NTNU – Trondheim
Norwegian University of Science and Technology

# AMOS

## Centre for Autonomous Marine Operations and Systems

Annual Report 2013

Norwegian Centre of Excellence

# 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: Thor I. Fossen and Marit Solheim

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# Director's Report

**The vision of AMOS is to establish a world-leading research centre for autonomous marine operations and systems. This is a new step following strong education, research, and industry traditions within marine technology and engineering cybernetics in Norway.**

Due to the successful research achievements and experiences of the Centre for Ships and Ocean Structures (CeSOS) in recent years, in early 2010, the Centre applied to the Research Council of Norway for a Centre of Excellence (CoE) award for the 2012-2022 period, representing the third round of CoEs in Norway. Researchers from earlier CoEs were allowed to apply with new key scientists, management, and research directions. CeSOS has been an inspiration and role model for delivering high-quality research results and graduating numbers of MSc students, PhDs, and researchers for the ultimate benefit of academia, industry, and governmental agencies.

In November 2012, the Research Council of Norway announced that our CoE proposal for the Centre for Autonomous Marine Operations and Systems (AMOS) was awarded CoE status. We are grateful for the evaluation and strong support from the following AMOS partners: the Research Council of Norway, Statoil, DNV GL, MARINTEK, SINTEF Fisheries and Aquaculture, and SINTEF ICT. AMOS is collaborating with leading universities in Scandinavia, Europe, the US, and Australia and is involved in several associated projects, with collaboration agreements with other national and international collaborators.

As AMOS is addressing fundamental research areas for some of Norway's most important areas of industry and governance-maritime activities, offshore oil and gas, fisheries and aquaculture comprise more than 70% of Norway's export revenue – the expectations and responsibility to deliver fundamental knowledge and competence with relevance and impact over the next 10 years are high. In addition, AMOS supports the emerging areas of offshore renewable energy, marine mining, and ocean science. Global challenges, such as limited energy resources, limited mineral resources, the food supply, climate change, and environmental damage, are all vital in defining the research questions addressed by AMOS.

AMOS is performing direct research on and applying results from numerous enabling technologies, including information and communication technology, autonomy, biotechnology, and micro-electro-mechanical systems (MEMS). Moreover, the integration of disciplines is essential in our research. Combining enabling technologies with marine technology and engineering cybernetics is a unique opportunity for AMOS to deliver fundamental research results, innovations, and game-changing technologies with industrial impact. Thus, NTNU is supporting AMOS as a pilot for the exploration of innovation from large research programmes that are developing a culture for innovation, including the training of students and researchers. The goal of this effort is to shorten the period of time between fundamental research and industrial use in existing industries, as well as the time required to establish new companies.

The main achievement in 2013 was the establishment of AMOS as a CoE, including offices, administrative staff, laboratory engineers, scientific staff, and the recruitment of PhDs and researchers. AMOS has been established as a new office at the Marine Technology Centre. In addition, an AMOS satellite has been established in the Department of Engineering Cybernetics at the main campus. Another important achievement is the development of the new Unmanned Aerial Vehicle Laboratory (UAV-Lab) in the Department of Engineering Cybernetics. The UAV-Lab is a test facility for hardware and software, including inertial navigation systems, global satellite navigation systems, and unmanned aerial systems (UASs).

AMOS is also heavily involved in the Applied Underwater Robotics Laboratory (AUR-Lab), the Marine Cybernetics Laboratory (MC-Lab), and the power, machinery and hydrodynamics laboratories at the Marine Technology Centre. We are developing a research methodology encompassing theory, numerical simulations, and experimental work to produce high-quality research results to be published in leading journals and at international scientific conferences, where theoretical results are verified by numerical and experimental results.

Concerning the recruitment of PhDs, it is encouraging to observe that the research questions posed by AMOS are attractive for the young generation of scientists, including Norwegian students. More than 30 PhDs are currently employed at AMOS. The exciting research questions and knowledge disciplines addressing global challenges are found to be meaningful and appealing.

To meet these challenges and utilise the opportunities offered by the Norwegian Research Council's CoE scheme, we have defined the following values for AMOS:
*- Excellent, generous, courageous*

guiding us to deliver on NTNU's vision:
*- Knowledge for a better world, internationally outstanding*

All the best for productive years to come.

*Sincerely*
*Professor Asgeir J. Sørensen, Director*

# Organisation and Management

## Organsation

**AMOS BOARD**

Dean **Ingvald Strømmen,** Chair
Dean **Geir Øien,** NTNU
**Torbjørn Digernes,** NTNU
**Oddvar Eide,** MARINTEK
**Kjetil Skaugset,** Statoil
**Liv Hovem,** DNV

**AMOS MANAGEMENT**

**Asgeir J. Sørensen,** Director
**Thor I. Fossen,** Co-director
**Ingrid Schjølberg,** Project director
**Sigrid B. Wold,** Sr. Executive Officer

**SCIENTIFIC ADVISORY BOARD**

International and national recognized experts to be appointed for 2–4 years periods

**USER PANEL**

Members from research partners, companies, industry

**SENIOR SCIENTIFIC ADVISORS**

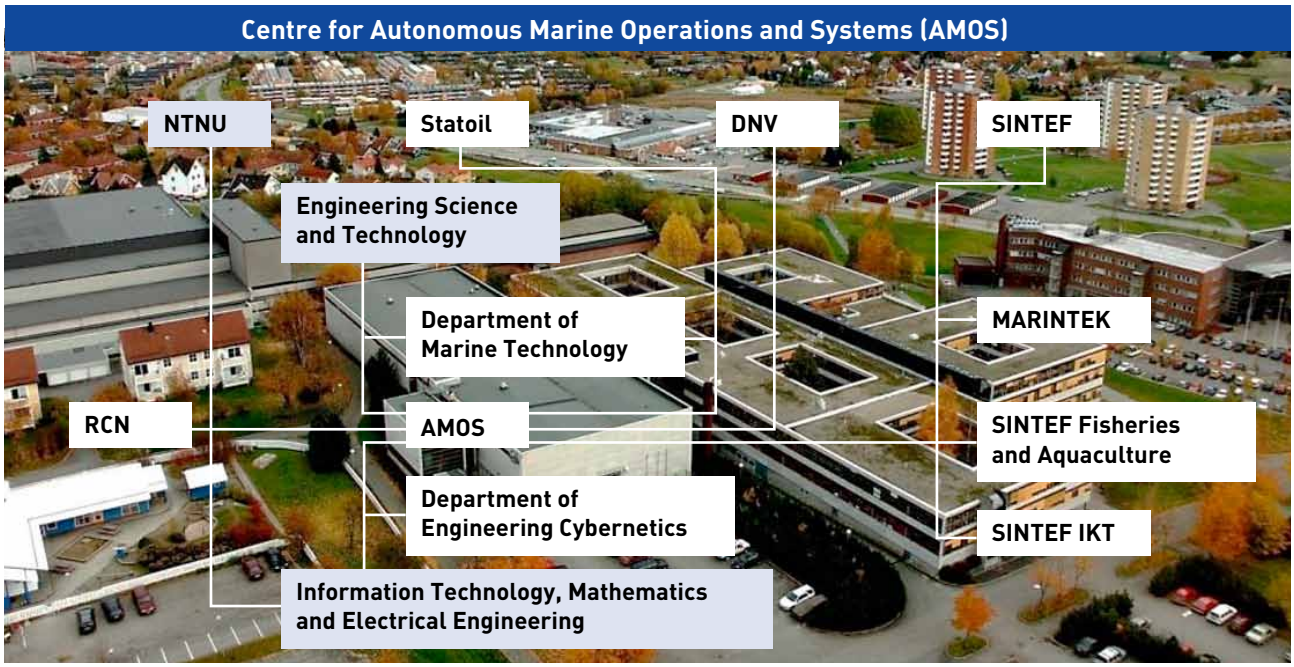
**Odd Faltinsen,** IMT, Hydrodynamics
**Torgeir Moan,** IMT, Marine Structures

**RESEARCH PARTNERS**

Principal investigators

**KEY SCIENTISTS**

**Jørgen Amdahl,** IMT, Marine Structures
**Thor I. Fossen,** ITK, Guidance, Navigation and Control
**Marilena Greco,** IMT, Hydrodynamics
**Tor A. Johansen,** ITK, Optimization and Control
**Kristin Y. Pettersen,** ITK, Motion Control
**Asgeir J. Sørensen,** IMT, Marine Control Systems



# Collaborators

### 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
- Denmark Technical University, 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 Delaware, USA
- University of Linköping, Sweden
- University of Newcastle, Australia
- University of Porto, Portugal
- Woods Hole Oceanographic Institution, USA

### National Collaborators

AMOS co-operates with many companies in R&D, the education of PhD candidates, and the sharing of research infrastructure and joint publications. The national co-operators are organised as associated R&D projects with PhD candidates and postdocs working in teams. The following companies and research institutes participated in such collaborations in 2013:

- DNV GL
- Ecotone AS
- Kongsberg Maritime
- Maritime Robotics AS
- NORUT
- Norwegian Defence Research Establishment (FFI)
- Rolls-Royce Marine
- SINTEF Fisheries and Aquaculture
- The University Centre in Kjeller (UNIK)
- The University Centre in Svalbard (UNIS)
- University of Tromsø

### Key Scientists

The research in AMOS is organised as research projects, which are managed by six key scientists:

- Professor Asgeir J. Sørensen, Director
- Professor Thor I. Fossen, Co-director
- Professor Jørgen Amdahl
- Professor Marilena Greco
- Professor Tor Arne Johansen
- Professor Kristin Y. Pettersen

Each of the key scientists is presented below.

**PROFESSOR ASGEIR J. SØRENSEN** was born in 1964. He received an MSc in Marine Technology in 1988 and a PhD in Engineering Cybernetics in 1993, both from NTNU.

From 1989 to 1992, Sørensen was employed at MARINTEK as a Research Scientist. In 1993, Sørensen was employed as a Research Scientist at ABB Corporate Research Norway.

*Professor Asgeir J. Sørensen, Director, Key Scientist Department of Marine Technology, NTNU*

In 1994, he became an R&D Coordinator/Project Manager at ABB Industri. In 1996, he was appointed as the Manager of Positioning Systems at ABB Industri. From 1998 to 2001, Sørensen was the Technical Manager in the Business Area Automation Marine and Turbochargers at ABB Automation. In December 2002, Sørensen and 5 partners founded the company Marine Cybernetics AS, where he acted as President and Chief Executive Officer (CEO) until June 2010. In 2012, Sørensen became a co-founder of the NTNU spin-off company Ecotone AS. Since 1999, Sørensen has held the position of Professor of Marine Control Systems at the Department of Marine Technology, NTNU. Sørensen has authored more than 160 scientific articles and book chapters on SES ride control, the dynamic positioning of ships and semi-submersibles, the guidance and control of underwater vehicles, the control of marine structures, the modelling and control of propulsion systems, power and energy management systems, and the HIL testing and verification of control systems. Sørensen has graduated more than 80 MSc and 12 PhD candidates.

**PROFESSOR THOR I. FOSSEN** was born in 1963. He received an MSc in Naval Architecture and a PhD in Engineering Cybernetics in 1987 and 1991, respectively, both from NTNU.

From 1989 to 1990, he pursued postgraduate studies as a *Fulbright Scholar* in aerodynamics and flight control at the Department of Aeronautics and Astronautics of the University of Washington, Seattle.

*Professor Thor I. Fossen, Co-director, Key Scientist Department of Engineering Cybernetics, NTNU*

In 1993, Fossen was appointed as a Professor of Guidance, Navigation, and Control at NTNU, and he was elected to the Norwegian Academy of Technological Sciences in 1998. Fossen has graduated more than 150 MSc candidates, and he is the main supervisor of 26 PhD candidates. He teaches the mathematical modelling of aircraft, marine craft, unmanned vehicles, and nonlinear control theory. Fossen has authored approximately 300 scientific papers and 5 textbooks, including the Wiley textbooks *"Guidance and Control of Ocean Vehicles"* and *"Handbook of Marine Craft Hydrodynamics and Motion Control"*. He has also served as an Associate Editor of Automatica. Fossen is one of the co-founders of Marine Cybernetics, where he was the Vice President of R&D from 2002 to 2008. A patent for the weather-optimal positioning control of marine vessels was granted in 1998. This work received the Automatica Prize Paper Award in 2002. In 2008, he received the Arch T. Colwell Merit Award at the SAE 2008 World Congress.

**PROFESSOR JØRGEN AMDAHL** was born in 1951 and obtained an MSc and PhD in Marine Technology from NTNU in 1975 and 1981, respectively.

He was employed as a Research Engineer by DNV GL from 1977 to 1980 and as a Research Engineer by SINTEF's Department of Structural Engineering from 1983 to 1988.

*Professor Jørgen Amdahl, Key Scientist Department of Marine Technology, NTNU*

He was employed by NTNU in 1988 and appointed Professor in 1994. Amdahl has authored approximately 140 conference and journal papers and has served as principal supervisor for 10 PhD candidates. He is a co-author of the book *Nonlinear Analysis of Offshore Structures* (Research Studies Press, 2002). His core expertise is in the analysis and design of ships and offshore structures subjected to abnormal and accidental actions (e.g., grounding, collisions, fires, explosions, and extreme waves). He was instrumental in the development of the NORSOK code for design against accidental loads (N-004, Appendix A). He is engaged in the development and maintenance of the USFOS software, which is widely used by international engineering and oil companies for accidental and abnormal load analysis of offshore structures. Amdahl is presently the Norwegian representative to the International Ships and Offshore Structures Congress (ISSC).

**PROFESSOR MARILENA GRECO** was born in 1972. She obtained her MSc in Aeronautical Engineering at the University "La Sapienza" of Rome and her PhD in Marine Hydrodynamics at NTNU.

In 1999, she began working as a Researcher and then as a Senior Researcher in seakeeping and manoeuvring at the research centre now named CNR-INSEAN, the Italian Ship Model Basin, and is presently involved with the centre through a part-time cooperation.

*Professor Marilena Greco, Key Scientist Department of Marine Technology, NTNU*

In 2004, she became associated with the CoE CeSOS in Trondheim, first as a Visiting Researcher and then as an Adjunct Professor. In January 2010, she began as a Full-time Professor in marine hydrodynamics at the Department of Marine Technology at NTNU in Trondheim, in a position funded for five years by Det Norske Veritas. For her expertise in marine hydrodynamics, she collaborated, as one of six key individuals, in the creation of AMOS, located in Trondheim, which was accepted as a CoE in November 2012. AMOS will educate 60 doctoral candidates and provide postdoctoral training for 15 researchers. Greco has co-authored more than 60 conference and journal papers and contributes as a referee for leading journals in fluid dynamics and marine hydrodynamics. She has tutored master students from Italian and French universities and has advised PhD students at CeSOS. To date, she has been a supervisor or co-advisor for fourteen master students for their projects and master theses at NTNU; six of these master theses are presently ongoing. She is the supervisor for three PhD candidates and co-advisor for one PhD candidate. She has participated in Italian and international research projects and managed a four-year European project. Her research interests lie in marine hydrodynamics, computational fluid dynamics, nonlinear free-surface and multiphase flows, fluid-structure interactions, and hydroelasticity. Her investigative tools of choice are primarily numerical and theoretical,

but she also conducts experiments. In connection with the CoE AMOS, her upcoming research will focus renewable energy sources in marine environments, aquaculture, vehicle safety in extreme sea conditions, and other related topics.

**PROFESSOR TOR A. JOHANSEN** was born in 1966 and received his MSc and PhD degrees in Engineering Cybernetics from NTNU in 1989 and 1994, respectively.

He worked at SINTEF Electronics and Cybernetics as a Researcher before he was appointed as an Associated Professor in Engineering Cybernetics at NTNU in 1997 and promoted to Professor in 2001. He was a Visiting Researcher at the USC, TU-Delft, and UCSD.

*Professor Tor Arne Johansen,*
*Key Scientist*
*Department of Engineering*
*Cybernetics, NTNU*

He has published more than 100 articles in international journals as well as numerous conference articles and book chapters in the areas of nonlinear control and estimation, optimisation, adaptive control, and model predictive control (MPC) with applications in the marine, automotive, biomedical, and process industries. He has supervised more than 10 PhD students, holds several patents, and has directed numerous research projects. In December 2002, Johansen co-founded the company Marine Cybernetics AS, where he acted as Vice President until 2008. Professor Johansen received the 2006 Arch T. Colwell Merit Award from SAE, is currently a principal researcher at AMOS, and is strongly involved in the Unmanned Aerial Vehicle (UAV) Laboratory at NTNU.

**PROFESSOR KRISTIN Y. PETTERSEN** obtained MSc and PhD degrees in Engineering Cybernetics at NTNU in 1992 and 1996, respectively.

She is a Professor in the Department of Engineering Cybernetics, NTNU, where she has been a faculty member since 1996. She was the Vice-Head of the Department from 2009 to 2011, Head of the Department from 2011 to 2013, and Director of the NTNU ICT Programme from 2010 to 2013.

*Professor Kristin Y. Pettersen*
*Key Scientist*
*Department of Engineering*
*Cybernetics, NTNU*

She has published more than 150 papers for international conferences and journals, and her research interests lie in the nonlinear control of mechanical systems with applications in robotics, satellites, AUVs, and ships. She has edited a Springer Verlag book on group coordination and cooperative control, is a co-author of a Springer Verlag book on Snake Robots and is also the co-author of a Springer Verlag book on Modelling and Control of Vehicle-Manipulator Systems to be published in 2014. She was a Visiting Professor at the Section for Automation and Control, University of Aalborg, Denmark, in 2008 and a Visiting Fellow at the Department of Mechanical and Aerospace Engineering, Princeton University, in 1999. In 2006, she and her co-authors were awarded the IEEE Transactions on Control Systems Technology Outstanding Paper Award for Global Uniform Asymptotic Stabilization of an Underactuated Surface Vessel: Experimental Results (K.Y. Pettersen, F. Mazenc, and H. Nijmeijer). She has served as Associate Editor for several conferences, including the IEEE Conference on Decision and Control, the IEEE Conference on Robotics and Automation, and the IEEE/RSJ International Conference on Intelligent Robots and Systems. She has served as a member of the Editorial Board of Simulation Modelling Practice and Theory and is an Associate Editor of the IEEE Transactions on Control Systems Technology and the IEEE Control Systems Magazine. She is a member of the Board of Governors of the IEEE Control Systems Society and holds/has held several board positions in industrial and research companies.

## Project Director

**DR INGRID SCHJØLBERG** obtained MSc and PhD degrees in Engineering Cybernetics at NTNU. She is currently the Project Director at AMOS and has been appointed as an Adjunct Professor in the Department of Marine Technology starting in 2014.

*Dr Ingrid Schjølberg,*
*Project Director*
*Department of Marine*
*Technology, NTNU*

From 1997 to 2013, she was employed in SINTEF, first as a Research and Senior Scientist and later as Research Manager. She has been the Head of the Centre for Advanced Robotics at NTNU/SINTEF since 2007, and she founded ROBOTNOR in 2012. In 2012-2013, in addition to her full-time SINTEF position, she was an Adjunct Associate Professor in the Department of Engineering Cybernetics supervising MSc and PhD students and leading a lighthouse programme on Robotics and ROBOTNOR. Her current research activities include underwater robotics and subsea intervention, risk management, and autonomy.

Her main interests lie in mathematical modelling for control, distributed control methods, tele-operation, robotics perception, and learning. She has extensive experience from initiating and leading national and international industry-driven research projects, including the following: Participant and Coordinator of European Commission projects; Project Manager of Next Generation Robotics for Norwegian Industry (2009-2013), funded by the Norwegian Research Council and members of industry; and Key Scientist in and Leader of a number of important industrial research projects (e.g., compressor simulations in a LNG plant and near-well models for dynamic GOR estimates, NTNU IO Centre).

