SFI
OFFSHORE
MECHATRONICS

ANNUAL REPORT 2022

UiA Universitetet i Agder

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Annual Report 2022

Summary

HISTORY

SFI Offshore Mechatronics has its origins from the Agder cooperation within the field of Mechatronics, initiated by University of Agder with partners from the local industry related to offshore engineering. This cooperation has been active for several years, and has its origin in the establishment of Master and PhD education to produce candidates for the regional and national labour market. Since then, the cooperation has developed to include R&D projects and mobility between industry companies and UiA. During the project period a strong relation between the industry partners and the other universities and research institute partners (NTNU, Aalborg University, RWTH Aachen and NORCE) have been formed.

THE RESEARCH

The main goal is to develop new concepts for autonomous systems where the construction, engineering, and design invite autonomy to minimize the number of manual processes, as well as to improve accuracy and quality, and to reduce risk and cost related to offshore engineering and operations. The research will result in enabling technologies, equipment, processes and solutions for higher degree of autonomy and monitoring of heavy machinery, and for handling and analysing large data flows under demanding conditions. The research is carried out in seven work packages: WP1 Drives, WP2 Motion Compensation, WP3 Robotics and Autonomy, WP4 Modelling and Simulation, WP5 Monitoring Techniques, WP6 Data Analytics, IT Integration and Big Data and WP7 Technology Vision.

ORGANISATION

SFI Offshore Mechatronics is hosted by UiA, Faculty of Engineering and Science. UiA is responsible for three work-packages, NTNU for two, University of Aalborg for one and NORCE for one work package. In addition, NTNU Aalesund and RWTH Aachen participate in different WPs. GCE NODE heads a non-scientific work package for technology vision. In 2022 the industrial partners have been Cameron Sense, Egde Consulting, Lundin, MacGregor, HMH (MHWirth), National Oilwell Varco, Skeie Technology Consulting and Stepchange. The SFI Offshore Mechatronics Steering board consists of 7 partners, where the industry partners hold majority. The Centre Director heads the daily operations, assisted by an administrative manager.

SCIENTIFIC ACTIVITIES AND RESULTS
Each PhD dissertation is a milestone in the SFI Offshore Mechatronics centre. In 2022, four PhD fellows defended their thesis. The number of active PhD fellows is decreasing, resulting in a reduced number scientific publications. The percentage of journal publications at the highest level (Level-2 in Norway) have remained high at 29%.

INTERNATIONAL COOPERATION
The SFI Offshore Mechatronics centre is distributed with industry and research partners across three countries (Norway, Denmark and Germany). In addition to this, the researchers in the centre utilize their extensive international networks.

RECRUITMENT
During the project period a total of 40 researcher and technicians have been recruited. At the end of 2020 all final PhD positions had been filled. In 2022 one new short term Post.Doc positions was hired.

COMMUNICATION AND DISSEMINATION ACTIVITIES
The main event for communication and dissemination in the project is the SFI Offshore Mechatronics Annual Conference. On May 19.-20. the annual conference took place in Denmark at Aalborg University. After two years of cancelled conferences due to COVID-19, the conference was a great success with good presence from both industry and research partners.

