5th year of my master studies. This course was captivating and one reason why I took up PhD studies at AMOS. Also, some of my friends already were PhD candidates at AMOS.

How is it to be a PhD candidate at AMOS?

It is social, and there is a good mix of nationalities and personalities. I feel like I'm part of a team.

What is the best thing about being a PhD candidate?

I like the flexible working hours. Also, I'm my own project manager and I can influence the direction of my project. And of course I can focus on what I'm really interested in.

What is the worst thing about being a PhD candidate?

When you're stuck with your research and can't find the answer to a problem, it's difficult. However, at AMOS, there is always someone to ask, and you won't be judged by your questions.

Is it worth it?

Definitely.

What is your primary research field at AMOS?

The system I am enhancing is called a dynamic positioning (DP) system; it is a system that controls the propellers and thrusters of the vessel to maintain a specified position and heading automatically. It is a useful, often necessary, tool for making marine operations possible to accomplish.

What are your plans for the future?

After finishing my PhD, I would like to work in the industry, at least for a while. I will grasp a great opportunity when it comes along.

Dennis Belleter

PhD candidate at AMOS

Age: 25
Title of thesis: Multi-agent control systems
Time left in the programme: 1,5 years
Supervisor: Prof. Kristin Y. Pettersen
Co-supervisors: Prof. Henk Nijmeijer (TU/e Eindhoven), Prof. Asgeir J. Sørensen
Where are you from: Moerstraten, Netherlands

Why did you choose to become a PhD candidate?
I grasped the opportunity when it presented itself to me. I like research. Also, I felt like if I was ever going to live abroad, now is the right time.

How is it to be a foreign PhD candidate at AMOS?
The advantage with a centre like AMOS is that there are more foreigners who form a more inclusive environment than if it were only Norwegians. Everybody is in the same situation and is open to socialize.

There are social activities outside of work. We go out together, and before the AMOS workshop in February 2015, many of the PhD candidates went skiing together. We were maybe 23 AMOS PhDs.

It is quite a supportive research environment. You can easily exchange your ideas with other PhD candidates and professors.

Also, the research facilities are good.

Is it different to study in Norway instead of the Netherlands?
It seems easier to get funding for a centre like AMOS in Norway than in the Netherlands. It is less common in the Netherlands to have research centres that collocate many PhD candidates.

What is the best thing about being a PhD candidate?
I can shape my own project. I have the freedom to go where I want within my project, and that makes me feel more involved.

What is the worst thing about being a PhD candidate?
Because of the freedom, in the beginning, it can be challenging to find the right direction. Then, it is important to have a good supervisor, which I fortunately have.

Also, when you have a problem, it will occupy your mind, also after 5 pm or on the weekends.

Is it worth it?
Yes, it has been a good learning experience so far, and I anticipate it will remain that way.

What is your primary research field at AMOS?
Multi-agent control systems. That means there are several autonomous robots that work together to perform a joint task.

What are your plans for the future?
I would like to stay in research because that is what I enjoy. Preferably in academia, but R&D in the industry would be fine as well.

APPENDICES

AMOS Personnel and Collaborators

Management and administration

Name	Title	Acronym
Prof. Sørensen, Asgeir J.	Director	AJS
Prof. Fossen, Thor I.	Co-director	TIF
Adjunct prof. Schjølberg, Ingrid	Project director (until summer 2014)	IS
Wold, Sigrid Bakken	Senior executive officer	SBW
Bremvåg, Annika	Higher executive officer (from August 2014)	AB
Solheim, Marit	Executive officer (until August 2014)	MS

Key scientists

Name	Institution, department	Main field of research	Acronym
Prof. Amdahl, Jørgen	NTNU, Dept. Marine Technology	Structural load effects, resistance, accidental actions	JA
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

Name	Institution	Main field of research	Acronym
Prof. Blanke, Mogens	Technical Univ. of Denmark (DTU), Denmark	Automation and control	MB
Prof. Jensen, Jørgen Juncher	Technical Univ. of Denmark (DTU), Denmark	Wave-induced hydro-elastic response of ships	JJJ
Dr Lugni, Claudio	INSEAN, Italy	Marine hydrodynamics	CL
Associate prof. Nielsen, Ulrik Dam	Technical Univ. of Denmark (DTU), Denmark	Wave-ship interactions	UDN
Dr Sokolova, Nadezda	SINTEF ICT	GNSS and integrated navigation systems	NS
Dr Storvold, Rune	NORUT, Tromsø	Developing aircraft, sensors, and communication and control systems for airborne remote sensing using unmanned aircraft	RS