She has published a number of international conference papers and SINTEF reports (mainly confidential) and holds two patents. From 1992 to 1993, she performed research at CERN in Geneva, Switzerland, involving tele-manipulated robots. She worked for SINTEF in Munich, Germany, from 2002 to 2005.

She has been on the Board of Directors of SME companies and has held positions in a number of steering committees and programme committees (e.g., IFAC and NFA). She has held several international positions, such as Operating Agent under the International Energy Agency's Hydrogen Implementing Agreement (2006-2013) and Member of an initiative group on regulations, codes, and standards for the European Commission's Hydrogen and Fuel Cell Technology Platform (2004-05).

# Board of Directors

**The Board is extremely satisfied with the activities undertaken at AMOS during 2013. Forty individuals were affiliated with the Centre during the year, including one researcher and 29 PhD students, some of whom had other financial support. The Board met twice to review progress, consider management issues, and offer advice on strategic directions for the Centre.**

*From left: Torbjørn Digernes (Rector staff, NTNU), Kjetil Skaugset (Chief Researcher, STATOIL), Bjarne E. Helvik (Vice Dean of Research, Faculty of Information Technology, Mathematics and Electrical Engineering, NTNU) representing 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 Hovem (Director of Operations, DnV-GL), and Oddvar Eide (President, MARINTEK).*

The Board is extremely satisfied with the recruitment of a large number of highly qualified PhD candidates from Norway and abroad. AMOS is in the process of appointing three adjunct professors from the Technical University of Denmark (DTU): Professor Mogens Blanke, Professor Jørgen Juncher Jenssen, and Associate Professor Ulrik Dam Nielsen. Strengthening the cooperation between DTU and NTNU by adjunct professorships and joint PhD programmes is an critical element of the AMOS strategy. AMOS also recruited three PhD candidates from DTU in 2013, and students from both universities have visited the research groups in Norway and Denmark. AMOS also has strong ties to INSEAN in Italy, and appointing Dr Claudio Lugni as Adjunct Professor has strengthened this cooperation. The international collaborators are important partners for students and researchers and align with our goal of international cooperation. The Board is also pleased to include young researchers at NTNU in participating in the AMOS research programmes. In 2013, these researchers included Professors Roger Skjetne and Ingrid Bouwer Utne at the Department of Marine Technology, and Professor Lars Imsland and Dr Morten Breivik at the Department of Engineering Cybernetics.

The Board is particularly satisfied with the Centre's success in obtaining funding beyond that contributed by the

### 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.

Research Council CoE programme and NTNU, as well as in producing high-quality scientific results in accordance with AMOS' high aspirations. AMOS's strategy in combining the marine technology and automatic control disciplines to develop marine autonomous systems has placed the Centre in a unique position and has made AMOS an attractive partner in several research programmes on autonomous systems. The Board is also impressed by the establishment of the new Unmanned Aerial Vehicle Laboratory (UAV-Lab) at NTNU in 2013, which will be a key laboratory for the experimental testing and verification of autonomous unmanned systems. Together with the existing infrastructure, including the research vessel Gunnerus and the AUR-Lab, this new laboratory provides NTNU researchers with a unique opportunity and world-leading test facilities for autonomous marine operations.

Finally, the Board looks forward to an exciting and productive year in 2014, with an increasing number of high-quality publications and excellent PhD candidates.

**The Board members will be portrayed in the annual reports in the next years. For 2013 we have interviewed Torbjørn Digernes and Kjetil Skaugset**

**Professor Torbjørn Digerens** was born in 1947. He obtained an MSc degree in Technical Physics in 1972 and a PhD degree in Computer Science in 1982, both from NTNU.

I started out studying technical physics at NTNU in 1966. Along the way, I decided to specialise in computer science in the last part of my master study. Computer science was a new field of education at NTNU at the end of the 1960s, and it looked exciting; it was clear to me that computers would have a deep impact on society in the coming decades.

*Professor Torbjørn Digernes, Board of Directors, Rector's staff*

I have always been interested in looking at how complex systems function and how their performance and behaviour is the result of how their constituents interact. Therefore, modelling has become a continuous element throughout my career. This interest is what took me to the marine sector, when I was offered a job at the Fishery Technology Research Institute to analyse the design and operation of fishing vessels. Thus, even though my doctorate thesis is stamped from the Department of Computer Science, my research involved the modelling of fishing vessels. When I returned to Norway and NTNU in 1996 after six years at the European Space Technical Centre (the technical headquarters of the European Space Agency), I began modelling the resupply of the European elements of the International Space Station. After a period in industry, I became a Professor in Marine Systems Design in 1998 and subsequently the Dean of the Faculty of Marine Technology. In 2002, I became the Dean of the Faculty of Engineering Science and Technology, and in 2005, I took up the position as Rector of NTNU, which I held until July 2013.

It has been a marvellous experience to see this institution grow and prosper as a Rector. We have had a strong increase in the production of both research and candidates, and we are involved in 20-25 large national centres, including centres of excellence, research-driven innovation, and environmentally friendly energy. We have a strategy that prioritises the fulfilment of our societal obligations, and I believe that this is an admirable trait of NTNU.

Looking back on my career, would I do it again? Society has developed considerably in the nearly 50 years since I began my studies. The challenges of the next decades have been shaped by these developments, so I would likely not follow the exact same path. However, I would still be occupied by relationships in complex systems. I am curious by nature, so I would also have been engaged in many different knowledge fields.

I will now discuss my expectations for CeSOS and AMOS. Regarding CeSOS, I felt that I was a midwife in the process of getting CeSOS on the tracks in 2001-2002. I knew that the quality of the people in the group behind that Centre was among the best in the world in their field. Indeed, the "CeSOS baby" was a great success, and its performance is the reason that NTNU is ranked top in the world in publishing scientific research in the field of ocean engineering.

It has been a pleasure for me to follow this development from a position on the Board of Directors of CeSOS and to sit ringside in the development of AMOS. AMOS is building on the achievements of CeSOS; indeed, key personnel in AMOS have contributed significantly to the success of CeSOS.

I have very high expectations for AMOS. I believe that the AMOS team can achieve Professor Asgeir J. Sørensen's goal of performing research for 1,000 million kroner in the 10 years for which AMOS is planned. Furthermore, I expect AMOS to produce a large number of MSc and PhD candidates who will become an invaluable contribution to the workforce in the marine and maritime industries. I also expect that these students will take the opportunity

provided by basic research in a Centre of Excellence to probe new scientific directions and thereby lay the foundations for significant advancements in the state-of-the-art technologies for this industry.

Outside of my work life, I have pursued one significant hobby: contributing to the sport of skating, primarily figure skating. I was never an active competition skater, as the climate where I grew up was not a suitable for such activities. However, I have been working in *Trondhjems Skøiteklub* since the end of the 1970s, a club which dates back to 1876 and whose roots are intertwined with the cities, as well as with the beginnings of NTNU.

I may have more time to devote to this hobby in the coming years. However, in the near future, I will be investigating how the industrial successes of NTNU have occurred—what are the backgrounds of the people who have created them, how have they been cooperating with international colleagues, how have their relations with industry been, and what are the contributions that their candidates have made? A better understanding of these patterns will make it easier for NTNU to repeat these successes.

**Statoil's Chief Researcher Kjetil Skaugset** was born in 1973. He obtained a BSc degree in Marine Engineering at Ålesund College in 1995 and MSc and PhD degrees from NTNU in Marine Structures and Hydrodynamics in 1998 and 2003, respectively.

I began my technical studies in 1992, pursuing a BSc focused on ship structures. This degree was a great foundation from which I planned to proceed further. Starting MSc studies at NTNU after spending one year of naval military service at Marintek felt very natural. At NTNU, I enjoyed the fact that fellow students came from all around the globe and that all courses were taught in English.

My MSc thesis was a feasibility study of a compliant towers platform solution for the Norwegian Continental Shelf. The study focused on the towers' dynamic behaviour, and the solution allowed for dry wellheads. This cost-effective solution is also relevant today, as it fits well with the new Statoil initiative "subsea on slim legs".

I was offered to write my MSc thesis abroad at Texas A&M University, which provided me with a unique opportunity to connect closely with the oil and gas industry in Houston. Hence, it was not certain that I would make the move back to Trondheim; instead, I might have stayed in Houston to work for the oil and gas industry. However, I made the move back to NTNU, as it was evident to me that I can have an even greater impact in industry with the detailed knowledge gained through a PhD.

*Kjetil Skaugset,*
*Statoil's Chief Researcher*

For my PhD, I considered the industry challenge of reducing problems with the vortex-induced vibrations (VIVs) of marine risers. I addressed this issue from three angles; theory, numerical simulations, and hydrodynamic experiments.

The fact that NTNU has such world-class facilities available is a considerable advantage that students should utilise to the full extent. During my years as a PhD candidate at NTNU, I engaged in the management of the university as a faculty board member and held a number of other committee positions as a representative for those temporarily employed at the university. Such engagements provided valuable insights and widened my horizon.

It is important to gain knowledge and learn from the best. During my PhD studies, I had research stays at the Department of Applied Mathematics of Brown University in the USA. It was inspiring to collaborate with the unique group advancing computational fluid dynamics and direct numerical simulations of Navier-Stokes equations.

After graduating with my PhD from NTNU, my hunger for knowledge was still not satisfied. I worked as a postdoc for one year at the Massachusetts Institute of Technology (MIT), considering the high-Reynolds-number VIVs of marine risers. Being a part of the Ocean Engineering Department of MIT was truly a great experience.

I returned to NTNU for my second postdoc position at CeSOS, focused on providing essential insights into the fluid-structure interactions (VIVs) of marine risers by experimental techniques, including particle imaging velocimetry (PIV).

I presently enjoy holding the highest professional position in Statoil. I was told by my predecessor that it is the best job in the company; having held this position for 2 years, I now completely agree with his statement. My professional journey in Statoil prior to my current position comprises numerous positions within research, project, and personnel management.

I have also had the pleasure of working on some of the great field development projects in Statoil. I was most engaged with the development of the Aasta Hansteen field. In fact, my trial lecture on graduation day for my

PhD was: "Will SPAR Buoys be applied under North Sea conditions?" Participating in making just that happen for Statoil at Aasta Hansteen, which is the first ever SPAR with storage (FPSO), the first SPAR on NCS, and the first permanent installation in Statoil with steel catenary risers (SCRs) and polyester mooring, was inspiring and is a good example of how detailed technical knowledge can make a significant impact.

My motivation for proceeding as a postdoc after finishing my PhD was mainly a thirst for knowledge, curiosity about the unexplored, and my wish to make an impact. However, do not expect to have all the knowledge you will need when you are finished with a PhD or even two postdocs. Professional life outside academia also provides constant learning.

I would like to offer some reflections and expectations on AMOS going forward. I believe that Professor Asgeir J. Sørensen has put forth a great vision and ambition for AMOS. It is now time to deliver on these ambitions. I expect AMOS to attract and develop world-leading students and researchers and for them to undertake innovative research for future value creation. Never aim low with your research, making sure you just hit the target. If you wish to make an impact, aim high. Be bold, and dare the risk of failure. When you fail, work hard to rise again. In some cases, even a well-documented failure is a great success. AMOS should propel innovation and establish game-changing technologies.

I find inspiration in using the innovation approach toward working every day. In Statoil, we define innovation as "creating something new that is **valuable** and **implemented**". The three highlighted elements are equally important for successful innovation. Working in a systematic way, where you test ideas and technologies early to disclose flaws in assumptions and in the technology itself, can provide valuable insights that will rapidly progress your research.

To succeed with innovation, you must be sure that you solve the real problem at hand and that the solution is of sufficient value and hence worth implementing. It is often easier to focus on a problem and try to solve it rather than take the additional time to determine the actual problem and instead solve that one. The great virtue of the innovation approach is that the same logic applies to any level of task you might have. Whether you are coding new software, designing an experimental set-up, or searching for a new and cost-effective way to install subsea templates in deep water, you should start by asking, "What is the *actual* problem?" This strategy will help you to focus on the most value-adding approach.

> Help each other,
> make your colleagues shine,
> and appreciate the value of
> AMOS as a team.

When you have succeeded in obtaining high-impact research results, you should ask yourself: "How could this result have 10 times (or even 100 times) the value impact I can see now?" Equally important, you should ask, "What do I need to do to make it happen?" Finally, identify who can help you in this process.

Another expectation I have is that AMOS interact closely with partners in all phases of existing and new projects and that new projects emerge from a dialogue between us. I believe that industry partners can play a large role in AMOS, calibrating the focus on value-adding topics.

In your everyday AMOS work, it is not only *what* you deliver that is important; it is also *how* you deliver. Be open, excellent, thorough, impatient, daring, and open to failure. Help each other, make your colleagues shine, and appreciate the value of AMOS as a team. Finally, make sure that you and your colleagues stay safe during your work at AMOS. Work just as systematically with HSE as you do your scientific work during laboratory activities and field trips. Remember that you always have time to work in a safe way.

This is what I expect of you.

*Kjetil Skaugset*

# AMOS meets Tord Lien, Minister of Petroleum and Energy

*Tord Lien, Minister of Petroleum and Energy, is acknowledged for his support by Asgeir J. Sørensen.*

Over many years as a top politician in Norway, Tord Lien has paid attention to research, education, management, and industrialisation related to the energy sector. His support is highly appreciated and has been an inspiration in defining ambitious targets and objectives for AMOS.

The principal responsibility of the Ministry of Petroleum and Energy is to achieve a coordinated and integrated energy policy. A primary objective is to ensure high-value creation through the efficient and environmentally friendly management of Norway's energy resources. Several of the research areas in AMOS are particularly important for the petroleum sector. In addition, research that strengthens offshore renewable energy as an emerging area is promising. "Knowledge and competence are both key factors to being successful. I am looking forward to following the progress of AMOS," states Tord Lien.

# Facts and Figures 2013

## Personnel

- 6 key persons (6.0 man-years)
- 1 project director (1.0 man-year)
- 1 PostDoc/researcher (0.8 man-years)
- 29 PhD candidates (29.0 man-years)
- 1 adjunct professor (0.3 man-years)
- 3 affiliated professors
- 1 administrative staff (0.5 man-years)
- A total of 37.6 research man-years

## Revenues

- Income: 23,823 KNOK
- Costs: 24,038 KNOK
- Year-end allocation: -215 KNOK

## Publications

- 14 journal papers
- 2 book chapters
- 60 refereed conference papers
- 2 international keynote lectures

## Dissemination

- 7 guest lectures have been delivered to AMOS by national and international visitors.
- 31 popular science presentations have been delivered in newspapers, TV, and conferences.

# Research Projects

**The AMOS research projects aim to answer the following research questions:**

**Q1:** How can autonomous vessel operation and optimisation in terms of fuel consumption, emissions, safety, and operational efficiency be achieved?

**Q2:** How can intelligent guidance, navigation, and control (GNC) systems for fully autonomous vehicles and robotic systems that support marine operations and monitor conditions in demanding environments be achieved?

**Q3:** How can sustainable and autonomous systems for offshore renewable energy in shallow-to-deep waters be defined and operated?

**Q4:** How can methods and fully autonomous systems for the characterisation, prediction, control and monitoring of marine environmental parameters and biological production be developed?

**Q5:** How can the safety and success of marine operations with increased autonomy in hostile conditions, such as extreme seas, violent water-structure interactions, very deep water, close vicinity to the sea floor, and icy environments, be ensured?

The AMOS research areas and knowledge fields are shown in Figure 1.

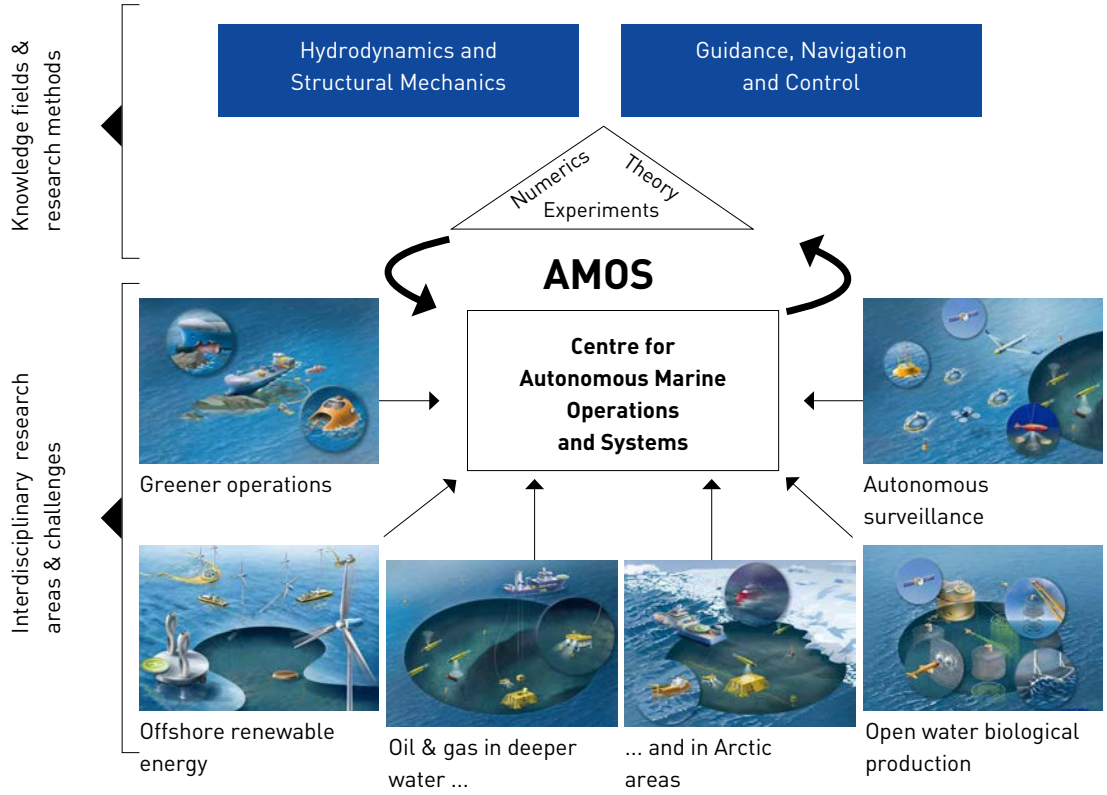



**Figure 1:** *AMOS research areas and knowledge fields.*

AMOS began six research projects in 2013 within the scope of the aforementioned research questions:

- Intelligent offshore aquaculture structures
- Autonomous unmanned vehicle systems
- Autonomous underwater robotics for mapping, monitoring, and intervention
- Autonomous aerial systems for marine and arctic monitoring and data collection
- Autonomous marine operations in extreme seas, violent water-structure interactions, deep waters, and the Arctic
- Consequences of accidental and abnormal events on ships and offshore structures

The research projects will be evaluated annually, and their redirection will be a dynamic process based on the re-

search findings and on advice received from the scientific advisory board and at internal and external workshops. The research projects are presented below.