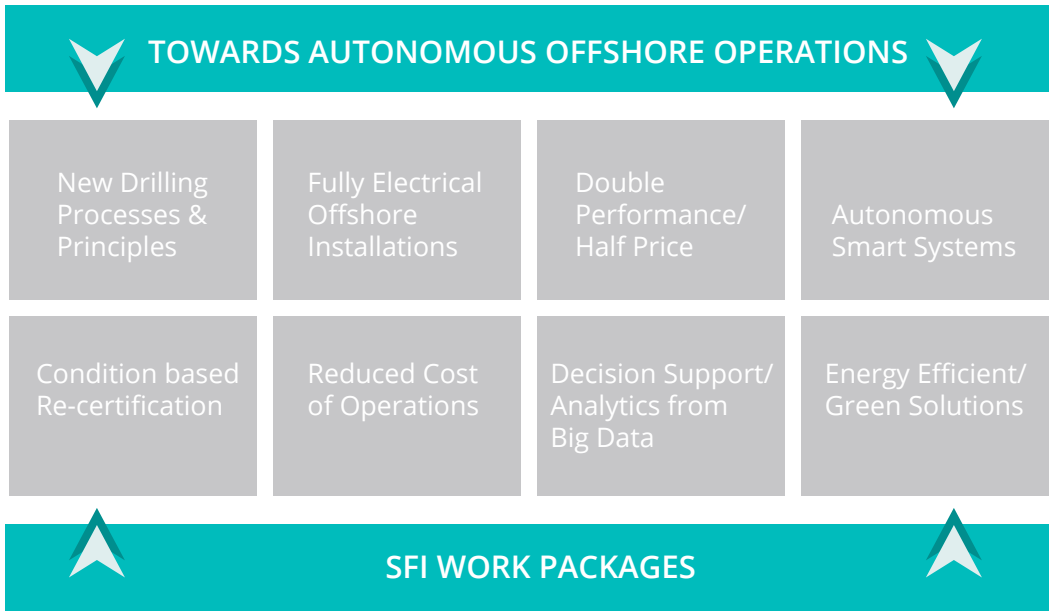
Vision and Objectives

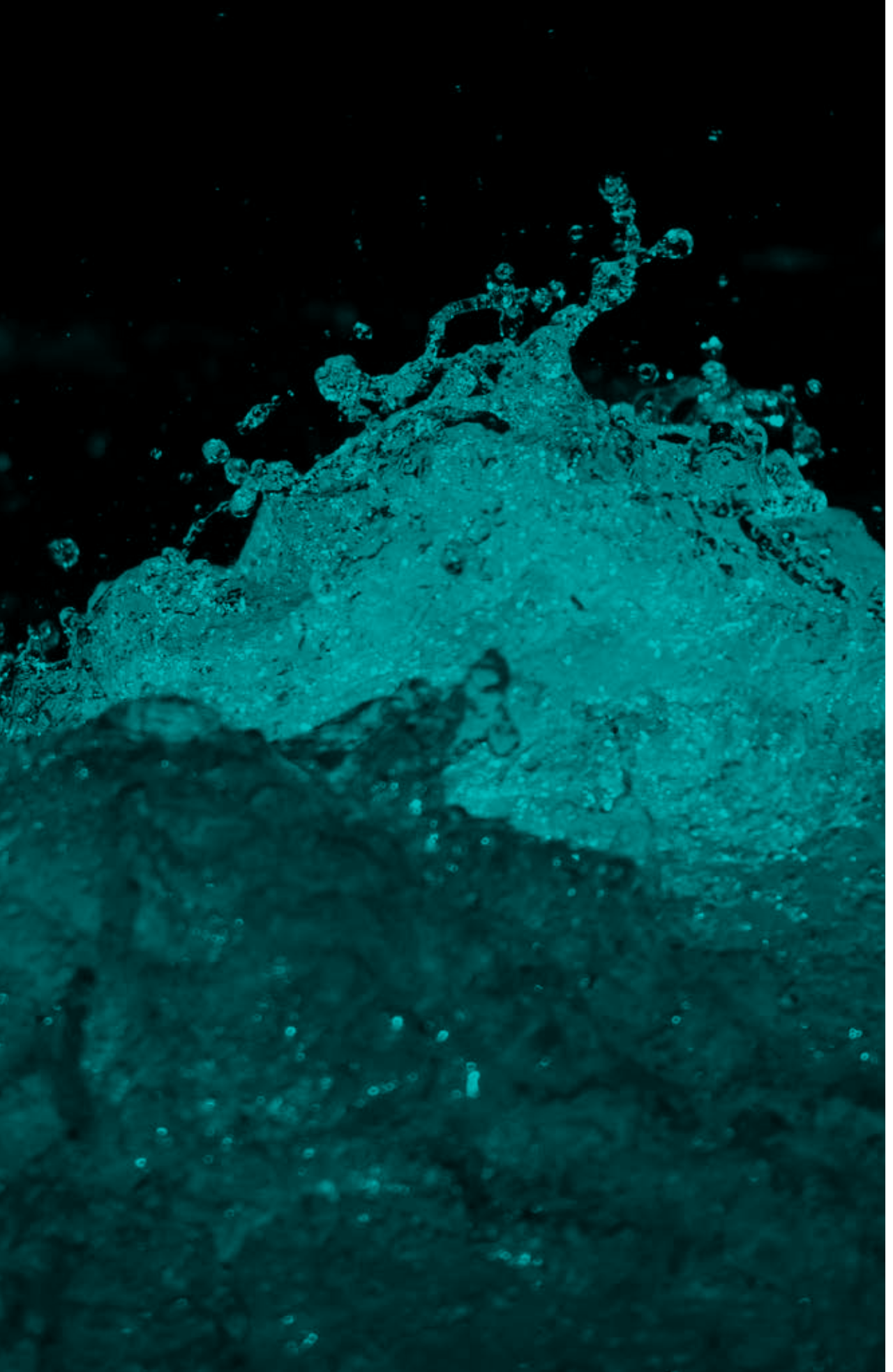
VISION
"The SFI Offshore Mechatronics will become the international knowledge and research hub for the next generation of advanced offshore mechatronic systems for autonomous operation and condition monitoring of offshore engineering systems under the control of land-based operation centres, to ensure safe and efficient operation in deeper water and in harsh environments. The centre shall contribute significantly to growth and innovation in the industry, creating jobs and business with potential both within the target sector, and beyond, such as maritime industry, with a net positive impact on society."