Post-docs

Name	Institution	Main field of research	Acronym
Dr Cristofaro, Andrea	NTNU, Dept. Engineering Cybernetics	Optimization	AC
Dr Hassani, Vahid	MARINTEK	Application of hybrid systems theory in marine applications and active real-time hybrid cyber-physical model-testing	HV
Dr Kim, Ekaterina	NTNU, Dept. Marine Technology	Understanding rare, extreme ice-structure collisions	EK
Dr Lekkas, Anastasios	NTNU, Dept. Marine Technology	Guidance and path planning for marine vehicles	AL

Affiliated scientists

Name	Institution	Main field of research	Acronym
Associate prof. Alfredsen, Jo Arve	NTNU, Dept. Engineering Cybernetics	Automation in fisheries and aquaculture	JAA
Adjunct associate prof. Bachynski, Erin	NTNU, Dept. Marine Technology	Wind energy/offshore renewable energy systems	EB
Dr Breivik, Morten	NTNU, Dept. Engineering Cybernetics	Nonlinear and adaptive motion control	MBR
Associate prof. Brekke, Edmund	NTNU, Dept. Engineering Cybernetics	Bayesian estimation with applications in parameter estimation, target tracking and autonomous navigation	EB
Adjunct associate prof. Gao, Zhen	NTNU, Dept. Marine Technology	Wind energy/offshore renewable energy systems	ZG
Prof. Johnsen, Geir	NTNU, Dept. Biology	Marine biology	GJ
Prof. Imsland, Lars S.	NTNU, Dept. Engineering Cybernetics	Automatic control, optimization	LSI
Prof. Ludvigsen, Martin	NTNU, Dept. Marine Technology	Underwater technology and operations	ML
Adjunct prof. Schjølberg, Ingrid	NTNU, Dept. Marine Technology	Underwater robotics	IS
Prof. Skjetne, Roger	NTNU, Dept. Marine Technology	Marine control systems	RS
Prof. Tymokha, Oleksandr	National Academy of Sciences of Ukraine	Mathematical aspects of hydromechanics with emphasis on free-surface problems (sloshing)	OT
Prof. Utne, Ingrid B.	NTNU, Dept. Marine Technology	Safety critical systems and systems engineering	IBU

Technical staff

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. Teel, Andrew R.	Univ. of California, Santa Barbara, USA	Hybrid dynamical systems	AT
Prof. Arcak, Murat	Univ. of California, Berkeley, USA	Cooperative control design	AM
Prof. Prpić-Oršić, Jasna	Univ. of Rijeka, Croatia	CO_2 emission from ships in waves	JP
Dr Sasa, Kenji	Kobe University, Japan	Seakeeping of ships and ocean structures	KS
Prof. Moline, Mark A.	Univ. of Delaware, USA	Applications for autonomous underwater vehicles	MM
Dr Colicchio, Giuseppina	CNR-INSEAN	Mesh generation and analysis for computational fluid mechanics	GC

PhD candidates with financial support from AMOS

Name	Period (yyyymmdd)	Super-visor	Topic
Belleter, Dennis	20130819-20160818	KYP	Multi-agent control systems
Brodtkorb, Astrid H.	20140101-20170630	AJS	Dynamic positioning in extreme seas: increasing the operation window of dynamic positioned vessels using hybrid design methods
Cisek, Krzysztof	20140501-20170430	TAJ	Multi-body unmanned aerial systems
Fortuna, Joao	20140815-20170814	TIF	Autonomous UAV recovery and rendezvous on moving ships
Hanssen, Finn-Christian W.	20130826-20160816	MG	Nonlinear wave loads on marine structures in extreme sea states
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	Autonomous object detection and tracking in maritime environments using infrared sensors
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	Simultaneous mapping, navigation, and monitoring with unmanned underwater vehicles using sensor fusion
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 control systems: coordinated and cooperative control for intelligent task execution and collision avoidance in uncertain maritime environment
Shen, Yugao	20130812-20160811	MG	Limiting operational conditions for a well boat
Siddiqui, Mohd Atif	20140813-20170812	MG	Behaviour of a damaged ship in waves
Sørensen, Kim Lynge	20130601-20160531	TAJ	Autonomous ice protection of UAVs
Tutturen, Svenn Are	20140101-20161231	RS	Topics in motion control of offshore vessels
Vilsen, Stefan A.	20140201-20180131	AJS/HG	Hybrid model testing of marine systems
Wiig, Martin Syre	20140815-20180814	KYP	Motion planning for autonomous underwater vehicles
Yu, Zhaolong	20140811-20170810	JAM	Ship/ship and ship/offshore installation collisions including fluid structure interaction
Zolich, Artur	20140401-20170331	TAJ	Autonomous control and communication architectures for coordinated operation of unmanned vehicles (UAV, AUV, USV) in a maritime mobile sensor network
Ødegård, Øyvind	20130820-20170819	AJS	Autonomous operations in marine archaeology - technologies and methods for managing underwater cultural heritage in the Arctic