## Intelligent offshore aquaculture structures

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

The rapid development of marine fish farming has led to new challenges. The dimensions used are expected to increase, and locations are expected to move to areas exposed to more energetic waves and stronger currents. These conditions can lead to large net deformations, greatly affect the hydroelastic behaviour of the cage, and raise concerns regarding the volume within the fish cage and the design of mooring lines. Contacts between the net and bottom-weight chains may be damaged, structural deformation of the ring weight may occur, waves may overtop the floater, and fish may escape the cage. Fish escapes will not be tolerated on a large scale. The operating limits of feed hoses connected to feed barges or other floating structures, as well as the limits of wellboats moored to fish farms, must be investigated in wave conditions. Biofouling is another issue for net loading. The development of intelligent aquaculture structures subject to large variations in environmental conditions is a challenge. Extreme loading scenarios must be properly designed. The research activities conducted this year focused on the experimental study of closed, flexible fish cages in terms of deformations and loads at different filling levels. The project (see Figure 2) will focus on the following:

- Operating limits for wellboats
- Intelligent structures
- Development of rational design formulations for aquaculture structures

### HIGHLIGHTS: Operating limits for wellboats

The limiting operational conditions for a wellboat moored to the fish farm will be investigated numerically in severe environmental conditions. Emphasis will be placed on the approaching and departing phases of a wellboat relative to a fish cage in waves and to the occurrence of accidental loads, such as the propeller slip stream blowing into the netting. For this problem, 3D flow effects are generally important. Wave overtopping occurs in realistic extreme wave conditions, and thus, nonlinear effects must be considered. Viscous effects are essential for the loading on the net structures and the wake inside the cage. The challenge is to simplify the problem while retaining the essential physical effects.

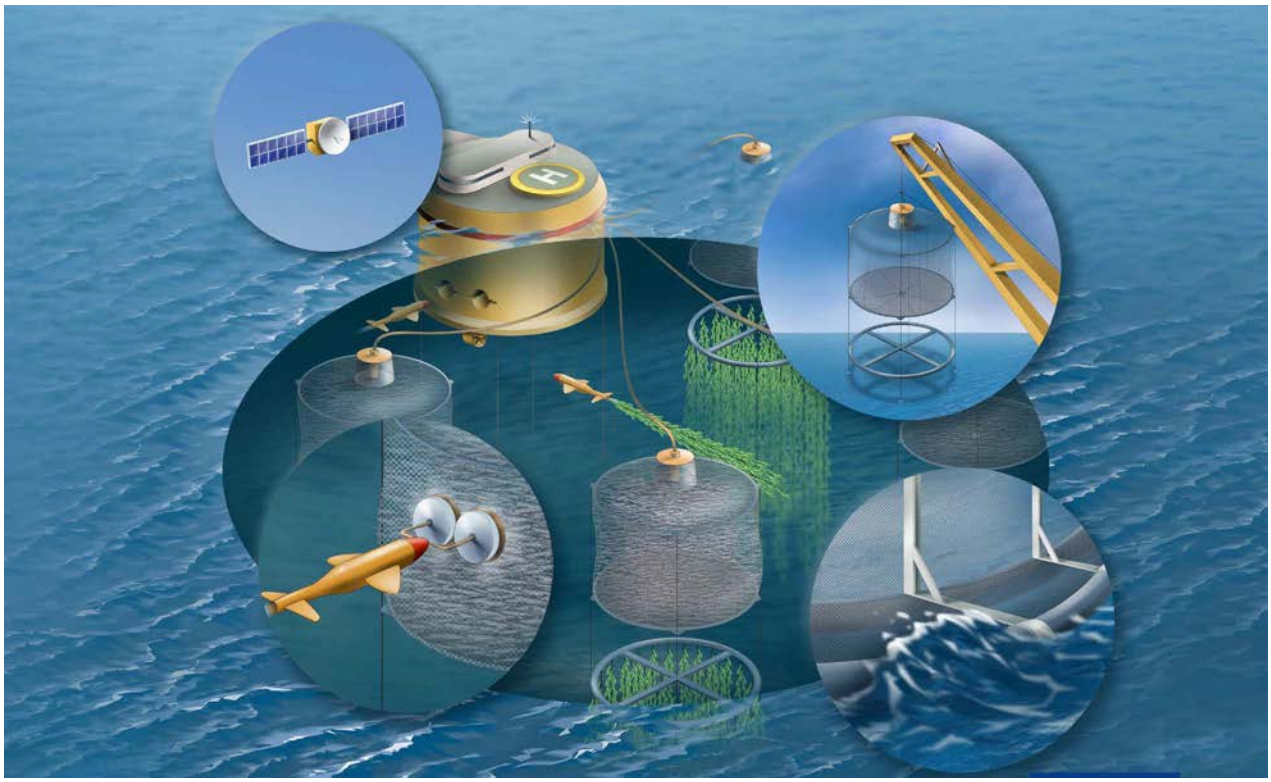


**Figure 2:** *Intelligent offshore aquaculture structures. Copyright: Bjarne Stenberg/NTNU*

### HIGHLIGHTS: Intelligent structures/closed flexible cages

This research will also investigate closed flexible fish cages using membrane structures with various geometrical configurations, filling levels, and control principles subject to current and wave loads. Closed flexible cages may be a promising concept addressing ecological challenges in the aquaculture industry (see Figure 3).

The flexibility and deformation of the bag membrane are coupled to the hydrodynamic forces (hydroelasticity), making the hydrodynamic load of a bag membrane more difficult to understand than that of a rigid structure.

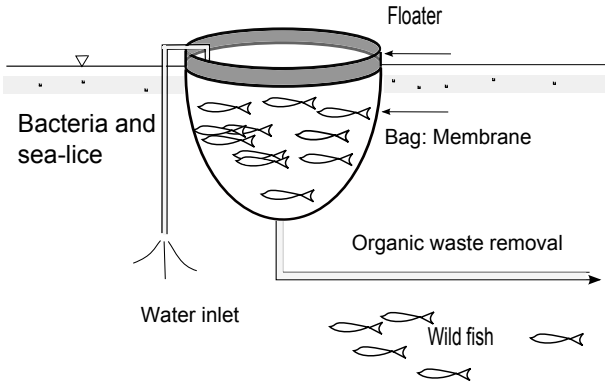



**Figure 3:** *Illustration of a closed flexible cage.*

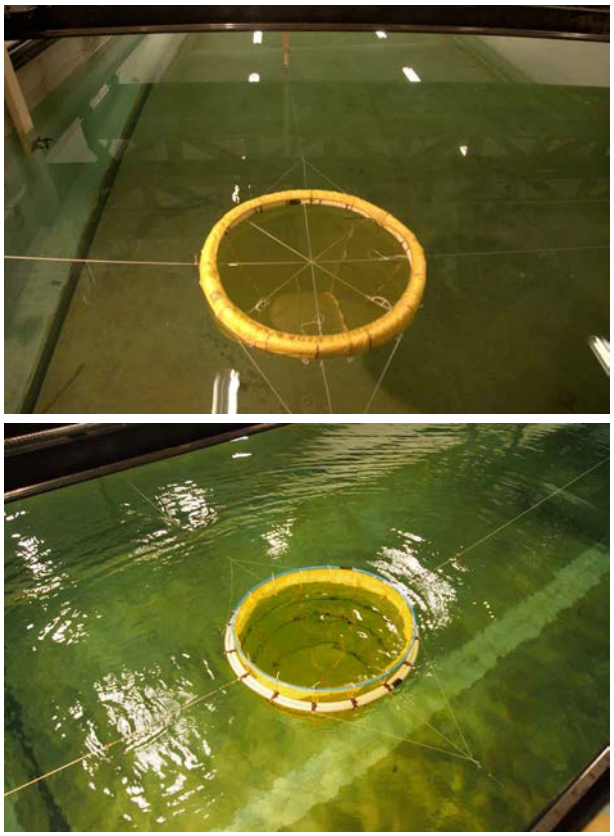


**Figure 4:** *Closed flexible cage subjected to current (top) and waves (bottom) studied at the Marine Cybernetics Laboratory.*

Very few ocean structures exist with large, heavily pliant submerged components, and there is presently limited knowledge on how aquaculture systems with closed flexible cages will respond to external sea loads. It is crucial to limit the forces to secure the cage against structural collapse and fish escapes. Thus, it is critical to obtain additional knowledge of the behaviour of such structures. New mathematical models supported by experimental work are currently under development.

Experiments were conducted in the Marine Cybernetics Laboratory at the Marine Technology Centre, NTNU, to obtain an initial understanding of the hydrodynamics of the cage. The behaviour of an elliptical flexible cage was studied in terms of the forces and deformations experienced when subjected to waves and current at different filling levels.

Illustrations from the experiments are presented in Figure 4. The drag increased with decreasing filling level, as shown in the left panel of Figure 5. Large deformations were observed for low filling levels (see the right panel of Figure 5, directly affecting the forces. The preliminary results from the wave experiments (not shown here) indicate an opposite trend, i.e., that the wave forces decrease with decreasing filling level.

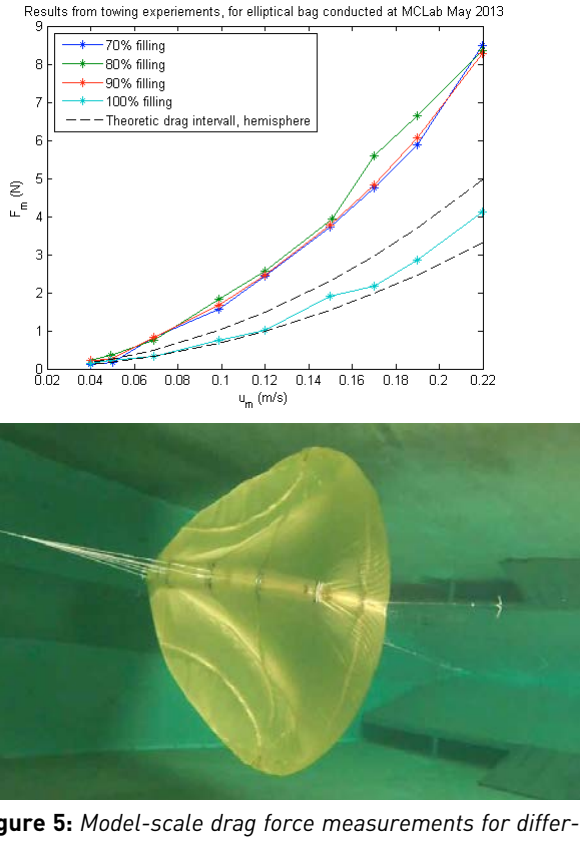



**Figure 5:** *Model-scale drag force measurements for different filling levels (top); deformation pattern of a bag with a low filling level subjected to current (bottom).*

**HIGHLIGHTS: Development of rational design formulations for aquaculture structures**
The aim is to develop rational design requirements for aquaculture structures based on first principles for simulations of the governing physical phenomena and structural load effects in irregular seas. Fatigue, ultimate strength, and accidental limit state conditions will be considered.

## Autonomous unmanned vehicle systems

**Project manager:** Professor Tor Arne Johansen
**Research associate:** Professor Thor I. Fossen
**PhD candidates:** Fredrik Leira, Anders Albert

This project on autonomy is dedicated to the study of fundamental challenges that must be addressed to enable fully autonomous vehicle systems to support marine operations. The research 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 project (see Figure 6) will focus on the following:

- Autonomous system and payload architectures
- Coordinated operation of a sensor network of unmanned vehicles and floating nodes
- Integrated underwater navigation and mapping
- Autonomous object detection and tracking in marine environments using infrared sensors
- Sensor-based guidance and path optimisation
- Coordinated and cooperative control architectures for intelligent task execution and collision avoidance in uncertain maritime environments

To support multi-vehicle operations at some level of autonomy, more robust ad hoc mesh network architectures are needed for communication between heterogeneous vehicle systems and sensor networks; these architectures should be capable of handling degraded and time-varying radio and hydro-acoustic communication channels in the context of delay-tolerant networking.

Robust navigation and on-board intelligent real-time processing of payload sensor data are needed for the autonomous execution of advanced missions. Nonlinear observer theory can provide algorithms of superior computational efficiency and accuracy for the fusion of inertial, magnetic, range/position, velocity, and imaging sensors.

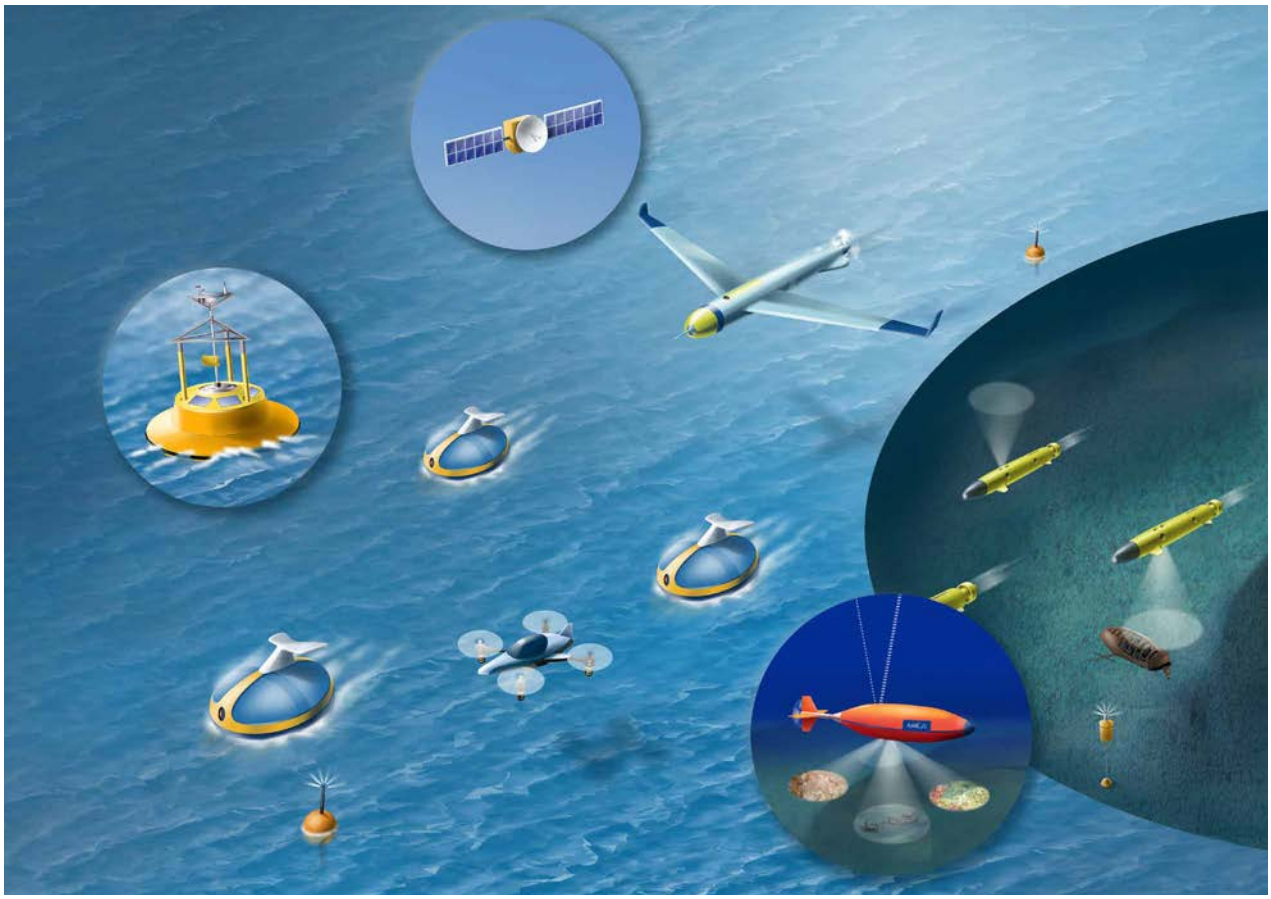


**Figure 6:** *Autonomous unmanned vehicle systems. Copyright: Bjarne Stenberg/NTNU*

Target detection and tracking based on imaging sensors are important elements of the research.

Challenging applications call for multi-vehicle distributed missions and path-planning methods at higher levels of autonomy and operational flexibility, using optimisation and heuristic search methods in combination with sensory and estimation information, terrain models, and simulations of vehicles and communication channel losses. More powerful and robust architectures and algorithms for fault-tolerant and intelligent command execution in autonomous unmanned vehicles, including obstacle avoidance and re-configurable control, will accompany these developments.

### HIGHLIGHTS: Autonomous object detection and tracking in marine environments using infrared sensors

A multi-object search, detection, and tracking algorithm is to be developed and implemented on-board a UAV (see Figure 7). More specifically, the algorithm should be able to track already discovered objects while simultaneously searching for new objects. This goal necessitates good position estimation filters, which are based only on the position of the objects in the image, coupled with the GPS information available on-board the UAV. Algorithms for optimal path planning will also be of interest. In addition, the results of the tracking algorithm and infrared video feed should be relayed to a ground station, where the operator can display the information. In summary, the combination of mathematical models, computer vision, and on-board data processing will provide a highly intelligent autonomous decision-making system. Such a system can be of assistance during search and rescue missions and other maritime operations.

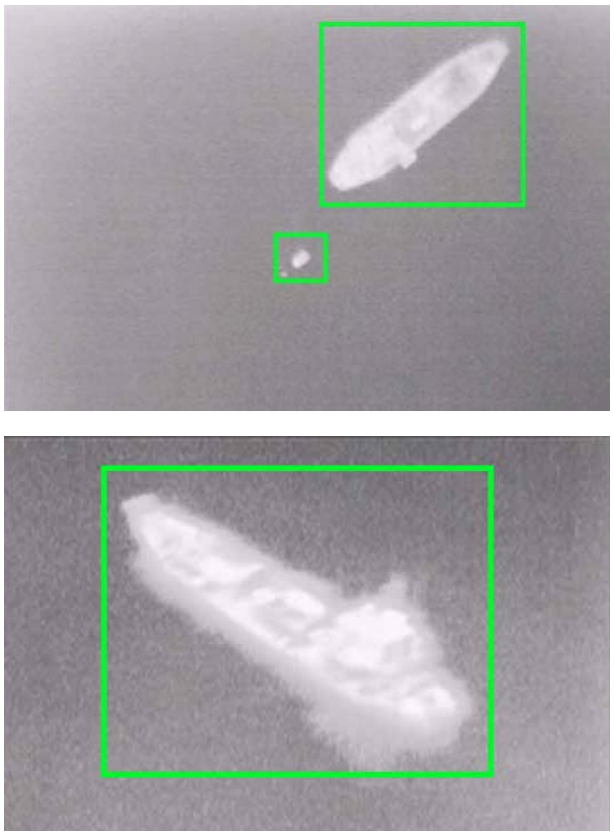


**Figure 7:** *Automatic object detection in infrared images. The green boxes are the detected objects. These images were taken during experiments in Portugal during the summer of 2013.*

## Autonomous underwater robotics for mapping, monitoring, and intervention

**Project manager:** Professor Kristin Y. Pettersen
**Research associates:** Professors Asgeir J. Sørensen, Thor I. Fossen, Ingrid Schjølberg
Postdoc/Researcher: Martin Ludvigsen
**PhD candidates:** Stein M. Nornes, Øyvind Ødegaard, Dennis J.W. Belleter, Signe Moe, Fredrik Dukan, Mauro Candeloro, Daniel Fernandes, Petter Nornes, Petter Norgren, Walter Caharija, Eleni Kelsadi

Ocean research using underwater robotics is important for mapping; for characterising and monitoring the climate and environment; and for exploring and exploiting hydrocarbons and other minerals and resources in demanding areas, such as deep water and under ice. The main challenges are to increase the level of autonomy and robustness for automatic mapping, monitoring, and intervention and to enable the planning/re-planning and reconfiguration of single and multiple vehicles according to the particular mission, environmental conditions, available energy, communication constraints, and any failure conditions. The project (see Figure 8) will focus on the following:

- Information-gathering networks
- AUVs with manipulation capabilities
- Mapping and monitoring

### HIGHLIGHTS: Information-gathering networks

Information-gathering networks require autonomous operations of the agents in the network and coordinated and cooperative agent behaviour. Therefore, cooperative and coordinated control strategies are specifically developed for multi-agent AUV systems. Coordinated and cooperative control strategies are particularly useful in situations where it is beneficial to cover a larger area at once by controlling the agents to achieve a desired formation, such as when conducting doing sea-bed scanning or

performing search-and-recovery or localisation missions. Moreover, a multi-agent AUV system can replace an ROV in challenging environments, such as deep-sea or under-ice operations. This ability allows for more autonomous operation and reduces the effects of robot loss, as operations do not have to be stopped and the financial loss of an AUV is generally less than that of an ROV. The development of coordinated and cooperative control strategies results in a number of challenges. In particular, because the existing theory for multi-agent systems mainly focuses on linear systems, it will have to be extended to nonlinear robotic systems. Moreover, underwater operation introduces problems inherent to hydro-acoustic communication, which will need to be addressed to add robustness to the control strategies.