MISSION STATEMENT
By 2023, SFI Offshore Mechatronics shall have succeeded in becoming an internationally renowned research-based innovation centre reaching national, international and long-term targets.

National target – develop new concepts for autonomous systems where the construction, engineering, and design invite autonomy to minimize the number of manual processes, as well as to reduce risk and cost related to offshore operations.
International target – support the industry partners to strengthen the global position by developing the most efficient and safe future offshore operations.
Long-term target – enable technologies, equipment, processes and solutions for autonomy and monitoring of heavy machinery, and for handling and analysing large data flows under demanding conditions.

GRAND CHALLENGES
The grand challenges are:





Research Plan/Strategy

The research shall result in enabling technologies, equipment, processes and solutions for autonomy and monitoring of heavy machinery, and for handling and analysing large data flows under demanding conditions. Since there are several companies in the centre which operate in the same business segment, it has been decided that the researchers focus on enabling technologies and technological building blocks, rather than working too closely with product specific development.

The work is organized into seven work packages that address important challenges for the offshore industries such as;
Reliable and energy-efficient drives (WP1: Drives)

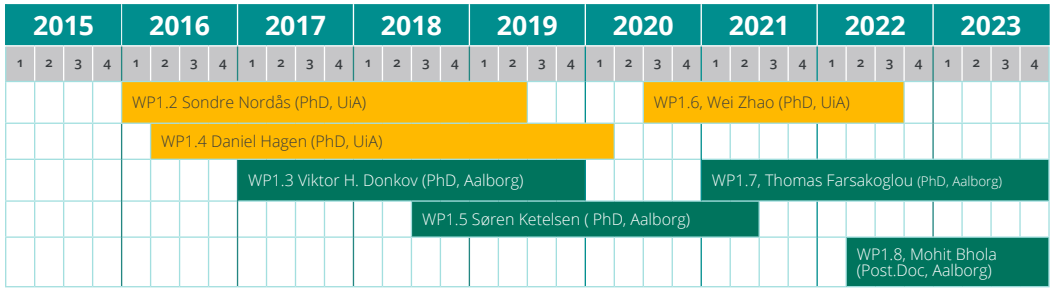
- Operation in deep water and harsh conditions (WP2: Motion Compensation)
- Cost-effective and safe autonomous operations (WP3: Robotics and Autonomy)
- Multi-physics and co-simulation (WP4: Modeling and Simulation)
- Life-time estimation and decision support (WP5: Monitoring Techniques)
- Optimization of operations and early warning (WP6: Data Analytics &Big Data)
- Business model innovation and digital transformation (WP7: Technology Vision)

The centre conducts research on the fundamental challenges and thus, the results are relevant within a wide range of applications. The industry partners have extensive experience and knowledge of what is required to succeed with systems and solutions for demanding offshore operations.