PhD candidates associated with AMOS with other financial support

Name	Period (yyyymmdd)	Supervisor	Topic
Aamodt, Inga	20120316-20160316	GJ/AJS	Use of underwater robotics and optical sensors to map distribution and physiological condition in the Norwegian kelp forest
Acero, Wilson G.	20130801-20160731	TM	Marine operations
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
Borup, Kasper T.	20130516-20160515	TIF	Model-based nonlinear integration filters for INS and position measurements
Bryne, Torleiv H.	20130815-20160804	TIF	Fault-tolerant sensor fusion for marine vessels by exploiting redundant IMUs
Bø, Torstein I.	20130501-20160731	TAJ	Power management based on model predictive control
Caharija, Walter	20110101-20140501	KYP	Integral line-of-sight guidance and control of underactuated marine vehicles
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 analysis of wind turbines
Cho, Seong-Pil	20140804-20170803	TM/ZG	Dynamic analysis of floating wind turbines

Dahl, Andreas R.	20130819-20160818	RS	Nonlinear and fault-tolerant control of electric power production in Arctic DP vessels
Dukan, Fredrik	20100104-20140103	AJS	ROV motion control systems
Fernandes, Daniel De Almeida	20100816-20141015	AJS	GNC systems for underwater vehicles
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 analysis of wind turbines under fault conditions
Hansen, Jakob Mahler	20130801-20160731	TIF	Nonlinear observers for tight integration of IMU and GNSS pseudo-range and carrier-phase-ambiguity resolution
Hassel, Martin	20140101-20161231	IU	Risk and safety of marine operations
Hegde, Jeevith	20140822-20170821	IS	Safety and reliability of marine underwater autonomous vehicles
Heyn, Hans-Martin	20140813-20180812	RS	Fault-tolerant control and parameter estimation for thruster assisted position mooring in Arctic offshore conditions
Jørgensen, Ulrik	20100830-20140331	RS	Underwater ice topography estimation
Kelasidi, Eleni	20120318-20150317	KYP	Underwater snake robots
Lin, Li	20110810-20160531	TM/ZG	Marine operations
Mathisen, Siri Holthe	20140818-20170817	TAJ	Embedded optimization for autonomous unmanned aerial vehicle mission planning and guidance
Moe, Signe	20130801-20160731	KYP	Guidance and control of marine vehicles
Nilssen, Ingunn	201204xx-201604xx	GJ/AJS	Integrated environmental monitoring; taking environmental data into decision making processes
Norgren, Petter	20130301-20170428	RS	AUVs for subsurface monitoring of sea-ice and icebergs
Rejani Miyazaki, Michel	20130503-20170502	AJS	Control of hybrid power plants
Rogne, Robert	20130801-20160731	TAJ	Fault-tolerant sensor fusion by exploiting redundant inertial measurements
Rokseth, Børge	20140815-20170814	IU	A new approach for handling risk in dynamic position systems for marine vessels
Sanfilippo, Filippo	20110901-20150831	KYP	Control methods, robotics, artificial intelligence and modular robotic grasping
Skjong, Espen	201408xx- 201708xx	TAJ	Optimization based design of modular power management systems for modern ships, with focus on efficiency and fuel consumption
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
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
Veksler, Aleksander	20101004-20140430	TAJ	Optimization-based control of diesel-electric ships in dynamic positioning
Zhao, Yuna	20140901-20170831	TM/ZG	Marine operations

Annual Accounts and Man-Year Efforts

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

Nationality	Key professor	Adjunct/ Ass. prof.	Affiliated scientist	Sci-entific advisor	Post-doc/ researcher	Visiting professor/ researcher	PhD	Assoc. PhD	Admini-strative staff *)	SUM
Norwegian	5	2	8	2			12	17	7	43
Other nationalities	1	5	2		5	6	15	14	1	36
SUM	6	7	10	2	5	6	27	31	8	80
Man-years	3.5	1.5	1.7	1.5	3.3	1.4	17.6	24.8	3.5	58.8