### HIGHLIGHTS: Mapping and monitoring

The project will focus on the automation of tasks and functions on ROVs and AUVs, which is necessary to achieve robust autonomous systems, using mathematical models, real-time data, and advanced algorithms, such as numerical optimisation and nonlinear control. Coordinated and cooperative control of marine multi-agent systems will be developed. Real-time sensor fusion, combining one or several sensors (e.g., navigational inertial platforms, acoustics sensors for positioning, anti-collision, bathymetry and sub-bottom profiling, and imaging/optical sensors for the identification, mapping, and monitoring of bio-geo-chemical objects of interest) with new sensors, such as underwater hyper-spectral imaging and photo mosaics, in an uncertain or unknown environment will be addressed. This topic is important for providing the level of situational awareness that is needed for autonomous operations. In addition, intervention operations with combined vehicle and manipulator control will be studied. The next technology advancement in intervention robots will be to develop methods for underwater intervention from AUVs.

## Autonomous aerial systems for marine monitoring and data collection

**Project manager:** Professor Thor I. Fossen
**Research associate:** Professor Tor Arne Johanen
**PhD candidates:** Mariann Mertz, Kim Lynge Sørensen, Kristian Klausen, Lorenzo Fusini

The main research challenges of marine UAV operations arise from requirements for fuel/weight, reliability, and operational safety and particularly for autonomy, commu-

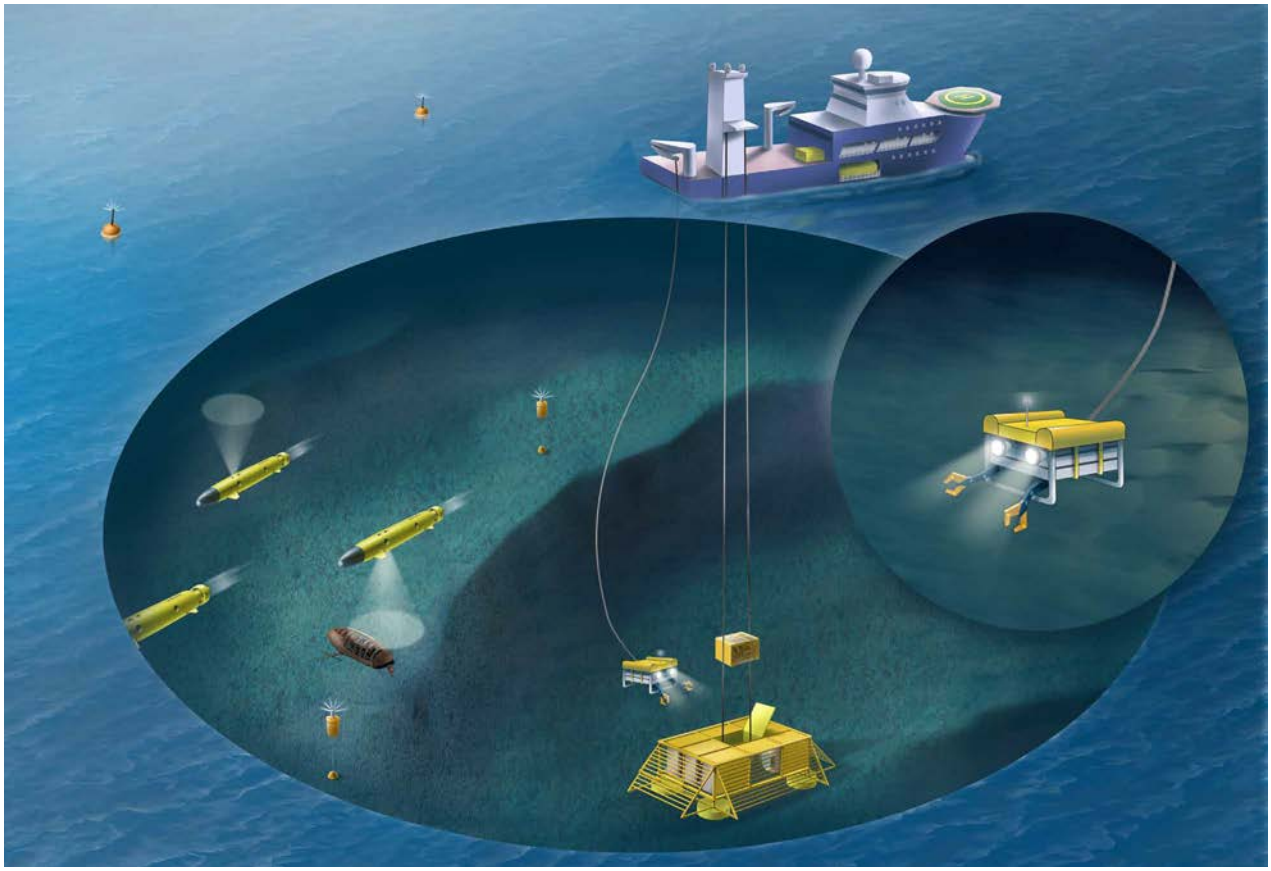


***Figure 8:*** *Autonomous underwater robotics for mapping, monitoring, and intervention. Copyright: Bjarne Stenberg/NTNU*

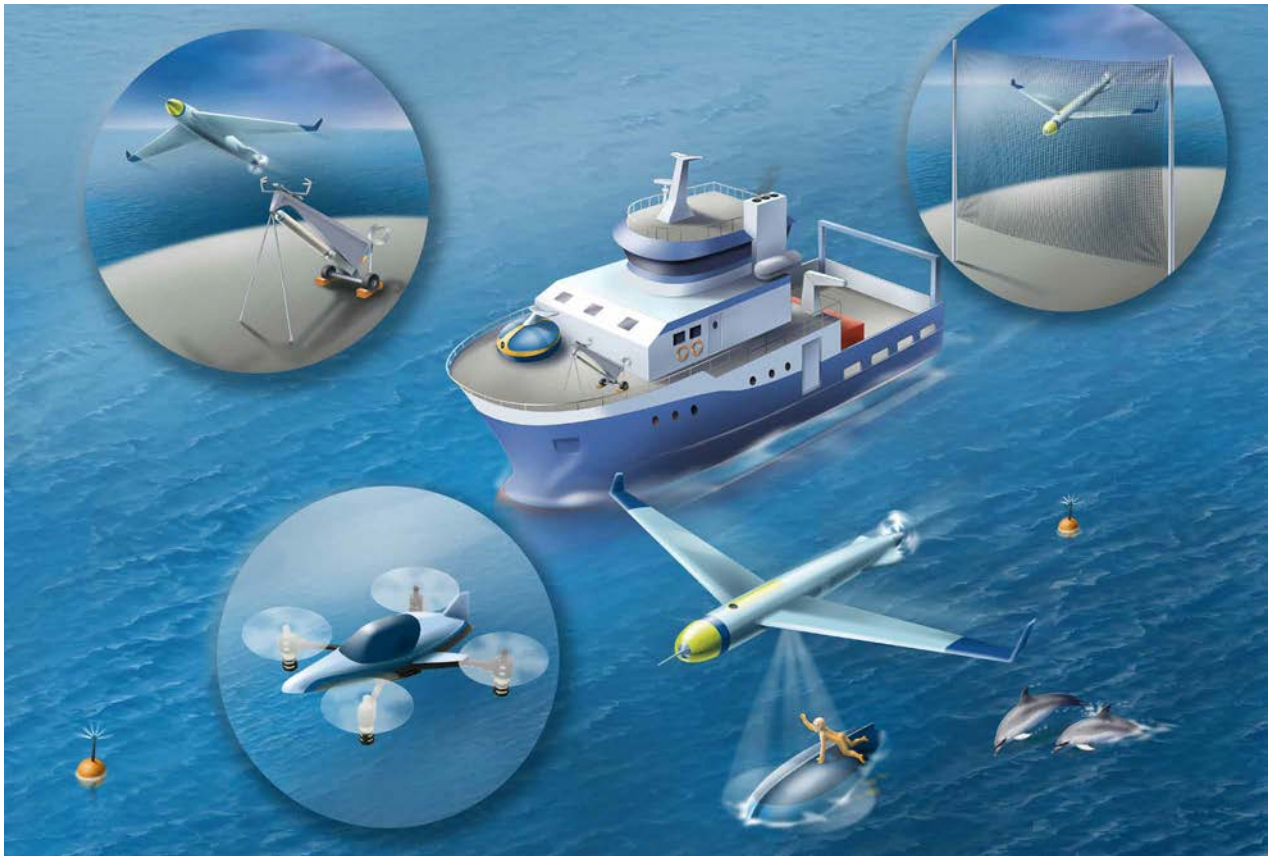


***Figure 9:*** *Autonomous aerial systems for marine monitoring and data collection. Copyright: Bjarne Stenberg/NTNU*

nication, guidance, and navigation. UAVs that carry sensors, communication equipment, and other payloads can support such operations as ice management in the Arctic, monitoring of resources and environmental parameters, such as oil spills, and monitoring of traffic and operations at sea. To allow for complex missions or tasks, UAVs will require autonomous mission-planning capabilities to support simultaneous operations with multiple UAVs and other vessels. The project (see Figure 9) will focus on the following:

- A coordinated ship and UAV recovery system
- Deployment, search, and recovery of marine sensors using a fixed-wing UAV
- Autonomous anti-icing of UAVs
- Deployment, search, and recovery of marine sensors using multiple rotary-wing UAVs
- A robust UAV attitude and navigation system for marine operations using nonlinear observers and camera measurements

The research focuses on operations with UAVs that are able to handle a number of operational events without operator input, including intelligent command execution with path re-planning, energy management, fault-tolerant control, automatic launch and recovery from ships, operational safety and collision avoidance, 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 being observed.

The short-term research outcomes will be robust GNC algorithms for use in UAV systems and demonstrations, and 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.

### HIGHLIGHTS: Deployment, search, and recovery of marine sensors using a fixed-wing UAV

While such tasks as sensor package placement and retrieval are more easily performed with the more manoeuvrable rotorcraft UAVs, only a fixed-wing UAV will have the range and speed foreseen to be necessary for auto-

nomous missions in the remote parts of the Arctic. The greatest challenge associated with the use of a fixed-wing UAV for such applications is the requirement to maintain a relatively high forward speed to prevent the UAV from stalling. To reach the high-precision manoeuvring goals required, the most promising path forward involves a "circle-tow" manoeuvre known in various manned applications, where the primary UAV will fly in a small-diameter circular motion with a long extended tow-line, to which a mechanism is attached. By carefully selecting all parameters involved, the end of the tow-line will follow a circular motion with a significantly smaller diameter than the UAV. The attached mechanism will enable independent (from the UAV) manoeuvring of the end-point of the tow-line and also facilitate high-precision drop-off and pick-up operations. The research will include methods of stabilising the end-point to provide a system that is reliable and robust to disturbances.

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

**Project manager:** Professor Asgeir J. Sørensen
**Research associates:** Professors Thor I. Fossen, Jørgen Amdahl, Marilena Greco, Kristin Y. Pettersen, Odd Faltinsen, Torgeir Moan
**PhD candidates:** Finn Christian Hanssen, Ida Strand, Ulrik Jørgensen, Ekaterina Kim

Smarter, safer, and greener marine operations in extreme seas, deep water, and Arctic areas north of 62° latitude are defining the next step for the maritime and offshore oil and gas industries. These areas are important for marine resources and are regarded as one of the breeding grounds for marine biological life as well. Extreme performance and capabilities beyond any earlier expectations will be

**Figure 10:** *Autonomous marine operations in extreme seas, violent water structure interactions, deep waters, and the Arctic. Copyright: Bjarne Stenberg/NTNU*

required due to the cold climate in these areas, with icing and ice, remoteness, and darkness half of the year, as well as the sensitivity of these areas to environmental damage. AMOS addresses the research challenges related to the development of smarter, safer, and greener vessels and marine operations considering normal, extreme, and degraded operations.

Moored offshore structures can be exposed to severe waves and strong currents. Steep waves can induce nonlinear loads on the platform that may be non-impulsive or impulsive (when breaking waves occur). The safety of the mooring system may be at risk if the induced motions are sufficiently large. Whereas waves die out in the water column in deep and finite waters, currents may also maintain substantial speeds at great depth and directly affect the mooring lines and platform. The scenario becomes more complex when waves and current interact with the structure. Morison's equation is often used to estimate the loads in slender structures; however, this method has limitations in terms of nonlinearities in the incident waves and on induced loads. Full 3D CFD methods are time consuming even when identifying an idealised scenario by simplifying the structural geometry and operational conditions; however, Navier-Stokes solvers are needed to capture the flow separation effects, and turbulent flow should be modelled precisely to handle the wake effects. The use of numerical hybrid strategies will be investigated for an efficient and effective solution and assessed by comparison with available experimental investigations. The project (see Figure 10) will focus on the following:

- Autonomous model-based hybrid control systems for manoeuvring and dynamic positioning (DP)
- Marine lowering and lifting operations in higher sea states
- Floating structures in severe waves and current.

### HIGHLIGHTS: Autonomous model-based hybrid control systems for manoeuvring and DP

The high-level control of the DP system is revised to extend the operational window of marine vessels (see Figure 11). Using the hybrid control concept, a bank of controllers together with a switching algorithm will ensure rapid adaptation to changes in environmental and operational conditions with good performance. A hybrid system structure incorporating vessel, observers, controllers, and switching logic is studied. Major contributions of this paper include the formal description of a hybrid system proposed by Goebel, R., Sanfelice, R. G., and Teel, A. R. in the paper entitled "Hybrid Dynamical Systems, Modelling, Stability and Robustness" (2012) to describe a DP ship and bank of controllers in a varying sea state and prove the stability of the hybrid controller. Simulations in a sea state varying from calm to extreme are conducted with the hybrid

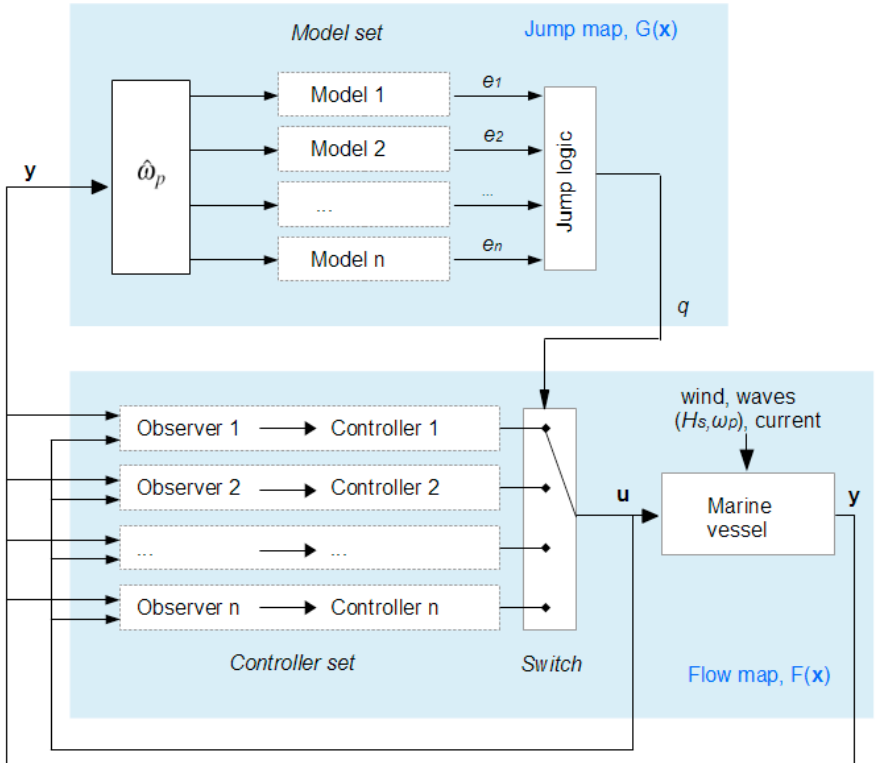



**Figure 11:** *Hybrid controller structure, including continuous and discrete dynamics*

controller, and a single PID controller with adaptive wave filtering is used for comparison purposes. The single controller becomes unstable in extreme seas, whereas the hybrid controller displays good performance.

### HIGHLIGHTS: Floating structures in severe waves and strong currents

Moored offshore structures can be exposed to severe waves and strong currents. Steep waves can induce non-linear loads on the platform that may be non-impulsive or impulsive (when breaking waves occur). The safety of the mooring system may be at risk if the induced motions are sufficiently large. Whereas waves die out in the water column in deep and finite waters, currents may also maintain substantial speeds at great depth and directly affect the mooring lines and platform. The scenario becomes more complex when waves and current interact with the structure. Morison's equation is often used to estimate the loads in slender structures; however, this method has limitations in terms of nonlinearities in the incident waves and induced loads. Full 3D CFD methods are time consuming even when identifying an idealised scenario by simplifying the structural geometry and operational conditions; however, Navier-Stokes solvers are needed to capture the flow separation effects, and turbulent flow should be modelled precisely to handle the wake effects. The use of numerical hybrid strategies will be investigated for an efficient and effective solution and assessed by comparison with available experimental investigations.