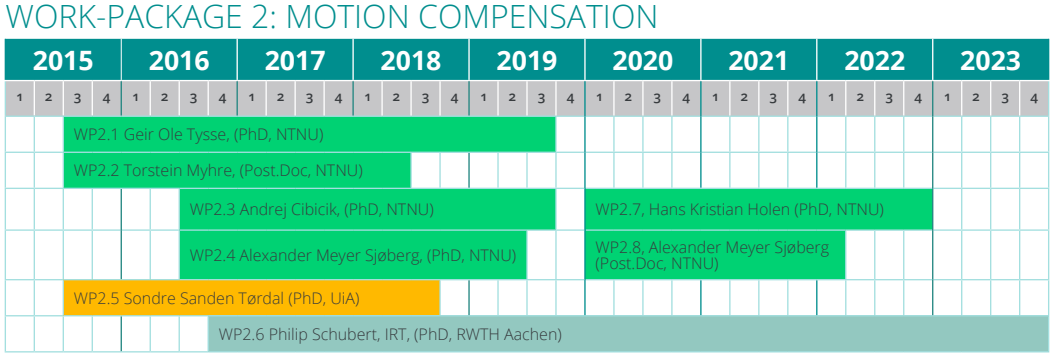
The research from the academic partners combined with the know-how from the industry partners provides a very good basis for implementing results and innovation. In addition, there is great potential for technology and knowledge transfer towards new offshore industries such as renewable energy production, aquaculture, etc.

To reach a higher Technology Readiness Level (TRL) level and to shape new concepts the industry partners are encouraged to establish industry-driven spin-off projects.