* Incl. technical staff

Total man-year efforts

Man-years	2014
Centre director	0.3
Co-director	0.2
Project director	0.5
Adm. personnel	1.5
Technical staff	1.0
Summary	3.5
Key professors	3.5
Affiliated prof. /scientists	4.7
Researchers/Post-docs	3.3
Visiting researchers	1.4
PhD candidates*)	42.4
Total research man-years	55.3
Total	58.8

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

Annual accounts

Amount in NOK 1000	Note	Accounted income and costs
Operating income		
The Research Council of Norway		20 189
NTNU	1	15 288
Others	2	9 375
Sum operating income		44 852
Operating costs		
Salary and social costs	3	28 837
Equipment investments		1 777
Procurement of R&D services		5 410
Other operating costs	4	4 679
Sum operating costs		40 703
Year end allocation		4 149
Closing balance 2013		4 149

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

Research and Education

PhD courses

Code	Subject	Professor in charge
IFEL8000	Introduction to Research Methodology, Theory of Science and Ethics	Torgeir Moan
MR8205	Advanced Topics in Structural Modelling and Analysis	Torgeir Moan
MR8206	Structural Reliability	Torgeir Moan
MR8207	Stochastic Methods Applied in the Analysis of Marine Structures	Torgeir Moan and Zhen Gao
MR8300	Hydrodynamic Aspects of Marine Structures 1	Odd M. Faltinsen
MR8404	System Safety	Ingrid B. Utne
MR8500	Advanced Topics in Marine Control Systems	Roger Skjetne
MR8501	Advanced Topics in Structural Modelling and Analysis	Jørgen Amdahl
TK8102	Nonlinear Observer Design	Kristin Y. Pettersen
TK8109	Advanced Topics in Guidance and Navigation	Thor I. Fossen
TK8115	Numerical Optimal Control	Lars S. Imsland

Master courses

Code	Subject	Professor in charge
Module B	Advanced Control Design Methods for Marine Systems	Roger Skjetne
TMR4195	Design of Offshore Structures	Jørgen Amdahl
TMR4205	Buckling and Ultimate Strength Analysis of Marine Structures	Jørgen Amdahl
TMR4260	Safe Operation and Maintenance	Ingrid B. Utne
TMR4505	Advanced Structural Analysis	Svein Sævik and Torgeir Moan
TMR4505	Integrated Dynamic Analysis of Wind Turbines	Torgeir Moan
TMR4515	Marine Control Specialization Subjects	Ingrid Schjølberg and Ingrid B. Utne
TMR4515	Marine Control Systems, Specialization Course	Asgeir J. Sørensen
TMR4555	Underwater Robotics in Safe and Autonomous Operations	Ingrid Schjølberg and Ingrid B. Utne
TTK4	Unmanned Aircraft	Rune Storvold
TTK4115	Linear System Theory	Tor Arne Johansen
TTK4130	Modeling and Simulation	Lars S. Imsland
TTK4150	Nonlinear Control Systems	Kristin Y. Pettersen
TTK4190	Guidance and Control of Vehicles	Thor I. Fossen
TTK4225	Systemteori Grunnkurs	Edmund Brekke

PhD degrees

Name	Topic	Supervisor:
Caharija, Walter	Integral Line-of-Sight Guidance and Control of Underactuated Marine Vehicles	Kristin Y. Pettersen
Veksler, Aleksander	Optimization-based Control of Diesel-electric Ships in Dynamic Positioning	Tor A. Johansen
Dukan, Fredrik	ROV Motion Control Systems	Asgeir J. Sørensen
Kim, Ekaterina	Experimental and Numerical Studies Related to the Coupled Behaviour of Ice Mass and Steel during Accidental Collisions	Jørgen Amdahl
Lekkas, Anastasios	Guidance and Path-Planning Systems for Autonomous Vehicles	Thor I. Fossen