## 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 Faltinsen
**PhD candidate:** Martin Storheim

The goal of the project is to develop improved procedures for analysis, design, and control in case of accidental events such as groundings and collisions of ships and offshore platforms. A key challenge is to incorporate the effects of hydrodynamics, such as external sea pressure and internal liquid cargo, in the assessment of structural

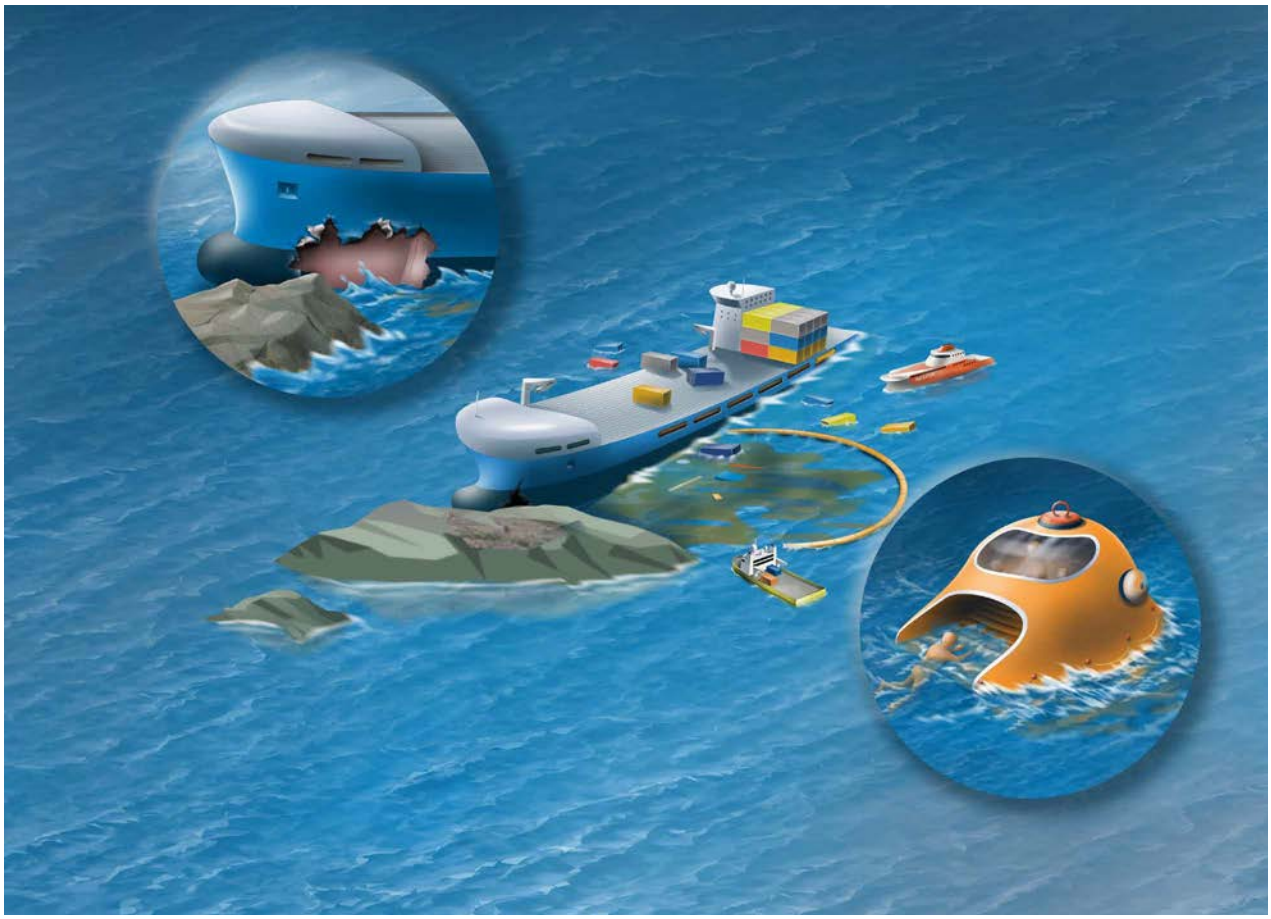


**Figure 12:** *Consequences of accidental and abnormal events on ships and offshore structures. Copyright: Bjarne Stenberg/ NTNU*

resistance to the penetration of impacted panels. The nonlinear finite element method based on the Arbitrary Lagrangian-Eulerian (ALE) method is a viable tool, but has only been used to a limited extent for such problems. The analysis is demanding because of the sheer size of the problem. The element size should not exceed 10 times the plate thickness, and for high-speed grounding involving a large part of the ship bottom, the required number of elements becomes extremely large, and the computation time may be prohibitive. 3D domain decomposition is an alternative analysis strategy for a damaged ship 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 (see Figure 12) focuses on the following:

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

### HIGHLIGHTS: Ship/platform and ship/ship collisions

Ship collisions with offshore structures have been addressed by AMOS researchers. Due to recent high-energy impacts, the design collision energy is expected to be increased by a factor of 3 to 10 for all new installations on the Norwegian continental shelf. The current simplified design tools have been investigated in detail, and improved analysis methods have been proposed when relevant. Force-deformation curves for bulbous bows, with and without ice strengthening, have been proposed. The increased demand for impact resistance can be a challenge for many installations, and guidance for strength design has been developed.

The outcome of the work will be proposals for revisions of the NORSOK standard N-004 Appendix A Design against accidental actions.

Ship collisions with icebergs have also been addressed. Emphasis has been placed on more accurate continuum mechanics modelling of ice as a material to allow for the simulation of interaction effects during abnormal ice impact events.

### Underwater explosions

Underwater explosions represent an important issue for ships and offshore structures. These events cause hot gas with high pressure and the release of a shock wave travelling in the surrounding fluid (see Figure 13). The bubble first expands while the high pressure reduces over time and propagates in the surrounding liquid; then, the bubble begins to oscillate. In the on-going numerical investigation, we assume that the explosion occurs very far from other boundaries and that hydrostatic pressure does not affect the explosion phenomenon, leading to a radial symmetry of the bubble evolution. A time-space domain-decomposition (DD) strategy is being developed: A compressible 1D solver is used to simulate the flow evolution in the radial direction until the shock wave reaches the vessel body. Then, a compressible 3D solver is used to investigate the fluid-body interactions.

The fluid-structure coupling is studied by modelling the bottom of a ship as an elastic, orthotropic plate. The stresses induced on the structure depend on the stand-off distance. For the case studied, the deformations fall within the plastic regime if the distance is less than 8 m.

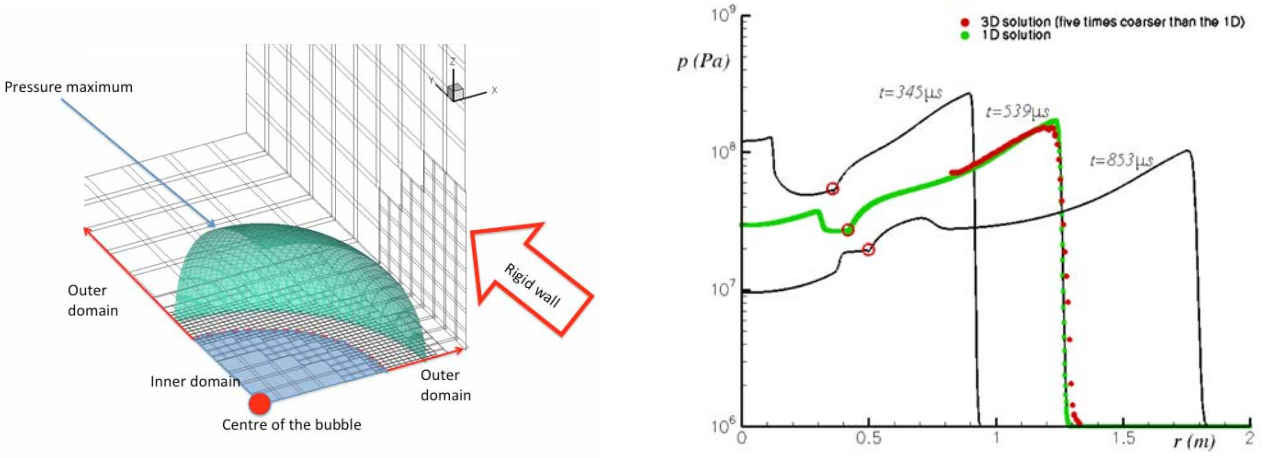



**Figure 13:** *Underwater explosion. Left: illustration of the DD strategy. Right: comparison of the 1D and 3D pressure solutions for the underwater explosion*

# Associated Research Projects

**AMOS cooperates with many companies on R&D, the education of PhD candidates, and the sharing of research infrastructure and joint publications. The following research projects were associated with AMOS in 2013:**

- **Fault-tolerant inertial sensor fusion for marine vessels (MarineINS)**
- **Low-cost integrated navigation systems using nonlinear observer theory (LowCostNav)**
- **Design and verification of control systems for safe and energy-efficient vessels with hybrid power plants (D2V)**
- **Closed flexible cage (CFC)**

## 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 web page:** http://www.itk.ntnu.no/english/research/maroff13

The MarineINS project for marine vessels is funded by the Norwegian Research Council through 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 use software algorithms to gain high-quality information from data from lower-grade sensors.

The goal of the project is to test nonlinear strapdown inertial navigation systems on-board marine vessels using new software architectures and nonlinear sensor fusion methods. Emphasis will be placed on fault-tolerant design techniques using inertial measurements, such as accelerometers and gyros, thus avoiding the use of a mathematical model for the vessel.

## Fault-tolerant inertial sensor fusion for marine vessels: Low-cost integrated navigation systems using nonlinear observer theory (LowCostNav)

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

The LowCostNav project is funded by the Norwegian Research Council through FRIPRO and will develop nonlinear observers for attitude estimation and the integration of MEMS-based inertial sensors aided by position reference systems. It is currently possible to buy accurate MEMS gyros and accelerometers with low-level software and built-in temperature compensation for less than USD 100. These units can be used in strapdown INS systems aided by GNSS, hydroacoustic positioning, radio, or other position reference systems. The goal of the project is to replace the extended Kalman filter (EKF) with nonlinear observers for attitude determination and sensor integration without performance degradation. This advancement will reduce the computational footprint significantly, 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 are changing the rules of the game and allow for the development of low-cost, compact position, velocity, and attitude (PVA) units. LowCostNav focuses on nonlinear observer design for the estimation of PVA, and the goal is to replace traditional EKF designs with comparable performance while guaranteeing global exponential stability. Hence, performance and robustness can be guaranteed and quantified by mathematical methods. Furthermore, it is possible to develop effective computer algorithms that can be implemented using only a fraction of the source code footprint while also representing computational complexity when compared to a standard EKF implementation. These algorithms will simplify implementation, maintenance, and software verification as well as documentation.

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

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

Dynamically positioned (DP) vessels with electric power plants in the range of 10-80 MW are used in the offshore industry in several safety-critical operations, including drilling, supply, offloading, construction, anchor handling, and production. DP vessels are being increasingly used, and they constitute a major part of the national and international maritime activities related to the exploration and exploitation of hydrocarbons and other advanced offshore operations. The development of knowledge and competence in the design and qualification of safe and environmentally robust power and energy management systems for safer and greener offshore vessels is critical for Norwegian industry. The power and energy management systems and the interactions among the different control systems are crucial in ensuring the efficient operation of electric energy consumers, such as propulsion, drilling, and cranes, and the electric energy production powered by, for instance, diesel engines, LNG engines, and fuel cells. The successful operation of DP vessels depends on the advanced integrated functionality of software-based control systems. Thus, software-related problems, often in conjunction with hardware and/or human faults, may lead to unacceptable pollution and emissions to the environment, vessel delays, downtime during operation, reduced income and increased cost for clients, and reduced safety. In this project, improved methods for the qualification and verification of technology for power and energy management control systems will be addressed for all system building phases, ranging from design to testing.

### Closed flexible cage

**Project manager:** Professor Asgeir J. Sørensen
**PhD candidate:** Ida M. Strand
**Project collaborators:** AMOS, SINTEF Fisheries and Aquaculture with an industry cluster

Recent environmental considerations, such as salmon lice, the escape of farmed fish, and the release of nutrients, have prompted the Norwegian aquaculture industry to consider the use of closed fish production systems (CFPSs). The use of such systems is considered to be a potential method of expanding salmon production. In a closed system, the farmer can have greater control over how the fish are exposed to pathogens, parasites, algae, or pollution by controlling the flow and quality of water going into and out of the containment volume to establish a more bio-secure production environment. Closed flexible cages (CFCs) offer a route for the development of CFPSs that might be faster than developing new CFPSs out of rigid material. The rationale behind this effort is that flexible floating systems are not extremely different than the current net cage floating fish farm systems and can be used in existing floating fish farms (both circular plastic and square steel farms) in combinations with net cages. The fundamental understanding and characterisation of sea loads and consequences and the identification of relevant design parameters from a long-term statistics perspective represent critical research topics and inputs to the design of robust marine structures and control systems. Intelligent structures characterised by improved monitoring capabilities and the use of passive and active controllers for vibration damping and configuration control are studied.

# Innovation and Training

### The AMOS innovation model

**Project manager:** Dr Ingrid Schjølberg

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: **excellent, generous, and courageous.** 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.

### Innovation strategy

Four building blocks constitute the AMOS innovation model (see Figure 14):

- Excellent research
- Culture building
- Resources
- Capital

**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 high-ranked international journal and conference articles. This is academic innovation 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. This priority is made through the establishment of a monthly innovation day, where we invite industrial experts to participate in guest lectures on innovation. All PhD candidates learn to pitch their research and gain knowledge in business development. This work is performed in close collaboration with the NTNU School of Entrepreneurship. Innovation often lies in the intersection between disciplines. Therefore, establishing arenas for open discussions across disciplines and providing avenues for collaboration across disciplines is an important future focus.

**Resources** is 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 ensuring business and opportunities.

Knowledge in entrepreneurship and on how to raise **capital** is an important part of the AMOS innovation strategy. AMOS will work in close collaboration with NTNU Technology Transfer and the NTNU School of Entrepreneurship to further develop ideas for spin-off companies and to contact venture capital firms to develop start-up companies.

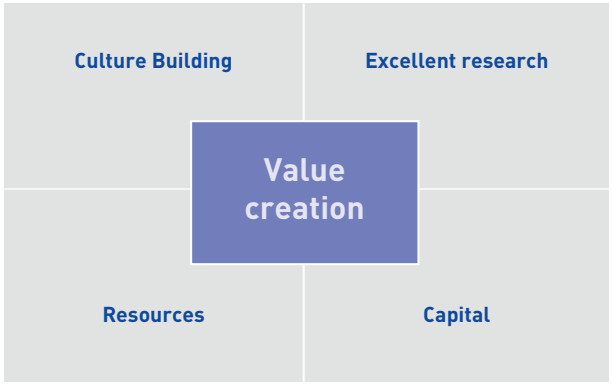



**Figure 14:** *Value of creation*

### Well-being of people

Our personnel are located in both Gløshaugen and Tyholt, with Tyholt being the main hub. A centre has been formed in Tyholt, and the locations have been upgraded and re-decorated to form an excellent physical meeting and working environment for AMOS personnel. An open meeting area has been designed as a room for social events and discussions. In AMOS, a number of activities will support the creation of a good social environment: speed dating between PhD candidates, annual workshops, celebrations with coffee and cake, and summer and Christmas parties.

*From a social meeting at AMOS.*

# Infrastructure and Research Facilities

### AUR-LAB – Applied Underwater Robotics Laboratory


*Minerva equipped with an IMU (MRU 6), a high-resolution scanning sonar, and CT. Photo: Johanna Järnegren*

### ROV Minerva

Minerva is used in biological research and sampling, for supplying ground truth in geological investigations, and for the development of new research technology.

The remotely operated vehicle (ROV) Minerva was specially designed by Sperre AS in 2003 to fulfill the needs of scientists at NTNU. The vehicle is rated to a depth of 700 m, thereby covering all depths in Trondheimsfjord. Equipped with a fiber optic cable, Minerva produces high-quality digital real-time video, and the HiPap positioning system of R/V Gunnerus accommodates extremely precise positioning. Minerva is operated from a standard 15 ft cargo container arranged with all necessary equipment, including a 42" flat screen. Real-time video is available in the mess room aboard R/V Gunnerus during operation.

### UAV-Lab – Unmanned Aerial Vehicle Laboratory

The Unmanned Aerial Vehicle Laboratory (UAV-Lab) is a new test facility developed at the Department of Engineering Cybernetics and AMOS. It includes several UAV systems based on the Penguin B airframe, the Skywalker X8 airframe, and multi-rotors of different size.

NTNU is collaborating closely with Maritime Robotics AS in developing this research facility based on open system architecture that facilitates a wide range of research on payload systems, avionics, launch-and-recovery systems, autonomous control, and applications. This partnership strengthens our system integration and operational capacity and contributes to a unique research infrastructure for UAV field experiments in challenging coastal and marine environments.

*Penguin B landing. Photo: Tor Arne Johansen*

## HIGHLIGHTS: Field experiments on ocean and coastal monitoring using UAVs

**Contacts:** Atle Sægrov, Radionor Communications; Vegard Hovstein, Maritime Robotics; Tor Arne Johansen, AMOS/NTNU

AMOS and the Trondheim-based companies Maritime Robotics AS and Radionor Communication AS are collaborating on technology development for the aerial monitoring of marine and coastal environments. The research performed in 2013 focused on beyond-line-of-sight (BLOS) operations and long-range digital data links, with funding from the Research Council of Norway through the Regionalt Forskningsfond.

Field experiments were conducted from the Ørland airfield in October and November 2013. A UAV was operated in controlled airspace where separation from other air traffic is provided by the Air Traffic Control (ATC). The UAV operation followed normal ATC procedures, with two-way VHF communication between the UAS Operator and ATC to provide separation either vertically or by operation within pre-defined areas according to specific operational procedures developed by ATC. Tests were conducted using direct 2.4 GHz radio and GPRS mobile network control links at a distance of up to 20 km from the ground control station when operating at an altitude of 1,500 ft.

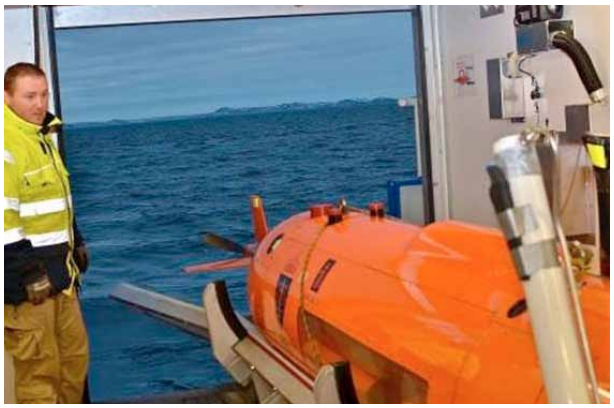
*NTNU's UAV operator Lars Semb controlling the unmanned aircraft. Photo: Tor Arne Johansen*

A new lightweight, small-size experimental phased-array antenna developed by Radionor Communications to provide a digital high-capacity data link was tested and observed to provide stable live HD video at a distance of 50 km under line-of-sight conditions at an altitude of 2,500 ft. The testing provided valuable operational and technical experience for the participants, providing a foundation for further research and the development of operational capacity for field experiments. AMOS collected data from inertial sensors, cameras, satellite navigation, and flight control data to be used in our research on robust and fault-tolerant navigation.

*Maritime Robotics' UAV pilot Carl Erik Stephansen preparing for take-off.*

## HIGHLIGHTS: **Research Campaign in the Trondheim fjord**

In December 2013, AMOS participated with several researchers in a one-week research campaign on integrated mapping and monitoring of cultural heritage and the marine environment in Trondheimsfjord. The campaign was organised by AUR-Lab with participants from FFI, NGU, Ecotone, and Statoil. The objective of the cruise was to demonstrate integrated operations from the Research Vessel Gunnerus using multiple platforms and sensors for underwater monitoring and documentation. The participants obtained valuable experience exploiting the complementary properties of an ROV and AUV. Data processing and interpretation was completed in near-real-time to utilise the advantage of having these platforms in an integrated operation. The DP system for ROVs developed by AMOS/AUR-Lab researchers was used for high-precision seabed mapping using video surveys, photomosaics, and underwater hyperspectral imaging.



*The AUV REMUS was deployed and recovered from RV Gunnerus.*

FFI participated with the AUV HUGIN HUS. In addition, the NTNU ROV MINERVA was used. The following sites were investigated:

- Mapping of coral reefs at Tautra, North Leksa, and Agdenes
- Seabed mapping of dumping areas at Agdenes
- Seabed mapping of shell sand outside Brekstad
- Seabed mapping of Trondheim Harbour

The AUV investigation was successfully carried out at the Tautra reef. Both AUV SAS and AUV photomosaic surveys at the dumping site were successful. Several objects of interest were located; of particular interest were the objects that are believed to be ammunition that has been dumped at the site. Further investigations are required, using the ROV to acquire HD video of the objects. High-quality SAS data were gathered at both the Agdenes and Nord Leksa coral reefs. Both the ROV and AUV were operated at the shell sand site at Brekstad. The AUV was used to survey an area of 2.1 km2 in Trondheim Harbour. Several objects of interest to be visited by ROV in 2014 were identified.