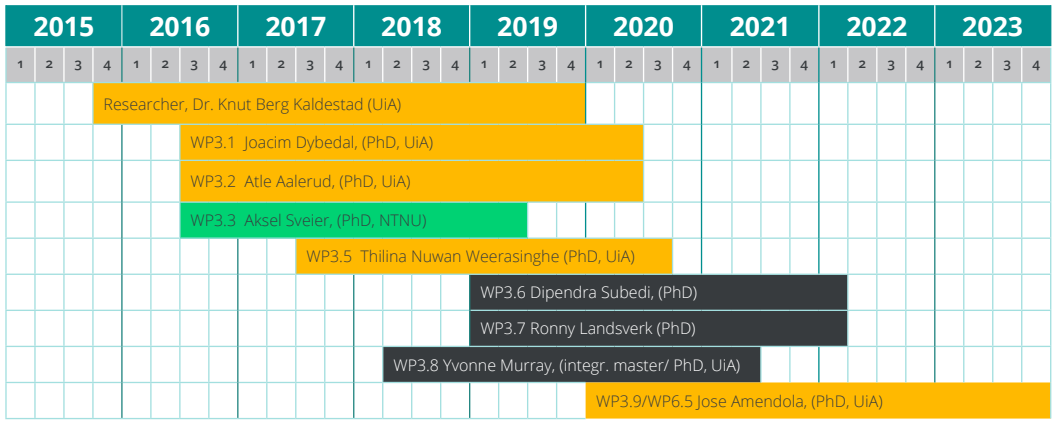
WORK-PACKAGE 1: DRIVES



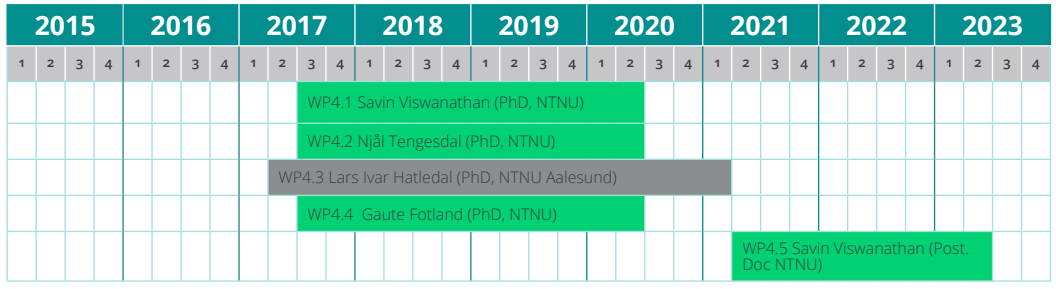
WORK-PACKAGE 2: MOTION COMPENSATION



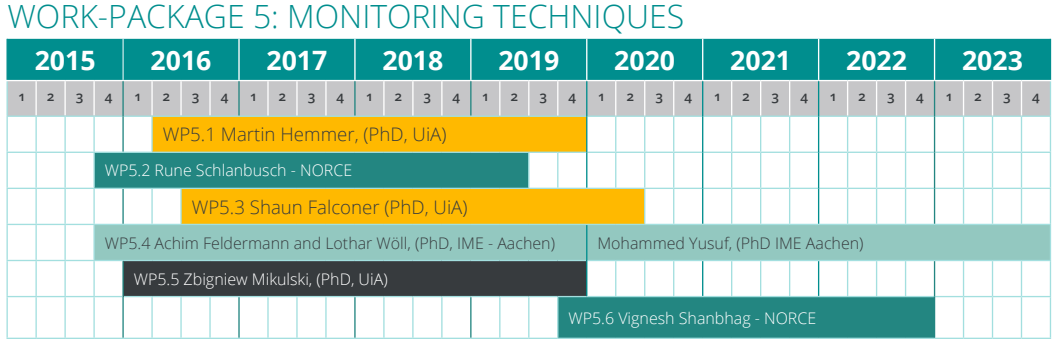
WORK-PACKAGE 3: ROBOTICS AND AUTONOMY



WORK-PACKAGE 4: MODELLING AND SIMULATION

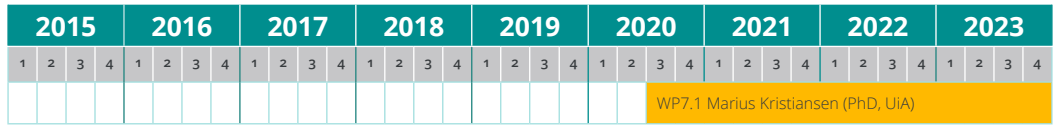


WORK-PACKAGE 5: MONITORING TECHNIQUES



WORK-PACKAGE 6: DATA ANALYTICS, IT INTEGRATION AND BIG DATA

WORK-PACKAGE 7: TECHNOLOGY VISION



The working titles of the positions

WP1.2 Using digital hydraulic in secondary control of motor drive.

WP1.3 Using digital hydraulic in secondary control of cylinder drive.

WP1.4 Electrical and electrohydraulic linear actuators.

WP1.5 Cylinder direct drive.

WP1.6 Energy efficient mobile hydraulic systems with focus on rotary actuation.

WP1.7 Energy efficient mobile hydraulic systems with focus on linear actuation.

WP1.8 Energy efficient mobile hydraulic systems with focus on digital valve technology.

WP2.1 Computer vision and 3D sensors for topside automation of offshore drilling.

WP2.2 High-performance control for motion compensation.

WP2.3 Nonlinear friction compensation in motion compensation systems with significant elasticity.

WP2.4 Vision systems for offshore crane control in ship-to-ship operations.

WP2.5 Real-time multiple DOF motion compensation using an industrial robot, sensor fusion and conformal geometric algebra.

WP2.6 Real-time teleoperation and model-based control of cranes with loads.

WP2.7 Vision systems for supervision of offshore drilling operations.

WP2.8 Fusion of vision, Lidar and IMU data for 3D tracking of objects in offshore crane operations.

WP3.1 Development of offshore 3D sensor package.

WP3.2 Autonomy systems foundation development.

WP3.3 Handling of sensor fusion, point-clouds and 3D maps.

WP3.4 Implementation of situational awareness/human factors concepts for operators using virtual arena.

WP3.5 Reliable Communication in 5G.

WP3.6 Instrumentation and real-time control of long-reach, light-weight arm intended for use offshore (associated PhD position).

WP3.7 Coupled dynamics between vessel and crane (associated PhD position).

WP3.8 Formal Methods in Robotics (integrated MSc / PhD position).

WP3.9 /WP6.5 Sensor fusion for perception, collision avoidance and navigation towards autonomous systems

WP4.1 Integrated simulation of multi-physical systems in offshore operations.

WP4.2 Component-based simulation systems for drilling automation and crane systems.

WP4.3 Protocols and standard for integration of simulation models and co-simulation.

WP4.4 Modelling and simulation of cable and pulley systems in offshore cranes.

WP4.5 Modeling and simulation of the motion of ships, cranes and drilling systems in waves

WP5.1 Tapered big bearings.