Master degrees

Name	Topic	Supervisor:
Andersen, Håvard Lægreid	Path Planning for Search and Rescue Mission using Multicopters	Tor Arne Johansen
Andresen, Simen	Underwater Robotics	Kristin Ytterstad Pettersen
Bahar, Md Habibullah	Analytical & Numerical Analysis of Ship/FPSO Side Structures Subjected to Extreme Loading with Emphasis of Ice Actions	Jørgen Amdahl
Barbatei, Remus-Gabriel	Data Acquisition with Unmanned Aerial Vehicle (UAV) from Floating Sensor Nodes	Tor Arne Johansen
Bense, Marvin Phillip	Comparison of Numerical Simulation and Model Test for Integrated Installation of GBS Wind Turbine	Torgeir Moan
Bertelsen, Torleif Ølund	Installation of Large Subsea Structures	Marilena Greco
Bjørneset, Solveig	Modelling and Control of Thruster Assisted Position Mooring System for a Semi-submersible	Asgeir Johan Sørensen
Brauer, Simon Adrian	Damage Identification of an Offshore Wind Turbine Jacket Support Structure	Torgeir Moan
Braun, Moritz	Fatigue Assessment of Threaded Riser Connections	Torgeir Moan
Brodtkorb, Astrid Helene	Dynamic Positioning in Extreme Sea States	Asgeir Johan Sørensen
Bækkedal, Eivind	Alternative Methods of Realizing the Sea Spectrum for Time-domain Simulations of Marine Structures in Irregular Seas	Jørgen Amdahl
Chen, Ying	Bucket Foundation in Clay for OWT Subjected to Combined Cyclic Loads	Torgeir Moan
Cook, Timothy Wade	Buckling of Cylindrical Shells with a Granular Core Under Global Bending	Torgeir Moan
Deac, Marius	Design and Analysis of a Large Wind Floater	Torgeir Moan
Dekker, Marijn Johannes	The Modelling of Suction Caisson Foundations for Multi-Footed Structures	Torgeir Moan
Drægebø, Elisabeth	Reliability Analysis of Blowout Preventer Systems	Ingrid Bouwer Utne
Erstad, Camilla	Tilstandsbasert Vedlikehold på Tørrgasstetninger	Ingrid Bouwer Utne
Evjen, Ole Tomas	Marine Laser Radar	Tor Arne Johansen
Folgerø-Holm, Jon Andreas	Long Term Scheduling of Major Renewals	Ingrid Bouwer Utne
Fuglaas, Simen	Precision Airdrop from a Fixed-Wing Unmanned Aerial Vehicle	Tor Arne Johansen
Galaxy, Tri Buana	Ship Energy Efficiency and CO2 Abatement Cost Analysis	Ingrid Bouwer Utne
Gottschal, Espen Joris	Dynamic Thrust Allocation	Roger Skjetne
Hagen, Hilde Christine	Feasibility Study on Active Wave Compensation of ROV	Asgeir Johan Sørensen
Hatlevik, Edvin	Heave Disturbance Attenuation in Managed Pressure Drilling from a Floating Platform using Model Predictive Control	Tor Arne Johansen
Hauff, Kristian Stenvågnes	Analysis of Loss of Position Incidents for Dynamically Operated Vessels	Ingrid Bouwer Utne
Haugen, Kenneth Eide	Surface Mapping using Quadcopter	Lars Imsland
Haugene, Tormod	Evaluation of Methods for Robust, Automatic Detection of Net Tear with Remotely Operated Vehicle and Remote Sensing	Tor Arne Johansen
He, Zhengmin	Analysis and Design of the SEVAN FPSO against Extreme Ice Actions	Jørgen Amdahl
Heiervang, Mads Fredrik	Time Domain Analysis of Fish Farms Subjected to Extreme Environmental Conditions	Jørgen Amdahl
Helland, Andreas Strand	UAV Anti-icing System Based on Conductive Coating	Tor Arne Johansen
Helland, Øystein	Review of IACS Unified Requirements for Design of Polar Ships against Ice Loads	Jørgen Amdahl