*One of our major partners, MARINTEK, ensures that AMOS has access to world-leading hydrodynamic laboratories for testing designs at a scale model.*

NTNU, FFI, and NGU investigated a dumping field outside Agdenes. Terje Thorsnes, NGU, and Petter Lågstad (FFI) analysed anomalies on the seabed at a water depth of 650 m.

More information about the cruise can be found at the website on AUR-Lab: http://www.ntnu.no/aur-lab

## Research Vessel Gunnerus

Gunnerus is equipped with the latest technology for a variety of research activities within biology, technology, geology, archaeology, oceanography, and fishery research. The ship is fitted with a dynamic positioning system and HiPap 500 unit, which provides optimal conditions for AUV and ROV operations and the positioning of deployed equipment. In addition to research, the ship is used for educational purposes and is an important platform for marine courses at all levels and disciplines.

*R/V Gunnerus starboard side view* http://www.ntnu.edu/marine/gunnerus.

## Marine Cybernetics Laboratory

The Marine Cybernetics Laboratory (MCLab) is the newest test basin at the Marine Technology Centre. It is located in what was originally a storage tank for ship models made of paraffin wax. As the name indicates, the facility is especially suited for tests of marine control systems due to its relatively small size and advanced instrumentation package. It is also suitable for more specialised hydrodynamic tests, mainly due to the advanced towing carriage, which is capable of the precise movement of models in 6 degrees of freedom.

The MCLab is operated by the Department of Marine Technology and has been a Marie Curie EU Training Site (2002-2008). It is mainly used by MSc and PhD students but is also available for MARINTEK and external users.

*Scaled models can be run without cables using a wireless Ethernet connection and micro-PC onboard.* http://www.ntnu.edu/amos/mclab

## Key Scientists

Prof. Asgeir J. Sørensen, Director

Prof. Thor I. Fossen, Co-director

Prof. Jørgen Amdahl

Prof. Marilena Greco

Prof. Tor Arne Johansen

## Project Director

Prof. Kristin Y. Pettersen

Dr Ingrid Schjølberg

# AMOS
## Centre for Autonomous Marine Operations and Systems 2013

## Affiliated Scientists

Prof. Lars S. Imsland

Prof. Roger Skjetne

Prof. Ingrid B. Utne

Dr Morten Breivik

## Adjunct Professor

Adjunct Prof. Mogens Blanke – Professor at DTU

## Senior Scientific Advisors

Prof. Torgeir Moan

Prof. Odd M. Faltinsen

## Administration

Sigrid Bakken Wold, Senior Executive Officer

## Researcher

Dr Oleksandr Tymokha – Professor at the National Academy of Science of Ukraina

## PhD Candidates


Anders Albert (Norway)


Dennis Belleter (The Netherlands)


Kasper Trolle Borup (Denmark)


Torleiv Håland Bryne (Norway)


Torstein Ingebrigtsen Bø (Norway)


Walter Caharija (Italy)


Mauro Candeloro (Italy)


Andreas R. Dahl (Norway)


Fredrik Dukan (Norway)


Daniel de Almeida Fernandes (Brazil)


Lorenzo Fusini (Italy)


Jakob Mahler Hansen (Denmark)


Finn-Christian W. Hanssen (Norway)


Ulrik Jørgensen (Denmark)


Eleni Kelasidi (Greece)


Ekaterina Kim (Russia)


Kristian Klausen (Norway)

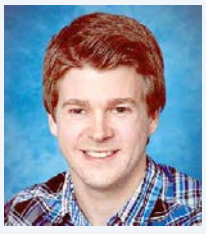

Fredrik S. Leira (Norway)


Marianne Merz (Norway)


Michel Rejani Miyazaki (Brazil)


Signe Moe (Norway)


Stein M. Nornes (Norway)


Petter Norgren (Norway)


Robert Rogne (Norway)


Yugao Shen (China)


Martin Storheim (Norway)


Ida Strand (Norway)


Kim Lynge Sørensen (Denmark)


Øyvind Ødegård (Norway)

# Presentation of New Scientists

## Adjunct professors

**PROFESSOR MOGENS BLANKE** received an MScEE in 1974 and a PhD in 1982 from the Technical University of Denmark, DTU.

*Professor Mogens Blanke*
*Technical University of Denmark*

He was a Systems Analyst with the European Space Agency from 1975 to 1976, with DTU from 1977 to 1984, Head of Division at Lyngs{\o} Marine from 1985 to 1989, and a Professor at Aalborg University from 1990 to 1999. He is now (2000 -) a Professor in Automation and Control at DTU and has also been an Adjunct Professor at NTNU since 2005. His research interests lie in automation and control, and diagnosis and fault-tolerant control are his areas of expertise. Application areas include autonomous vehicles in space and air, on land, and in marine environments.

Prof. Blanke has held various positions in the International Federation of Automatic Control, including Founding Member and First Chair of the Technical Committee on Marine Systems and subsequently Coordinating Committee Chair and Member of the IFAC Council. He is also a member of the IFAC SAFEPROCESS Technical Committee. Professional activities include being an Associate Editor for Control Engineering Practice and Technical Editor for IEEE Transactions of Aerospace and Electronic Systems.

## Affiliated scientists

**PROFESSOR INGRID BOUWER UTNE** (PhD) has been a Professor of Marine Operation and Maintenance Engineering since 2011.

*Professor Ingrid B. Utne*
*Department of Marine Technology*
*NTNU*

Utne's professional career started at the Officer Candidate School in the Norwegian Navy and as an Operations Officer (operasjonsbefal) onboard two frigates (KNM Narvik/Stavanger) from 1995 to 1997. She signed a contract with NATO's Immediate Reaction Force (IRF) and was deployed for three months with Standing Naval Force Atlantic (STANAVFORLANT).

From 2004 to 2009, she was a Research Fellow at SINTEF Fisheries and Aquaculture, a Research Scientist at SINTEF Safety Research, and a Post-Doctoral Fellow in the RAMS group at NTNU. In 2010, Utne was a Visiting Scholar in the Ocean Engineering Group at University of California, Berkeley, where she became a member of the Deepwater Horizon Study Group (DHSG) at the Center for Catastrophic Risk Management. The DHSG served as an advisor to the US Presidential Commission, the BOEMRE, and the public on issues related to the Macondo blowout. From 2012 to 2013, she was the Head of the Marine Systems Research Group at NTNU. Utne has co-authored one book, co-edited one book, and published 50 scientific articles on risk analysis, safety indicators, system safety engineering, maintenance, and sustainability analyses on offshore oil and gas installations, offshore wind, fisheries, and aquaculture.

**PROFESSOR LARS IMSLAND** received a PhD in electrical engineering from the Department of Engineering Cybernetics at NTNU in Trondheim, in 2002. He was a Visiting Scholar at the Institute for Systems Theory in Engineering at the University of Stuttgart, Germany, for a portion of his PhD studies.

*Professor Lars Imsland*
*Department of Engineering Cybernetics, NTNU*

After his PhD studies, he worked as a Postdoctoral Researcher at NTNU, a Research Scientist at SINTEF, and a Specialist for Cybernetica AS before becoming a Professor in Control Engineering at NTNU in 2009. His main research interests lie in the theory and application of nonlinear and optimising control and estimation. He has worked with applications within the oil and gas industry (both drilling and production), automotive industry, and mobile sensor networks for the monitoring of local ice features.

**PROFESSOR ROGER SKJETNE** received his MSc in Control Engineering at UCSB in 2000 and his PhD in 2005 at NTNU, for which he was awarded the Exxon Mobil Prize for Best PhD Thesis in Applied Research.

*Professor Roger Skjetne*
*Department of Marine Technology*
*NTNU*

Prior to his studies, he worked as an electrician for Aker Elektro AS on numerous oil installations for the North Sea. From 2004 to 2009, he was employed at Marine Cybernetics AS, which offered services for independent verification by HIL simulation on safety-critical marine control systems.

Since August 2009, he has held the position of Professor in Marine Control Engineering in the Department of Marine Technology at NTNU, awarded by Kongsberg Maritime AS. His research interests lie in arctic dynamic positioning and ice management systems for ships and rigs, the environmentally robust control of electric power systems on ships and rigs, and nonlinear control theory for the motion control of single and groups of marine vessels. Roger Skjetne is the Project Manager of the *KMB Arctic DP* research project and an Associate Researcher at CeSOS, *CRI Sustainable Arctic Marine and Coastal Technology* (SAMCoT), and AMOS.

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**DR MORTEN BREIVIK** has an MSc (2003) and a PhD (2010) in Engineering Cybernetics from NTNU in Trondheim, Norway.

*Dr Morten Breivik*
*Department of Engineering Cybernetics, NTNU*

From 2003 to 2006, he was employed as a PhD scholar at NTNU's Centre for Ships and Ocean Structures (CeSOS), including a period as a Fulbright scholar at the University of California, Santa Barbara (UCSB) in 2005-2006. Breivik was an Assistant Professor at NTNU's Department of Engineering Cybernetics (ITK) in 2006-2008 and at the Department of Marine Technology (IMT) in 2008-2010. He also worked as a researcher at CeSOS in 2008-2011 and as a scientific advisor and collaborator for Maritime Robotics in 2007-2011. At NTNU, Breivik acquired experience as a researcher, teacher, and supervisor at a leading international level.

In August 2011, he was employed as a Principal Engineer at Kongsberg Maritime (KM) in Kongsberg, Norway. Beginning in January 2012, he was responsible for building and leading a cybernetics R&D group in KM, focusing on advanced industrial products within dynamic positioning and automation. At KM, Breivik acquired experience as an engineer and R&D manager at an internationally leading company in the maritime industry. In September 2013, he returned to NTNU as Head of ITK and is also an Affiliated Scientist at AMOS. Breivik has research expertise in applied control systems, particularly concerning motion control of marine vehicles.

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# Interviews with PhD Candidates

## – Challenging, social, and fun

••• I want to do my share of saving the world

**NAME: IDA MARLEN STRAND**
**AGE: 26**

**Title of thesis:**
External Sea Loads and Internal Hydraulics of Closed Flexible Fish Cages.

**How much time left in the programme:** 2.5 years.
**Where are you from:** Innset, a small neighbourhood located near the intersection of two highways.

***How is it to be a student in AMOS?***
Challenging, social, and fun.

Is it a challenge that there are so few women, and what can be done to increase the number? No, not really. After five years at AMOS with 80% men, I am used to it. The most important factor for me is that I can talk, discuss, and laugh together with my colleagues, and this is independent of gender. I feel that AMOS has a good social culture, so I have found what I need.

Before I started my PhD, I spoke to some of the girls in my class, and one of them said: "I could not have started a PhD; I am too social to risk sitting only among antisocial foreigners." Keep up the good social work, so it is visible that we are not antisocial nerds sitting alone in our offices.

Then, more social persons will come, and among them, likely also some more women.

*Why did you choose to become a PhD student?*
Because I wanted to learn more and because I have long played with the idea that earning a PhD was something I wanted to do, and now was the best time. I also want to do my share of saving the world.

*What is the best thing about being a PhD?*
The satisfaction obtained by solving problems that actually matter; freedom to plan my own day; and having the possibility to travel to conferences around the world and telling others about my work.

*What is the worst thing about being a PhD?*
Being stuck! Not being able to solve those problems and having close deadlines.

*Is it worth it?*
Are you asking if it is worth it to go home at night and still think about loads on membranes? I really hope so!

*What is your primary field at AMOS?*
I am located under the project called "Intelligent offshore aquaculture structures", so my project is located in the borderline between hydrodynamics, structural loads, and cybernetics.

*What are your plans for the future?*
Get the best out of my years here at AMOS and then leave for the world.

## – I am very proud of being an AMOS student

••• Norwegian people are very friendly and warm-hearted

**NAME: YUGAO SHEN**
**AGE: 25**

**PhD-programme/name of programme:**
Limiting operational conditions for well boats
**How much time left in the programme:** 2.5 years
**Where are you from:** China

*How is it to be a student in AMOS? Is it a challenge that there are so few women, and what can be done to increase the number?*
I am very proud of being an AMOS student. My colleagues outside AMOS often express their admiration for AMOS's comfortable study environment, pleasant parties, and abundant fun.

Yeah, of course it is difficult to have so few women at AMOS. Nobody can deny beautiful ladies, so the centre should promote that there are many gentlemen to attract women.

*Why did you choose to become a PhD student?*
I feel that I still know so little about the area in which I am working, so I decided to further my education.

*What is the worst thing about being a PhD?*
Being a PhD, you need to overcome loneliness and the unclear future of your project.

*Is it worth it?*
Yes, of course. After completing a PhD, you are not who you were before.

*What is your primary field at AMOS?*
Working on a fish farming system and limiting the manoeuvring and sea keeping of well boats.

*What are your plans for the future?*
Working at a research institution in Norway to gain international experience.

*How is it to live in Norway?*
It is pleasant to live in Norway. The country has a peaceful lifestyle and great environment, except for the darkness in winter.

*What is your impression of Norwegian people?*
Norwegian people are very friendly and warm-hearted. One time I went to the supermarket without bringing any money, and a Norwegian just gave me money and left.

# Appendices 2013

# AMOS Personnel and Collaborators

## Management and administration

| Name | Title | Acronym |
|---|---|---|
| Professor Sørensen, Asgeir J. | Director | AJS |
| Professor Fossen, Thor I | Co-Director | TIF |
| Dr Schjølberg, Ingrid | Project Director | IS |
| Wold, Sigrid Bakken | Executive Officer | SBW |

## Key scientists

| Name | Institution, department | Main field of research | Acronym |
|---|---|---|---|
| Professor Fossen, Thor I. | NTNU, Department of Engineering Cybernetics | Guidance, navigation and control | TIF |
| Professor Amdahl, Jørgen | NTNU, Department of Marine Technology | Structural load effects, resistance, accidental actions | JA |
| Professor Greco, Marilena | NTNU, Department of Marine T echnology | Marine hydrodynamics | MG |
| Professor Johansen, Tor Arne | NTNU, Department of Engineering Cybernetics | Optimisation and estimation in control | TAJ |
| Professor Pettersen, Kristin Y. | NTNU, Department of Engineering Cybernetics | Automatic control | KYP |
| Professor Sørensen, Asgeir J. | NTNU, Department of Marine Technology | Marine control systems | AJS |
| Professor Schjølberg, Ingrid | NTNU, Department of Marine Technology | Underwater robotics | IS |

## Affiliated scientists

| Name | Institution, department | Main field of Research | Acronym |
|---|---|---|---|
| Dr Breivik, Morten | NTNU, Engineering Cybernetics | Unmanned systems, automatic control | MB |
| Professor Imsland, Lars S. | NTNU, Department of Marine Technology | Automatic control, optimization | LSI |
| Professor Skjetne, Roger | NTNU, Department of Marine Technology | Marine control systems | RS |
| Professor Utne, Ingrid B. | NTNU, Department of Marine Technology | Safety critical systems and systems engineering | IBU |

## Adjunct professor

| Name | Institution, department | Main field of Research | Acronym |
|---|---|---|---|
| Professor Blanke, Mogens | Technical University of Denmark | Fault-tolerant control | MB |

## Senior scientific advisors

| Name | Institution, department | Main field of Research | Acronym |
|---|---|---|---|
| Professor Faltinsen, Odd M | NTNU, Department of Marine Technology | Marine hydrodynamics | OF |
| Professor Moan, Torgeir | NTNU, Department of Marine Technology | Marine structures | TM |

## Researcher

| Name | Institution, department | Acronym |
|---|---|---|
| Professor Tymokha, Oleksandr | NTNU, Department of Marine Technology | OT |

## PhD candidates with financial support from AMOS

| Name | Period | Supervisor | Topic |
|---|---|---|---|
| Belleter, Dennis | 08.2013-08.2016 | KYP | Marine multi-agent control systems |
| Hanssen, Finn-Christian W. | 08.2013-08.2016 | MG | Nonlinear wave loads on marine structures in extreme sea states |
| Klausen, Kristian | 05.2013-08.2016 | TIF | Deployment, search, and recovery of marine sensors using multiple rotary-wing UAVs |
| Leira, Fredrik Stendahl | 06.2013-06.2016 | TIF | Infrared object detection and tracking in UAVs |
| Merz, Mariann | 12.2013-08.2016 | TAJ | Deployment, search, and recovery of marine sensors using a fixed-wing UAV |
| Nornes, Stein M. | 08.2013-08.2016 | AJS | Simultaneous mapping, navigation, and monitoring with unmanned underwater vehicles using sensor fusion |
| Shen, Yugao | 08.2013-08.2016 | MG | Limiting operational conditions for a well boat |
| Sørensen, Kim Lynge | 06.2013-05.2016 | TAJ | Anti-icing/de-icing of UAVs |
| Ødegård, Øyvind | 08.2013-08.2017 | 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 | Supervisor | Topic |
|---|---|---|---|
| Albert, Anders | 08.2013-08.2017 | LSI | Mission and path optimisation for mobile sensor network operations |
| Borup, Kasper | 05.2013-05.2016 | TIF | Model-Based nonlinear integration filters for INS and position measurements |
| Bryne, Torleiv H. | 08.2013-08.2016 | TIF | Optimal sensor fusion for marine vessels using redundant i nertial and position sensors |
| Bø, Torstein I. | 05.2013-07.2016 | TAJ | Power management based on model predictive control |
| Candeloro, Mauro | 09.2011-08.2015 | AJS | Autonomous operations for underwater vehicles using sensor fusion and vision systems |
| Dahl, Andreas R. | 08.2013-08.2016 | RS | Nonlinear and fault-tolerant control of electric power production in Arctic DP vessels |
| Dukan, Fredrik | 01.2010-01.2014 | AJS | Automatic control of remotely operated vehicles |
| Fernandes, Daniel De Almeida | 08.2010-08.2014 | AJS | Topics in the guidance, navigation, and control of unmanned underwater vehicles |
| Fusini, Lorenso | 01.2012-12.2015 | TIF | Robust UAV attitude navigation system for marine operations using nonlinear observers and camera measurements |
| Hansen, Jakob Mahler | 08.2013-07.2016 | TIF | Nonlinear observers for the tight integration of IMU and GNSS pseudo-range and carrier-phase-ambiguity resolution |
| Jørgensen, Ulrik | 08.2010-03.2014 | RS | Autonomous underwater ice observation system |
| Moe, Signe | 08.2013-07.2016 | KYP | Control systems for the interaction of underwater vehicles |
| Norgren, Petter | 03.2013-04.2017 | RS | Autonomous underwater vehicles for operations under ice: subsurface monitoring of sea ice and icebergs |
| Rejani Miyazaki, Michel | 05.2013-05.2017 | AJS | Energy management of hybrid electric power plants |
| Rogne, Robert | 08.2013-07.2016 | TAJ | Fault-tolerant sensor fusion by exploiting redundant inertial measurements |
| Strand, Ida | 08.2013-07.2016 | AJS | External sea loads and internal hydraulics of a closed flexible cage |
| Storheim, Martin | 09.2011-08.2015 | JA | Structural resistance of ships and offshore structures to extreme ice loads and other accidental events |
| Kim, Ekaterina | 01.2010-05.2014 | JA | Experimental and numerical studies related to the coupled behaviour of ice mass and steel structures during accidental collisions |
| Walter, Caharija | 01.2011-05.2014 | KYP | Guidance and control of autonomous marine systems |
| Eleni, Kelasidi | 03.2012-03.2015 | KYP | Underwater snake robots |

# Facts and Figures 2013

## Number of researchers and personnel man-years

| Nationality | Key professors | Adjunct professors | Scientific advisors | PostDocs/ researchers | PhD | Assoc. PhD | Adminis-trative | SUM |
|---|---|---|---|---|---|---|---|---|
| Norwegian | 5 | | 2 | | 7 | 10 | 4 | 28 |
| Other nationalities | 1 | 1 | | 1 | 2 | 10 | | 15 |
| SUM | 6 | 1 | 2 | 1 | 9 | 20 | 4 | 43 |
| Man-eyars | 3,5 | 0,3 | 0,5 | 0,6 | 3,7 | 14,6 | 1,9 | 25,1 |

*incl. associated PhD candidates

## Total man-year efforts

| **Man-years** | **2013** |
|---|---|
| Centre director | 0,3 |
| Co-director | 0,2 |
| Project Director | 0,7 |
| Adm.personnel | 0,2 |
| Technical staff | 1,0 |
| **Summary** | **2,4** |
| | |
| Key scientists | 3,8 |
| Researchers/Post-docs | 0,6 |
| Phd students*) | 18,3 |
| **Summary** | **22,7** |
| **Total** | **25,1** |

*) incl. personnel associated with AMOS with other financial support

## Annual accounts

| **Amount in NOK 1000** | **Note** | **Accounted income and costs** | **Budget** |
|---|---|---|---|
| **Operating income** | | | |
| The Research Council of Norway | | 5 846 | 5 846 |
| NTNU | 1 | 13 777 | 15 346 |
| Others | 2 | 4 200 | 9 300 |
| Sum operating income | | 23 823 | 30 492 |
| | | | |
| **Operating costs** | | | |
| Salary and social costs | 3 | 19 316 | 13 689 |
| Equipment investments | 4 | 426 | 900 |
| Procurement of R&D services | | 0 | 7500 |
| Other operating costs | 5 | 4 295 | 8 403 |
| Sum operating costs | | 24 038 | 30 492 |
| | | | |
| **Year end allocation** | | -215 | 0 |
| Closing balance 2013 | | -215 | |

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

# Research and Education

## New educational programme at NTNU

Master's degree in Cybernetics and Robotics with a major in Autonomous Systems.