WP5.2 Large diameter steel ropes.

WP5.3 Fibre ropes.

WP5.4 Condition-based lifetime prediction as result of calculated component loads.

WP5.5 Modelling the fatigue damage mechanism in welded joints (associated PhD position).

WP5.6 Monitoring of Hydraulic Cylinders

WP6.1 Distributed in-network intelligence across multiple components.

WP6.2 Coordinated multi-variable data acquisition, intelligent data reduction, as well as automatic data quality verification and validation.

WP6.3 Design of soft-sensors based on novel context-aware data fusion techniques

WP6.4 Optimization of energy consumption and emission reduction for O&G production platforms.

WP6.5/WP3.9 Sensor fusion for perception, collision avoidance and navigation towards autonomous systems

WP7.1 The management of digital business model innovation

Organisation

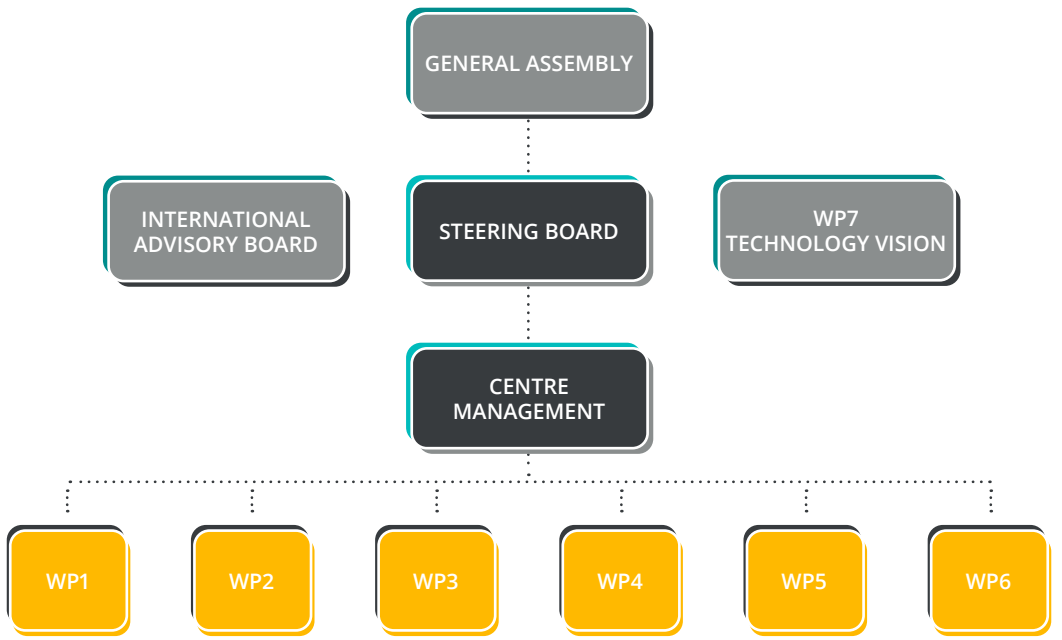
CENTRE MANAGEMENT

The SFI Offshore Mechatronics centre is hosted by UiA and the management is led by Centre Director, Professor **Geir Grasmo** (Since 1. April 2021) with assistance from Administrative Manager **Asle Pedersen**. In addition, UiA provides necessary resources from the Faculty and Central management.


Geir Grasmo


Asle Pedersen

ORGANISATION MAP



Work Packages WP1 – WP7

The research is carried out in seven work packages:

- Work-Package 1: Drives
- Work-Package 2: Motion Compensation
- Work-Package 3: Robotics and Autonomy
- Work-Package 4: Modelling and Simulation
- Work-Package 5: Monitoring Techniques
- Work-Package 6: Data Analytics, IT Integrationand Big Data
- Work-Package 7: Technology Vision

WP1

WP1 LEADER 1
Morten Kjeld Ebbesen, UiA
Co-sup. WP1.2, co-sup. WP1.3, and sup. WP1.4