Henriksen, Eirik Hexe-berg	ROV Control System for Positioning of Subsea Modules	Asgeir Johan Sørensen
Hestdal, Morten Rusten	The use of Model Predictive Control and Distributed Battery Energy Storage Systems for Primary Frequency Control	Lars Imsland
Holgersen, Lars Kristian	Performance Monitoring in Teekay Petrojarl	Ingrid Bouwer Utne
Hustveit, Bjarte	Kombinert Modelbasert og Sensorbasert Observer for Undervannsfartøy	Asgeir Johan Sørensen
Høglund, Sondre	Autonomous Inspection of Wind Turbines and Buildings using an UAV	Tor Arne Johansen
Håland, Sigve	Lowering and Lifting Operations through Moonpools: Hydrodynamic Investigations	Marilena Greco
Jacobsen, Heidi	Structural Design Considerations for an Ice Resistant Semi Submersible Drilling Rig	Jørgen Amdahl
Kajanus, Robert	Optimal Recursive Thrust Allocation Applied for ROV Minerva	Roger Skjetne
Knutsen, Mats Foss	Time Domain Analysis of Fish Farms Subjected to Extreme Environmental Conditions	Jørgen Amdahl
Konstali, Ørjan	Analysis and Design of Ship Collision Barriers on a Submerged Floating Tunnel subjected to Large Ship Collisions	Jørgen Amdahl
Lauritzsen, Martin	Hardware-in-the-Loop Testing Systems for ROV Control Systems	Asgeir Johan Sørensen
Lillemoen, Nina Fjell-dalen	Development of Software Tool for Identification of Ballast Errors in Autonomous Underwater Vehicles	Kristin Ytterstad Pettersen
Lyngra, Nora Helen Lund	Analysis of Ice-Induced Damages to a Cargo Carrier and Implications wrt. Rule Requirements	Jørgen Amdahl
Lønne, Lars	Development of an Irradiance Sensor Based on a Photon Counting Camera	Asgeir Johan Sørensen
Ma, Meilin	Damage Assessment of Sevan FPSO Subjected to Impacts From Shuttle Tankers	Jørgen Amdahl
Magnus, Andreas	MPC for Dual Gradient Borebrønnkontroll ved Hjelp av en Undervannspumpemodul og en Topside Strupeventil	Imsland, Lars
Marin, Traian Ionut	Fatigue Analysis of the Column-Pontoon Connection in a Semi-Submersible Floating Wind Turbine	Torgeir Moan
Marley, Mathias Huuse	Modelling and Robust Control of Production Force of a Wave Energy Converter	Roger Skjetne
Mathisen, Carl Magnus	Search and Rescue Operations using a Fixed-Wing UAV Equipped with an Automatically Controlled Gimbal	Tor Arne Johansen
Mathisen, Siri Holthe	High Precision Deployment of Wireless Sensors from Unmanned Aerial Vehicles	Tor Arne Johansen
Matland, Arild Eriksen	Simulation of Marine Lifting Operations with Focus on Structural Response Control	Jørgen Amdahl
Midthaug, Asgeir Hovdelien	Nonlinear Wave Loads on Offshore Wind Turbines in Storm Condition	Jørgen Amdahl
Nikolaisen, Svein Roald	Life Cycle Cost Comparison Study	Ingrid Bouwer Utne
Nundal, Stian Aas	Tracking Objects with Fixed-wing UAV using Model Predictive Control and Machine Vision	Tor Arne Johansen
Ofstad, Christoffer Andreas	Handling Unknown External Forces with Highly Responsive DP Controller	Tor Arne Johansen
Olafsen, Helle Kristine H	Control of Thruster Assisted Position Mooring System on Floating Production Storage and Offloading	Asgeir Johan Sørensen
Orsten, Andreas	Automatic Reliability-based Control of Iceberg Towing in Open Waters	Roger Skjetne
Ottemo, Torjus Sveier	Reconstruction of Building Facades in 3D for Remote Inspection Using a Multicopter	Tor Arne Johansen
Palmer, Christian	Asset Integrity	Ingrid Bouwer Utne
Rasmussen, Simen Kleven	Assessment of Structural Damage due to Cryogenic Spill for FLNG Plants	Jørgen Amdahl
Rosnes, Aleksander	Risikobasert Inspeksjon (RBI)	Ingrid Bouwer Utne
Rotevatn, Torstein	Modeling of the CAS-OB Process for Online Use	Lars Imsland
Skjong, Espen	Tracking Objects with Fixed-wing UAV using Model Predictive Control and Machine Vision	Tor Arne Johansen
Skulstad, Robert	Low-cost Instrumentation System for Recovery of Fixed-wing UAV in a Net	Tor Arne Johansen