## Master courses

| Code | Subject | Professor in charge |
|---|---|---|
| TMR4240 | Marine control systems | Asgeir J. Sørensen |
| TMR4290 | Marine electric power and propulsion systems | Roger Skjetne |
| TMR4243 | Marine control systems | Roger Skjetne |
| TMR 4167 | Marine technology structures | Jørgen Amdahl |
| TMR 4195 | Design of offshore structures | Jørgen Amdahl |
| TMR 4205 | Buckling and collapse of marine structures in steel and aluminium | Jørgen Amdahl |
| TMR4215 | Sea loads | Marilena Greco |
| TMR4217 | Hydrodynamics of high-speed marine vehicles | Marilena Greco |
| TTK4109 | Guidance and control of vehicles | Thor I. Fossen |
| TTK4115 | Linear system theory | Tor Arne Johansen |
| TTK4150 | Nonlinear systems | Kristin Y. Pettersen |
| TTK4130 | Modelling and simulation | Lars S. Imsland |
| TMR4260 | Operation and maintenance | Ingrid B. Utne |

## PhD courses

| Code | Subject | Professor in charge |
|---|---|---|
| MR8500 | Advanced topics in marine control systems | Asgeir J. Sørensen and Roger Skjetne |
| TK8109 | Advanced topics in guidance and navigation | Thor I. Fossen |
| TK8102 | Nonlinear observer design | Kristin Y. Pettersen |

## Master's degrees in 2013

| MSc student | Topic | Supervisor: |
|---|---|---|
| Rosenlund, Even | Nonlinear hydrodynamic effects for bottom-fixed wind turbines. | Marilena Greco |
| Geyssel, Johannes | Numerical and experimental investigation of parametric roll. | Marilena Greco |
| Johannessen, Peter and Jordal, Lars Otto | Statistical analysis of design loads for a vessel: slamming loads. | Marilena Greco |
| Luo, Yi | Numerical investigation of wave-body interactions in shallow water. | Marilena Greco |
| Moe, Signe | Path following of underactuated marine vessels in the presence of ocean currents. | Kristin Y. Pettersen |
| Øvrebø Paal, Lohne | Study of critical imaging parameters and variables for environmental monitoring using an ROV with experimental results. | Asgeir Johan Sørensen |
| Fossum, Trygve | Analysis and control of drilling riser dynamics in dual gradient drilling. | Asgeir Johan Sørensen |
| Strand, Ida Marlen | Modelling of hydroelastic response of closed flexible fish cages due to sea loads | Asgeir Johan Sørensen |
| Meese, Andreas Nordby | Analysis of ice-induced vibrations and comparison with full-scale experimental data | Jørgen Amdahl |

| | | |
|---|---|---|
| Bøhlerengen, Simen | Probabilistic material modelling of icebergs for analysis of accidental impacts with ships and offshore structures | Jørgen Amdahl |
| Stokkeland Storås, Lina Marie | Steel weight optimisation with respect to stiffener spacing and plate thickness of mid-ship structures for cargo vessels | Jørgen Amdahl |
| Myhre, Torstein | Iceberg shape characterisation for damage assessment of accidental impacts with ships and offshore structures | Jørgen Amdahl |
| Richardsen, Truls Dahl | Structural mechanics and numerical simulation of ship grounding | Jørgen Amdahl |
| Ma, Yao | Ductility limits for tubular joints | Jørgen Amdahl |
| El Jaaba, Mustapha | Structural resistance of polar ships to ice loading<br>Discussion of the IACS polar rules considering different structural and methodological aspects | Jørgen Amdahl<br>Jørgen Amdahl |
| Sætre, Jan Børge Mork | Collisions between the platform deck and service vessel wheelhouse | Jørgen Amdahl |
| Alvenes, Fredrik | Attitude observer-controller design for the NTNU test satellite | Thor I. Fossen |
| Bryne, Torleiv Håland | Fault-tolerant sensor fusion based on inertial measurements and GNSS | Thor I. Fossen |
| Dahl, Andreas | Path planning and guidance for marine surface vehicles | Thor I. Fossen |
| Dybsjord, Kerrin Andre | Fault-tolerant UAV flight control system | Thor I. Fossen |
| Klausen, Kristian | Cooperative behavioural control for omni-wheeled robots: experiments and simulations for formation control with obstacle and collision avoidance | Thor I. Fossen |
| Leira, Frederik Stendahl | Infrared object detection and tracking using UAVs | Thor I. Fossen |
| Sørbø, Eivind Hope | Vehicle collision avoidance system | Thor I. Fossen |
| Dælen, Jon | Nonlinear model predictive control using derivative-free optimisation. | Tor Arne Johansen |
| Nerbø, Viktor Mevold | Power management system for offshore cranes | Tor Arne Johansen |
| Rindarøy, Martin | Fuel optimal thrust allocation in dynamic positioning | Tor Arne Johansen |
| Løkseth, Espen | State monitoring of ship thruster systems | Tor Arne Johansen |
| Wold, Henrik Emil | Thrust allocation for DP in ice | Lars Struen Imsland |
| Wilhelmsen, Matias | Control structure and tuning method design for suppressing multi-phase disturbance | Lars Struen Imsland |
| Vintervold, Ylva Stokke | Camera-based integrated indoor positioning | Lars Struen Imsland |
| Raaen, Håvard Håkon | Software infrastructure for a UAV testbed for ice management guidance and estimation | Lars Struen Imsland |
| Rønneberg, Frode | Techniques for efficient covariance propagation in the extended/ unscented Kalman filter | Lars Struen Imsland |
| Møgster, Johannes | Bruk av MPC for MPD | Lars Struen Imsland |
| Mørk, Anders Jordtveit | Estimation of water formation rate using unscented Kalman filtering with application to the snøhvit gas/condensate field | Lars Struen Imsland |
| Hetland, Anders | Estimation of sea ice drift velocity | Lars Struen Imsland |
| Kristoffersen, Torstein T. | Optimal and stable production of high-pressure steam | Lars Struen Imsland |
| Ljones, Tone | Drilling mud property estimator | Lars Struen Imsland |

# Innovation

### Training

| Date | Activity | Participants |
|---|---|---|
| 30.09.13 | Kick-off and introduction to innovation<br>• This is AMOS, *Project Director Dr Ingrid Schjølberg*<br>• How to ensure excellence in our research, *Centre Director Prof. Asgeir J. Sørensen*<br>• Innovation at NTNU, *Pro-rector Prof. Johan Hustad*<br>• What is innovation? And why is it so exciting? *Professor of Innovation at the Institute of Industrial Economics NTN, Alf Steinar Sætre*<br>• Speed dating among all PhDs. Introduction to each other. *By the Senior Adviser, Rector's Staff for Innovation at NTNU, Camilla Prytz* | PhD candidates<br>Key personnel<br>Guests |

# Workshops 2013

| Date | Work shop | Topic |
|---|---|---|
| 10–12 April 2013 | AUR-Lab Workshop at Svalbard, UNIS | Underwater mapping, monitoring and robotics |
| 21 May 2013 | AMOS Days with partners | Review of research strategy and plans with AMOS partners; Statoil, DNV, MARINTEK, SINTEF Fisheries and Aquaculture and SINTEF ICT |
| 27–29 May 2013 | CeSOS Highlights and AMOS Visions | Highlights from 10 years of CeSOS research and opening seminar of AMOS.Highlights from 10 years of CeSOS |

# Guest Lectures and Seminars by Visitors to AMOS

| Date | Speaker | Title |
|---|---|---|
| 12 March 2013 | Guest lecture by Professor Maruthi R. Akella - University of Texas at Austin. | Autonomous control systems for UAV. |
| 10 June 2013 | Guest lecture by Dr Phil McGillivary, US Coast Guard. | Marine and arctic challenges with AUV, UAV and other technologies. |
| 9 September 2013 | Guest lecture by Professor Andrew R. Teel, UCSB | UCSB on stochastic hybrid systems with an application to global almost sure synchronization of planar orientation. |
| 9–20 September 2013 | Seminar by Professor Andrew Teel, UCSB | Hybrid dynamical systems |
| 15 October 2013 | Guest lecture by Dr Rune Storvold. | NORUT on NORUT's technical and operational experience with UAVs for remote sensing. |
| 15 November 2013 | Guest lecture by Dr Francesco Di Corato – University of Pisa. | On a unified framework for constrained visual-inertial navigation. |

# Publication and Dissemination 2013

## Journals

**Bouscasse, Benjamin; Antuono, Matteo; Colagrossi, Andrea; Lugni, Claudio.** Numerical and Experimental Investigation of Nonlinear Shallow Water Sloshing. *Int. J. Nonlinear Sci. Numer. Simul.,* 2013.

**Caharija, Walter; Pettersen, Kristin Y.; Sørensen, Asgeir J.; Candeloro, Mauro; Gravdahl, Jan Tommy.** Relative Velocity Control and Integral Line of Sight for Path Following of Autonomous Surface Vessels: Merging Intuition with Theory**.** *Journal of Engineering for the Maritime Environment, Part M,* 2013.

**Faltinsen, O. M.; Timokha, A. N.** Multimodal analysis of weakly nonlinear sloshing in a spherical tank. Journal of Fluid Mechanics, 719, pp. 129-164, 2013.

**Galeazzi, Roberto; Blanke, Mogens; Poulsen, Niels Kjølstad.** Early Detection of Parametric Roll Resonance on Container Ships. *IEEE Transactions on Control Systems Technology.* Vol. 21(2) pp. 489-503, 2013.

**Gavrilyuk, I.; Hermann, M.; Lukovsky, I.; Solodun, O.; Timokha, A.** Weakly-nonlinear sloshing in a truncated circular conical tank. Fluid Dynamics Research, 45, Paper ID 055512, pp. 1-30, 2013.

**Gavrilyuk, I.; Hermann, M.; Trotsenko, Yu.; Timokha, A.** Studying the coupled eigenoscillations of an axisymmetric tower-elevated tank system by the multimodal method. Journal of Fluids and Structures, 42, pp. 152-165, 2013

**Greco, Marilena; Colicchio, Giuseppina; Lugni, Claudio; Faltinsen, Odd M.** 3D Domain Decomposition for Violent Wave-Ship Interactions. *Int. J. for Numerical Methods in Engineering*, 2013, Vol. 95, pp. 661-684.

**Grenier, Nicolas; Le Touzé, David; Colagrossi, Andrea; Antuono, Matteo; Colicchio, Giuseppina.** Viscous bubbly flows simulation with an interface SPH model, *Ocean Engineering*. 2013, Vol. 69, pp. 88-102.

**Johansen, Tor Arne; Fossen, Thor I.** Control Allocation - A Survey. *Automatica* 2013; Vol. 49(5), pp. 1087-1103.

**Lekkas, A. M., A. R. Dahl, M. Breivik and T. I. Fossen.** Continuous-Curvature Path Generation using Fermat's Spiral. *Modelling, Identification and Control***.** Vol. 34, No. 4, 2013, pp. 1-14,

**Le Touzé, David; Colagrossi, Andrea; Colicchio, Giuseppina; Greco, Marilena.** A critical investigation of Smoothed Particle Hydrodynamics applied to problems with free-surfaces. *International Journal for Numerical Methods in Fluid.* 2013, Vol. 73.

**Liljebäck, Pål; Pettersen, Kristin Y.; Stavdahl, Øyvind.; Gravdahl, Jan Tommy.** Lateral Undulation of Snake Robots: A simplified model and fundamental properties. *Robotica***,** Vol. 31, pp. 1005-10036, 2013.

**Marino, Enzo; Lugni, Claudio; Borri, Claudio.** A novel numerical strategy for the simulation of irregular nonlinear waves and their effects on the dynamic response of offshore wind turbine. *Comput. Methods Appl. Mech. Engrg.* 2013, Vol. 255, pp. 275-288.

**Marino, Enzo; Lugni, Claudio; Borri, Claudio.** The role of the nonlinear wave kinematics on the global response of an OWT in parked and operation conditions. *, J. Wind Eng. Ind. Aerodyn.* 2013, Vol. 123, pp. 363–376.

## Book chapters

**Amdahl, Jørgen; Ehlers, Søren; Leira, Bernt Johan (editors).** *Collision and Grounding of Ships and Offshore Structures***,** CRC Press/Balkema - Proceedings and Monographs in Engineering, Water and Earth Sciences, Taylor & Francis Group, ISBN: 978-1-315-88489-9 (e-book), 2013.

**Lekkas, Anastasios; Fossen, Thor I.** Line-of-Sight Guidance for Path Following of Marine Vehicles. Line-of-Sight Guidance for Path Following of Marine Vehicles. Chapter 5, In *"Advanced in Marine Robotics"*, LAP LAMBERT Academic Publishing (O. Gal, Ed.), 2013, pp. 63-92. ISBN 978-3-659-41689-7.

## Conference papers

**Amdahl, Jørgen; Storheim, Martin.** Design of Offshore Installations against Ship Collision Based on Interaction Analysis, *Proc. Of the 12th Int. Symp. on Practical Design of Ships and Other Floating Structures (PRADS2013)*, Changwon City, South Korea, 20-25 October, 2013

**Auestad, Øyvind Fidje; Gravdahl, Jan Tommy; Fossen, Thor I.** Heave Motion Estimation on a Craft Using a Strapdown Inertial Measurement Unit. *Proc. of the 9th IFAC Conference on Control Applications in Marine Systems (CAMS'2013)*, Osaka, Japan, September, 2013**.**

**Auestad, Øyvind Fidje; Gravdahl, Jan Tommy; Sørensen, Asgeir Johan; Halvorsen, Trygve Espeland.** Simulator and Control System Design of a Free Floating Surface Effect Ship at Zero Vessel Speed. *Proc. of the 9th IFAC Conference on Control Applications in Marine Systems (CAMS'2013)*, Osaka, Japan, September, 2013.

**Belleter, Dennis; Breu, Dominik Andreas; Fossen, Thor I.; Nijmeijer, H. A** Globally K-Exponentially Nonlinear Observer for Wave Encounter Frequency. *Proc. of the 9th IFAC Conference on Control Applications in Marine Systems (CAMS'2013)*, Osaka, Japan, September, 2013.

**Bjerkeng, Magnus; Falco, Pietro; Natale, Ciro; Pettersen, Kristin Y.** Discrete-Time Stability Analysis of a Motion Control Architecture for Heterogeneous Robotic Systems. *Proc. IEEE/RSJ International Conference on Intelligent Robots and Systems*, Tokyo, Japan, Nov. 2013.

**Bouscasse, Benjamin; Antuono, Matteo; Colagrossi Andrea; Lugni Claudio.** A study of nonlinear shallow water sloshing. *32nd Int. Conference on Offshore Mechanics and Arctic Engineering* (OMAE'13), Nantes, 2013.

**Bø, Torstein Ingebrigtsen; Johansen, Tor Arne.** Scenario-Based Fault-Tolerant Model Predictive Control for Diesel-Electric Marine Power Plant. OCEANS'13 MTS/IEEE, Bergen, Norway, 10-14 June, 2013.

**Bø, Torstein Ingebrigtsen; Johansen, Tor Arne.** Scenario-Based Fault-Tolerant Model Predictive Control for Diesel-Electric Marine Power Plant. OCEANS'13 MTS/IEEE, Bergen, Norway, 10-14 June, 2013.

**Bø, Torstein Ingebrigtsen; Johansen, Tor Arne; Mathiesen, Eirik. U**nit Commitment of Generator Sets During Dynamic Positioning Operation Based on Consequence Simulation. *Proc. of the 9th IFAC Conference on Control Applications in Marine Systems (CAMS'2013)*, Osaka, Japan, September, 2013.

**Caharija, Walter; Pettersen, Kristin Ytterstad; Gravdahl, Jan Tommy.** Counter-Current and Co-Current Guidance of Underactuated Unmanned Marine Vehicles. IFAC Symposium on Intelligent Autonomous Vehicles; 2013.

**Caharija, Walter; Pettersen, Kristin Ytterstad; Gravdahl, Jan Tommy.** Path Following of Marine Surface Vessels with Saturated Transverse Actuators. *Proceedings of the American Control Conference (ACC'2013)*, Washington DC, 17-19 June.

**Caharija, Walter; Pettersen, Kristin Ytterstad; Gravdahl, Jan Tommy.** Path Following of Underactuated Surface Vessels in Presence of Unknown Constant Environmental Forces: Preliminary Results. *Proc. of the 9th IFAC Conference on Control Applications in Marine Systems (CAMS'2013)*, Osaka, Japan, September, 2013.

**Candeloro, Mauro; Lekkas, Anastasios; Sørensen, Asgeir Johan; Fossen, Thor I.** Continuous Curvature Path Planning using Voronoi diagrams and Fermat's spirals. *Proc. of the 9th IFAC Conference on Control Applications in Marine Systems (CAMS'2013)*, Osaka, Japan, September, 2013.

**Cristofaro, Andrea; Johansen, Tor Arne.** Fault-tolerant control allocation: an Unknown Input Observer based approach with constrained output fault directions. *IEEE Proceedings of the Conference on Decision and Control (CDC'13)*, Florence, Italy, December, 2013.

**Colicchio, Giuseppina; Greco, Marilena; Faltinsen Odd M.; Brocchini, Maurizio.** Gas cavity-body interactions: efficient numerical solution. *Euromech Colloquium 555 Small-scale numerical methods for multi-phase flows*, Pessac, France, 2013.

**Colicchio, Giuseppina; Greco, Marilena; Faltinsen Odd M.** A numerical strategy for gas cavity-body interactions from acoustic to incompressible liquid phases. *28th Int. Workshop on Water Waves and Floating Bodies*, France, 2013.