WP1 LEADER 2
Torben Ole Andersen, AAU
Sup. WP1.2, sup. WP1.3, and co-sup WP1.4

WP1.2
Sondre Nordås
UiA

WP1.3
Viktor Hristov Donkov
AAU

WP1.4
Daniel Hagen
UiA

WP1.5
Søren Ketelsen
AAU

WP1.6
Wei Zhao
UiA

WP1.7
Thomas Farsakoglou
AAU

WP1.8
Mohit Bhola
AAU

WP2

WP2 LEADER
Olav Egeland, NTNU
Supervisor WP2.1-2.8

Dirk Abel
RWTH Aachen
Sup. WP2.6

Geir Hovland
UiA
Sup. WP2.5

WP2.1
Geir O. Tysse
NTNU

WP2.2
Torstein Myhre
NTNU

WP2.3
Andrej Cibicik
NTNU

WP2.4
Alexander M. Sjøberg, NTNU

WP2.5
Sondre S. Tørdal
UiA

WP2.6
Philip Schubert
RWTH Aachen

WP2.7
Hans Kristian Holen, NTNU

WP2.8
Alexander M. Sjøberg, NTNU

WP3

WP3 LEADER
Jing Zhou, UiA
Supervisor WP3.1 and WP3.2, Co-supervisor WP3.6, WP3.7

Olav Egeland
NTNU
Sup. WP3.3

Geir Hovland
UiA
Sup. WP3.1, WP3.2, WP3.6, WP3.7

Ilya Tyapin
UiA Sup. WP3.6

Jing Zhou
UiA Sup. WP3.7

David Anisi
NMBU
Co.Sup WP3.8

WP3.1
Joacim Dybedal
UiA

WP3.2
Atle Aalerud
UiA

Ajit Jha
UiA
Sup. WP 3.9

Frank Y. Li
UiA
Sup. WP 3.5

Knut Berg Kaldestad
UiA
Technician
Sup. WPs

Charlotte Skourup
ABB
Co.Sup WP3.4

WP3.3
Aksel Sveier
NTNU

WP3.4
Thiago G. Monteiro
NTNU Aalesund

WP3.5
Thilina N. Weerasinghe
UiA

WP3.6
Dipendra Subedi
UiA

WP3.7
Ronny Landsverk
UIA

WP3.8
Yvonne Murray,
UiA

WP3.9
Jose Amendola
UiA

WP4

WP2 LEADER
Olav Egeland, NTNU
Supervisor WP4.5, Co-sup, WP4.1, WP4.2, WP4.4

Christian Holden, NTNU
Sup. WP4.1 & WP4.2

Houxiang Zhang
NTNU Aalesund
Sup. WP4.3

Terje Rølvåg
NTNU
Sup. WP4.4

Geir Hovland
UiA
Co-Sup. WP4.3

Bjørn Haugen
NTNU
Co-sup. WP4.4

Arne Styve
NTNU
Aalesund
Co-sup. WP4.3

WP4.1
Savin Viswanathan
NTNU

WP4.2
Njål Tengesdal
NTNU

WP4.3
Lars Ivar Hatledal
NTNU Aalesund

WP4.4
Gaute Fotland
NTNU

WP4.5
Savin Viswanathan
NTNU

WP5

WP5 LEADER
Rune Schlanbusch
NORCE

Ian K. Jennions
Cranfield U.

Subtask 5.1 «Big tapered roller bearings»

Tor Inge Waag
Task leader, NORCE

Kjell Gunnar Robbersmyr
UiA
Sup. WP5.1

WP51
Martin Hemmer
UiA

Subtask 5.2 «Big steel ropes»

Rune Schlanbusch
Task leader, NORCE

WP5.3
Shaun Falconer
UiA

Subtask 5.3 «Big fiber ropes»

Ellen Nordgård-Hansen
Task leader, NORCE

Geir Grasmo
UiA
Sup. WP5.3

Subtask 5.4 "Winch Lifetime predictions"

Stephan Neumann
Task leader, Aachen IME

WP5.4
Mohammed Yusuf
Aachen IME

Subtask 5.5 "Welded joints fatigue predictions"

Tom Lassen
Task leader, UiA

WP5.5
Zbigniew Mikulski
UiA

WP5.6
Vignesh Shanbhag
NORCE

WP6

WP6 LEADER
Baltasar Beferull-Lozano, UiA
Supervisor WP6.1 - WP6.2

Daniel Romero
UiA
Co. Sup. WP6.1

Linga Cenkeramaddi
UiA
Co. Sup.