Slagstad, Martin	Accidental Impact Resistance of Non-disconnectable Bouy Type FPSO	Jørgen Amdahl
Steen, Thor Audun	Search and Rescue Mission Using Multicopters	Tor Arne Johansen
Stettner, Oliver	Numerical Simulation for Installation of Jacket Foundation of Offshore Wind Turbines	Torgeir Moan
Stokkeland, Martin	A Computer Vision Approach for Autonomous Wind Turbine Inspection using a Multicopter	Tor Arne Johansen
Stovner, Bård Bakken	Model Predictive Control in UAV Trajectory Planning and Gimbal Control	Tor Arne Johansen
Straume, Jonas Gullaksen	Dynamic Buckling of Marine Structures	Jørgen Amdahl
Sunde, Christian Heimdal	3D Visualization of Autonomous Underwater Robots	Ingrid Schjølberg
Swensen, Ingrid	Modeling and Non-linear Control of Gel Breaking in Drilling Operations	Imsland, Lars
Syversen, Christoffer Lie	Low-cost Instrumentation System for Recovery of Fixed-wing UAV in a Net	Tor Arne Johansen
Thieme, Christoph	Development of a Risk Management Process for NTNU's REMUS 100 AUV	Ingrid Bouwer Utne
Tran, Nam Dinh	Line-Of-Sight-based Maneuvering Control Design, Implementation, and Experimental Testing for the Model Ship C/S Enterprise I	Roger Skjetne
Trømborg, Håkon	Control System for the DNV GL Fuel Fighter Prototype and the DNV GL Fuel Fighter UrbanConcept	Tor Arne Johansen
Tutturen, Svenn Are	Topics in Dynamic Positioning	Roger Skjetne
Tvare, Øyvind	Fatigue Analysis of Column-Pontoon Connection in a Semi-submersible Floating Wind Turbine	Torgeir Moan
Vandervaeren, Nathan	Distributed Control of a Drifting Formation of Autonomous Underwater Vehicles	Asgeir Johan Sørensen
Verheugt, Bas	Efficient Response Simulation Strategies for Jacket-based Offshore Wind Turbines	Torgeir Moan
Voldsund, Vegard	Drop and Recovery of Sensor Nodes Using UAVs	Tor Arne Johansen
Wang, Qiang	Design and Dynamic Analysis of a Steel Pontoon-type Semi-submersible Floater Supporting the DTU 10MW Reference Turbine	Torgeir Moan
Wattum, Sverre	Reliability Centered Maintenance on the Norwegian Continental Shelf	Ingrid Bouwer Utne
Xing, Zheng	Response and Structural Analysis of a Flap-type Wave Energy Converter in a Combined Wind and Wave Concept	Torgeir Moan
Zhou, Chunqi	Ultimate Strength and Post-Ultimate Behavior of Hybrid Platform Deck Girders	Jørgen Amdahl
Østhus, Vegar	Robust Adaptive Control of a Surface Vessel in Managed Ice Using Hybrid Position- and Force Control	Lars Imsland
Østrem, Tor Eirik	Model-free IMU-based DP State Estimator	Tor Arne Johansen

Innovation

Innovation meetings

Date	Activity	Participants
10 and 16 January	Pitching course, by Prof. Øystein Widding, School of Entrepeneurship	PhD candidates
27 February	Innovation processes in Statoil, by Innovation Manager Jan Richard Sagli	PhD candidates Key personnel
27 March	Why is IPR important, by IPR manager Dr. Ola Eirik Fjellstad, Kongsberg Seatex	PhD candidates Key personnel
25 September	How we work with innovation and company start-ups from NTNU, by innovation experts from NTNU Technology Transfer	PhD candidates Key personnel
17 December	Solution Seeker AS – a spin off company from the center for integrated operations at NTNU, by Dr Vidar Gunnerud, CEO of Solution Seeker AS	PhD candidates

New AMOS spin-off company

Name	Founders
Norwegian Subsea AS	Fredrik Dukan, Håkon Baste and Lars Torgersen

New patent

Title	Name	Patent/licence nr.
Risk Management	Ingrid Schjølberg, Ingrid Bouwer Utne, Jan Erik Vinnem	120737

Workshops

Date	Workshop/seminar	Topic
3-4 February 2014	AMOS Days	Strategic two-day seminar for all AMOS employees
3-4 March 2014	NTNU AUR-Lab-workshop	Underwater technology and operations
9 April 2014	CERN-AMOS-workshop	Collaboration between CERN and AMOS
28 April 2014	AMOS-DTU-workshop	Join forces between DTU and AMOS
19-20 May 2014	70 Years Anniversary Seminar and Celebration for Professors Faltin-sen and Moan	International seminar and celebration to honour Professors Faltinsen and Moan
26 May 2014	ROBOBUSINESS	Robotics in oil and gas industry
7 June 2014	AMOS user panel on smarter, safer, greener marine operations	Support dissemination and user interaction on AMOS research area - smarter, safer, greener marine operations
22 September 2014	AMOS-workshop about wind turbines	Wind turbines
13-14 November 2014	AMOS-DTU-workshop	Join forces between DTU and AMOS