**Dukan, Fredrik; Sørensen, Asgeir J.** Integration Filter for APS, DVL, IMU and Pressure Gauge for Underwater Vehicles. *Proc. of the 9th IFAC Conference on Control Applications in Marine Systems (CAMS'2013)*, Osaka, Japan, September, 2013.

**Faltinsen, O. M.; Timokha, A. N.** Nonlinear sloshing in a spherical tank.ASME 2013 32nd International Conference on Ocean, Offshore and Arctic Engineering, June 9-14, 2013, Nantes, France. Volume 9: Odd M. Faltinsen: Honoring Symposium on Marine Hydrodynamics (ISBN: 978-0-07918-5543-0), OMAE2013-10036 pp. V009T12A001

**Fernandes, Daniel de Almeida; Sørensen, Asgeir Johan; Donha, Decio C.** Trajectory Tracking Motion Control System for Observation Class ROVs. *Proc. of the 9th IFAC Conference on Control Applications in Marine Systems (CAMS'2013)*, Osaka, Japan, September, 2013.

**Forsmo, Erik Johannes; Grøtli, Esten Ingar; Fossen, Thor I.; Johansen, Tor Arne.** Optimal search mission with Unmanned Aerial Vehicles using Mixed Integer Linear Programming. *Proc. of the 2013 International Conference on Unmanned Aircraft Systems (ICUAS'13),* Atlanta, GA, on May 28-31, 2013.

**Galeazzi, Roberto; Gryning, Mikkel; Blanke, Mogens.** Observer Backstepping Control for Variable Speed Wind Turbine. *Proceedings of the American Control Conference (ACC' 2013)*, Washington DC, 17-19 June.

**Grancharova, Alexandra; Grøtli, Esten Ingar; Johansen, Tor Arne.** Rotary-Wing UAVs Trajectory Planning by Distributed Linear MPC with Reconfigurable Communication Network Topologies. Proc. of the IFAC Workshop on Distributed Estimation and Control in Networked Systems; September, 2013.

**Greco, Marilena; Lugni, Claudio.** Numerical study of parametric roll on a fishing vessel. *32nd Int. Conference on Offshore Mechanics and Arctic Engineering* (OMAE'13), Nantes, France, 2013.

**Grip, Håvard Fjær; Fossen, Thor I.; Johansen, Tor Arne; Saberi, Ali.** Nonlinear Observer for GNSS-Aided Inertial Navigation with Quaternion-Based Attitude Estimation. *Proceedings of the American Control Conference (ACC' 2013)*, Washington DC, 17-19 June.

**Hansen, Jakob Mahler; Blanke, Mogens; Niemann, Hans Henrik; Vejlgaard-Laursen, Morten.** Exhaust Gas Recirculation Control for Large Diesel Engines - Achievable Performance with SISO Design. *Proc. of the 9th IFAC Conference on Control Applications in Marine Systems (CAMS'2013)*, Osaka, Japan, September, 2013.

**Hansen, Søren; Blanke, Mogens.** Control surface fault diagnosis with specified detection probability – Real event experiences. *Proc. of the 2013 International Conference on Unmanned Aircraft Systems (ICUAS'13),* Atlanta, GA, on May 28-31, 2013.

**Hassani, Vahid; Sørensen, Asgeir Johan; Pascoal, Antonio.** A Novel Methodology for Robust Dynamic Positioning of Marine Vessels: Theory and Experiments. *Proceedings of the American Control Conference (ACC'2013)*, Washington DC, 17-19 June.

**Hassani, Vahid; Sørensen, Asgeir Johan; Pascoal, Antonio.** Adaptive Wave Filtering for Dynamic Positioning of Marine Vessels using Maximum Likelihood Identification: Theory and Experiments. *Proc. of the 9th IFAC Conference on Control Applications in Marine Systems (CAMS'2013)*, Osaka, Japan, September, 2013.

**Ho, Dac-Tu; Grøtli, Esten Ingar; Johansen, Tor Arne.** Heuristic Algorithm and Cooperative Relay for Energy Efficient Data Collection with a UAV and WSN. *Proc. of the International Conference on Computing, Management and Telecommunications*, 2013.

**Ho, Dac-Tu; Grøtli, Esten Ingar; Sujit, P.B.; Johansen, Tor Arne; Sousa, João.** Cluster-Based Communication Topo-

logy Selection and UAV Path Planning in Wireless Sensor Networks. *Proc. of the 2013 International Conference on Unmanned Aircraft Systems (ICUAS'13),* Atlanta, GA, on May 28-31, 2013.

**Ho, Dac-Tu; Grøtli, Esten Ingar; Sujit, P.B.; Sousa, João; Johansen, Tor Arne.** Performance Evaluation of Cooperative Relay and Particle Swarm Optimization Path Planning for UAV and Wireless Sensor Network. *IEEE Globecom 2013 Workshop - Wireless Networking and Control for Unmanned Autonomous Vehicles*; 2013.

**Holden, Christian, Pettersen, Kristin Y.; Stavdahl, Øyvind: Gravdahl, J. Tommy.** Optimal Mapping from a Continuous 3D Curve to the Position and Shape of a Snake Robot. *Proc. 2013 IEEE International Conference on Mechatronics (ICM 2013)*, Vicenza, Italy, Feb. 27 - March 1, 2013.

**Jørgensen, Ulrik; Skjetne, Roger.** Real-time 3D Reconstruction of Underwater Sea-ice Topography by Observations from a Mobile Robot in the Arctic. *Proc. of the 9th IFAC Conference on Control Applications in Marine Systems (CAMS'2013)*, Osaka, Japan, September, 2013.

**Kim, Ekaterina; Amdahl, Jørgen.** Review of Existing Methods for the Analysis of the Accidental Limit State due to Ice Actions, *Collision and Grounding of Ships and Offshore Structures – Amdahl, Ehlers & Leira (Eds) © 2013 Taylor & Francis Group, London, ISBN 978-1-138-00059-9*

**Lekkas, Anastasios; Fossen, Thor I.** A Quaternion-Based LOS Guidance Scheme for Path Following of AUVs. *Proc. of the 9th IFAC Conference on Control Applications in Marine Systems (CAMS'2013)*, Osaka, Japan, September, 2013.

**Lugni, Claudio; Bardazzi ,Andrea; Faltinsen, Odd M.; Graziani, Giorgio.** Fluid-structure interaction during wave-impact with air-entrapment in a sloshing tank, *28th Int. Workshop on Water Waves and Floating Bodies*, France, 2013.

**Lugni, Claudio; Bardazzi ,Andrea; Faltinsen, Odd M.; Graziani, Giorgio.** Hydroelastic challenges for wave-impact phenomena in sloshing flow. *32nd Int. Conference on Offshore Mechanics and Arctic Engineering* (OMAE'13), Nantes, 2013.

**Marino, Enzo; Nguyen, Hieu; Lugni, Claudio; Manuel, Lanse; Borri, Claudio.** Irregular nonlinear wave simulation and associated loads on offshore wind turbines. *32nd Int. Conference on Offshore Mechanics and Arctic Engineering* (OMAE'13), Nantes, 2013.

**Mauro, C., A. Lekkas, A. J. Sørensen and T. I. Fossen.** Continuous Curvature Path Planning using Voronoi diagrams and Fermat's spirals. *Proc. of the 9th IFAC Conference on Control Applications in Marine Systems (CAMS'2013)*, Osaka, Japan, September, 2013.

**Ludvigsen, Martin; Låge, Petter A.; Johnsen, Geir; Sørensen, Asgeir Johan; Ødegård, Øyvind.** Scientific operations combining ROV and AUV in the Trondheim Fjord. OCEANS'13 MTS/IEEE, Bergen, Norway, 10-14 June, 2013.

**Moe, Signe; Schjølberg, Ingrid.** Real-Time Hand Guiding of Industrial Manipulator in 5 DOF using Microsoft Kinect and Accelerometer. Proc. of the IEEE RO-MAN, South-Korea, August 2013.

**Nikoofard, Amirhossein; Johansen, Tor Arne; Mahdianfar, Hessam; Pavlov, Alexey.** Constrained MPC Design for Heave Disturbance Attenuation in Offshore Drilling Systems OCEANS'13 MTS/IEEE, Bergen, Norway, 10-14 June, 2013.

**Peymani, E., H. F. Grip, A. Saberi, X. Wang and T. I. Fossen.** H-infinity Almost Synchronization for Non-Identical Introspective Multi-Agent Systems under External Disturbances. *Proceedings of the American Control Conference (ACC' 2013)*, Washington DC, 17-19 June.

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**Pettersen, Kristin Ytterstad; Liljebäck, Pål; Stavdahl, Øyvind; Gravdahl, Jan Tommy.** Snake Robots - From Biology to Nonlinear Control. *Proc. of the IFAC Symposium on Nonlinear Control,* Toulouse, France, Sep. 2013.

**Raspa, Paolo; Benetazzo, F.; Ippoliti, G.; Longhi, S.; Sørensen, Asgeir J.** Experimental results of Discrete Time Variable Structure Control for Dynamic Positioning of Marine Surface Vessels. *Proc. of the 9th IFAC Conference on Control Applications in Marine Systems (CAMS'2013)*, Osaka, Japan, September, 2013.

**Rezapour, Ehsan; Pettersen, Kristin Y.; Liljebäck, Pål; Gravdahl, J. Tommy.** Path Following Control of Planar Snake Robots Using Virtual Holonomic Constraints. *Proc. of the 2013 IEEE International Conference on Robotics and Biomimetics (IEEE-ROBIO 2013),* Shenzhen, China, Dec. 2013.

**Rindarøy, Martin; Johansen, Tor Arne.** Fuel Optimal Thrust Allocation in Dynamic Positioning. *Proc. of the 9th IFAC Conference on Control Applications in Marine Systems (CAMS'2013)*, Osaka, Japan, September, 2013.

**Sanfilippo, Filippo; Hatledal, Lars Ivar; Schaathun, Hans Georg; Pettersen, Kristin Y.; Zhang, Houxiang. A Universal Control Architecture for Maritime Cranes and Robots Using Genetic Algorithms as a Possible Mapping Approach.** *Proc. of the 2013 IEEE International Conference on Robotics and Biomimetics (IEEE-ROBIO 2013),* **Shenzhen, China, Dec. 2013**.

**Schjølberg, Ingrid; Perez Garcia, Angel; Gale, Serge.** EEG control of an industrial robot manipulator. Proc. of the 4th IEEE Int. Conference on Cognitive Infocommunication,

Budapest, Hungary, 2013.

**Storheim, Martin; Amdahl, Jørgen.** Accidental Ice Management – Platform vs. Ice Breaking Supply Vessel Collision *(ISOPE2013,)* Anchorage, Alaska, USA June 30-July 5, 2013

**Strand, Ida Marlen; Sørensen, Asgeir Johan; Lader, Pål; Volent, Zsolt.** Modelling of Drag Forces on a Closed Flexible Fish Cage. *Proc. of the 9th IFAC Conference on Control Applications in Marine Systems (CAMS'2013)*, Osaka, Japan, September, 2013**.**

**Sørensen, Asgeir J.** Hydrodynamic Test Basins for Development and Testing of Marine Control Systems. Ten-Years LabOceano Celebration Workshop; UFRJ/COPPE, Rio de Janeiro, Brazil, 29th -30th April 2013.

**Sørensen, Asgeir J.** Overview of Control Levels and Integration Aspects in Energy-efficient Dynamic Positioning Systems. 1st Brazilian Conference on Dynamic Positioning, So Fundação Homem do Mar, Rio de Janeiro, Brazil, 24th – 25th April 2013.

**Theisen, Lukas Roy Svane; Galeazzi, Roberto; Blanke, Mogens.** Unmanned Water Craft Identification and Adaptive Control in Low-Speed and Reversing Regions. *Proc. of the 9th IFAC Conference on Control Applications in Marine Systems (CAMS'2013)*, Osaka, Japan, September, 2013.

**Vahid, Hassani; Pascoal, Antonio; Sørensen, Asgeir Johan.** A Novel Methodology for Marine Vessel Adaptive Wave Filtering: Theory and Experiments. In: the 25th Chinese Control and Decision Conference.

**Yum, Koosup; Pedersen, Eilif.** Transient Performance and Emission Prediction of Diesel Engine System Using Pseudo Bond Graph Model. Proc. Ninth Asia-Pacific Conference on Combustion; 2013.

## Plenary and keynote lectures

**Amdahl, Jørgen.** Analysis of Ship Collision and Grounding, V Int. Conf. on Computational Methods in Marine Engineering (MARINE2013), Hamburg, Germany, 29-31 May, 2013

**Sørensen, Asgeir J.** Overview of Control Levels and Integration Aspects in Energy-efficient Dynamic Positioning Systems. 1st Brazilian Conference on Dynamic Positioning, So Fundação Homem do Mar, Rio de Janeiro, Brazil, 24th - 25th April 2013.

## Dissemination

**Amdahl, Jørgen.** Methods for Analysis of Damage in Ship-ship and Ship-platforms Collisions, *Marine Structural Failure*, Lloyd's Maritime Academy & Information, Maritime Bonhill House, London, 10-11 September 2013

**Amdahl, Jørgen.** Developments in Boat Impact Analyses-Examples and Trends, *Seminar on Non-linear FE-methods in Structural Capacity Problems*, Det Norske Veritas, Høvik, Norge, 29 October, 2013

**Amdahl, Jørgen.** Design of Ships and Offshore Structures Against Extreme and Accidental Actions, *Invited lecture -Samsung Heavy Industries*, 24 October 2013

**Amdahl, Jørgen.** AMOS – Marine konstruksjoner og fartøys motstand mot ulykkeslaster og ekstreme miljølaster, *Marine konstruksjoner og fartøy* Norsk Petroleumsforening, Trondheim, November, 2013

**Bø, Torstein Ingebrigtsen.** Bruk av MPC i power management. *Servomøtet* 2013.

**Fossen, Thor I.** Presentation of the AMOS research projects. Norwegian Academy of Technological Sciences, 2013.

**Pettersen, Kristin Y.** Fremtiden er her. *Bilag om teknisk kybernetikk i Dagens Næringsliv,* 6. mars 2013.

**Pettersen, Kristin Y.** AMOS skal gjøre verden smartere *av Svein Inge Meland,* Adresseavisen 2013-02-26.

**Schjølberg, Ingrid.** Avansert produksjonsteknologi – muligheter i fremtidig industriproduksjon, Mørekonferansen, Molde, November, 2013

**Schjølberg, Ingrid.** Fra fremragende forskning til nyskapning-hvordan?', Topplederkonferansen,Trondheim, oktober, 2013.

**Schjølberg, Ingrid.** Robotics: enabling technology on platforms and subsea, Conference on Integrated Operations,Trondheim, Oktober, 2013.

**Schjølberg, Ingrid.** Autonom inspeksjon av havbunnsintallasjoner, Forum for strategisk inspeksjon, Trondheim, oktober, 2013.

**Schjølberg, Ingrid.** Neste generasjon intelligente farkoster for inspeksjon i ekstreme miljø, Marintekniske dager, Trondheim, oktober, 2013

**Schjølberg, Ingrid.** Norsk maritim kunnskap for fremtiden, 10års jubelium for NTNU Entrepeneurskolen, Trondheim, september, 2013

**Schjølberg, Ingrid.** AMOS and ROBOTNOR, NFA Automatisert produksjon, Ålesund, august, 2013

**Schjølberg, Ingrid.** Norge er en robotsinke, Aftenposten, August 5, 2013.

**Schjølberg, Ingrid.** Styrer roboter med tankene, Gemini, Mai, 2013.

**Schjølberg, Ingrid.** How to combine academic work and innovation? EU cities conference, Trondheim, April, 2013.

**Schjølberg, Ingrid.** Roboter roper på oppmerksomhet, Automatisering, 2013.

**Sørensen, Asgeir J. D**eep Water Operations. Seminar on R&D, Innovation and Industrialization; November 2013.

**Sørensen, Asgeir J.** Dynamic Positioning Systems - Overview and Trends. Havvindmøller - DP og Personoverførsel; October 2013.

**Sørensen, Asgeir J.** Fra forskning til innovasjon og skaperkraft. Verftskonferansen; November 2013.

**Sørensen, Asgeir J.** Greener and Safer DP Operated Ships and Rigs. Youngship Environmental Seminar; February 2013.

**Sørensen, Asgeir J.** The Conquest of the Ocean Space. Ocean Technology Summit; April 2013.

**Sørensen, Asgeir J.** Undervannsrobotikk i framtidens oppdrettsnæring. Frøya Havbrukskonferanse; March 2013.

**Sørensen, Asgeir J.** Underwater Science and Technology. AUR-Lab workshop; April 2014.

**Sørensen, Asgeir J.; Pettersen, Kristin Ytterstad; Schjølberg, Ingrid.** Dronene kommer. Forskningsdagene bilag, September 2013.

**AMOS is one of the four Centres of Excellence at NTNU**

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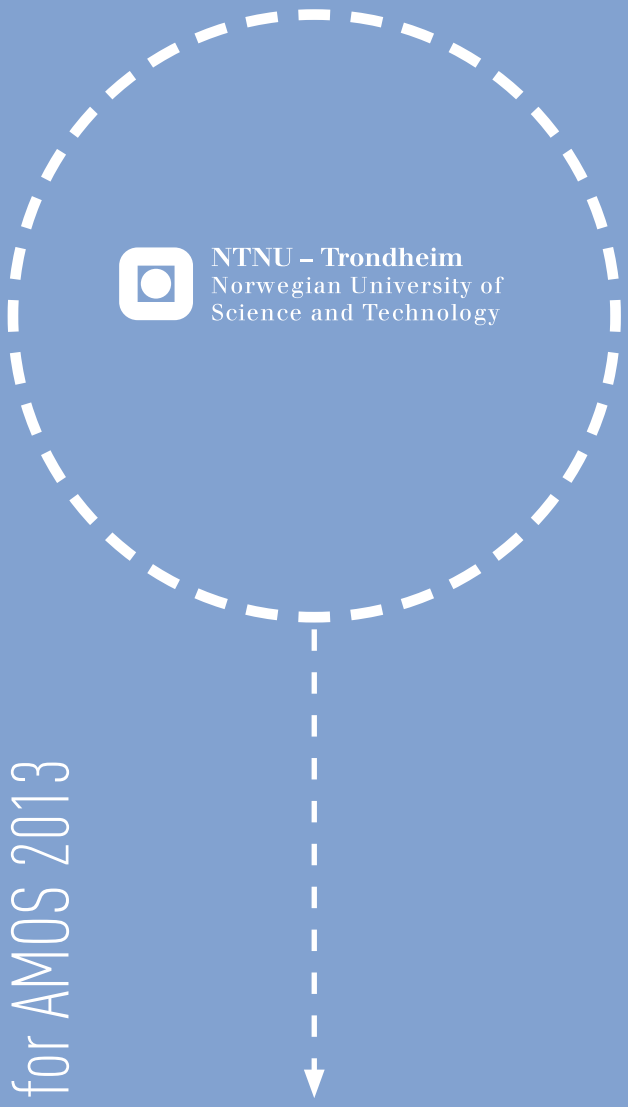


Annual Report for AMOS 2013

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The Norwegian University of Science and Technology (NTNU) has a name that reflects our national status and national responsibility in our main areas of expertise. NTNU represents academic eminence in technology and the natural sciences as well as in other academic disciplines ranging from the social sciences, the arts, medicine, architecture and the fine arts. Cross-disciplinary cooperation results in ideas no one else has thought of, and creative solutions that change our daily lives.

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