Guest Lectures and Seminars by Visitors to AMOS

Date	Speaker	Topic
14 January 2014	Professor João Borges de Sousa, University of Porto, Portugal	Networked vehicles for maritime operations: design and implementation
5 March 2014	Adjunct associate professor Claudio Lugni, INSEAN	Sloshing-induced slamming in small liquid conditions
23 April 2014	Professor Gianluca Antonelli, University of Cassino and Southern Lazio, Italy	Control problems for floating-base manipulators
7 August 2014	Professor Louis L. Whitcomb and Dr Christopher McFarland, Johns Hopkins University, USA	Underwater operations and robotics
24 September 2014	Professor Mark A. Moline, University of Delaware, USA	Applications for autonomous underwater vehicles
29 September 2014	Professor Nikos A. Aspragathos, University of Patras, Greece	Manipulation of non-rigid objects of sheet form
30 September 2014	Associate professor Ulrik Dam Nielsen, Technical University of Denmark	Safe and efficient ship operations in a seaway – response-based sea state estimation used in onboard DSS
13 and 14 October 2014	Professor David Q. Mayne, Imperial College London, UK	MPC stability and robustness
14 October 2014	Professor Murat Arcak, UC Berkeley, USA	An input/output approach to networked dynamical systems
15 October 2014	Professor David Q. Mayne, Imperial College London, UK	Tube-based control of constrained nonlinear systems
15 October 2014	Dr Jonathan Tu, UC Berkeley, USA	Data-driven approaches for overcoming temporal sampling rate limitations in particle image velocimetry
20-22 October 2014	Professor Fredrik Gustafsson, Linköping University, Sweden	Seminar on sensor fusion
31 October 2014	Professor A. Pedro Aguiar, University of Porto, Portugal	Cooperative navigation and motion control of multiple marine autonomous robotic vehicles
4 November 2014	ProfessorJing Sun, University of Michigan, Ann Arbor, USA	Predictive control of integrated power systems for electrified vehicles
13 November 2014	Associate professor Ulrik Dam Nielsen, Technical University of Denmark	Response-based sea state estimation - safe and efficient ship operations in a seaway
18 November 2014	Ondřej Marek, VUTS Liberec, Czech Republic	Repositioning of the flexible mechanical structures using wave-based control
19 November 2014	Professor Martin Kühn, ForWind and University of Oldenburg, Germany	Wake effects in the German offshore test field «alpha ventus« measured with synchronised long-range lidar windscanners

Honorary Positions and Memberships in Scientific Academies

Honorary positions

University/Society	Person	Period	Responsibility
Aalto University, Finland	TM	Since 2014	Honorary Doctoral Degree
American Society of Civil Engineers	TM	Since 1995	Elected Fellow
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
Int. Assoc. of Bridge and Structural Engineers	TM	Since 2001	Elected Fellow
National University of Singapore	TM	2002-2007	Keppel Professor
Offshore Energy Center, Hall of Fame, Houston, USA	TM	2002	Elected
Technical University of Denmark	TIF	2013	Visiting Prof./Otto Mønsted Professor
University College London	OF	Since 2005	Visiting Professor
University of Surrey, UK	OT	Since 2013	Visiting Professor
Zhejiang University, Hangzhou, China	TM	Since 2010	Visiting Professor

Memberships in scientific academies

Academy	Person	Period	Responsibility
Chinese Academy of Engineering	OF	Since 2007	Foreign Member
Croatian Academy of Sciences and Arts	OF	Since 2014	Corresponding Member
Danish Academy of Technical Sciences	JJJ	Since 1999	Member
Danish Academy of Technical Sciences	MB	Since 2001	Member
Danish Society of Naval Architecture and Marine Engineering	UDN	Since 2011	Board Member
Int. Community for Maritime and Ocean Professionals (SNAME)	JJJ	Since 2014	Fellow
Int. Community for Maritime and Ocean Professionals (SNAME)	UDN	Since 2014	Member
National Academy of Engineering of the USA	OF	Since 1991	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)	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
Norwegian Academy of Technological Sciences (NTVA)	TM	1993-1997	Vice-president
Royal Academy of Engineering, UK	TM	1995	Elected Fellow
Royal Institution of Naval Architects (RINA)	JJJ	Since 2002	Fellow
Royal Institution of Naval Architects (RINA)	UDN	Since 2012	Member
Royal Norwegian Society of Sciences and Letters (DKNVS)	OF	Since 1995	Member

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