Jing Zhou
UiA
Co. Sup. WP6.2

Ajit Jha
UiA
Sup. WP6.3 and WP6.5

WP6.1/WP6.4
Luis M. Lopez-Ramos
UiA

WP6.2
Emilio Ruiz Moreno
UiA

WP6.3
Kevin Roy
UiA

WP6.5/WP3.9
Jose Amendola
UiA

WP7

WP7 LEADER
Christian von der Ohe, GCE NODE

WP7 LEADER
Ellen Nordgård-Hansen, NORCE

Thor Helge Aas, UiA
Supervisor WP7.1

Jan Helge Viste, GCENode
Supervisor WP7.1

WP7.1
Marius T. Kristiansen
UiA

Steering Board

The Steering board (2022-2023) consists of 7 members, and 2 deputy members: Tom Fidjeland (GCE NODE), Peder Sletfjerding (NOV), Sjur Henning Hollekim (MHWirth), Anstein Jorud (Cameron), Jøran Bøch (Egde Consulting, deputy member) Olav Egeland (NTNU), Torben Ole Andersen (Aalborg University), Jorun Gislefoss (UiA), Rune Schlanbush (NORCE, deputy member)

The majority of the SFI Offshore Mechatronics Steering Board members are from the Industry Partners. The Steering board is appointed for 2 years. It is the General Assembly which appoints the Steering board.

Tom Fidjeland
GCE NODE
Chairperson

Peder Slettfjerding
NOV
Deputy Chairperson

Sjur Henning Hollekim
MHWirth

Anstein Jorud
Cameron

Rune Schlanbusch
NORCE

Torben Ole Andersen
Aalborg University

Jorun Gislefoss
UiA

Jøran Bøch
Egde Consulting

The Centre has one General Assembly every year, where all partners meet and work-plans for the following year are presented and discussed.

The General Assembly was held on November 10, 2022, where the budget for next year and the WP annual work plans were presented and approved.

KEY NUMBERS 2022

Steering Board Meetings	4
WP leader meetings	7
Workshops/Webinars	3
Reference Group Meetings	5
Conferences	1
General Assembly	1

Partners

*ABB until 2020, Bosch-Rexroth and Klüber Lubrication until 2021, Egde Consulting until 2022

New solutions for Norwegian offshore wind

In the annual report of 2021, we posed the question “What’s next?”. Offshore energy was outlined as a natural path to transfer and build upon the results from SFI Offshore Mechatronics. Within the greater offshore energy market, offshore wind is expected to have tremendous growth potential. But how great and how big can it become, and what research is needed to develop sustainable and cost-efficient solutions for offshore wind?

“We know a great deal about windmills on land, and something about fixed-bottom wind turbines at sea, but much less about floating wind turbines. We don’t have good answers on how to make the best possible use of offshore wind, and how we can design, build, operate, maintain, and manage fields at sea in harsh conditions”. Prof. Geir Grasmo says. In addition to being the SFI Offshore Mechatronics center director, Grasmo also coordinate UiA’s technological competence and research efforts on offshore wind.

By building on the experiences and results from SFI Offshore Mechatronics, University of Agder (UiA), have identified offshore wind as a strategic opportunity. The industry and researchers agree that offshore wind is a rather immature technology in Norway and there are plenty of knowledge and research gaps to fill. University of Agder is committed to supporting the development of a sustainable and competitive offshore wind industry sector. To prepare for the opportunities in the emerging offshore wind industry, UiA has teamed up with several players at the regional, national, and international level. The portfolio of projects related to offshore wind is increasing related to technical and engineering challenges as well as societal and commercial aspects. In relation to the national budget the Agder region was appointed a role in building up a national competence center for offshore wind.

Long service life in harsh environment

A wind farm in Norwegian waters must be sustainable in the best possible way to have a long service life in a harsh and demanding environment” Grasmo says.

Generally, wind turbines are designed to operate for 20-25 years. The stipulation assumes that the wind turbine will experience wind loads high enough to cause significant wear through this time that is evenly distributed over all turbines. Research shows that the wear over time can widely vary since wind is an uncertain source of energy and thus loading is unevenly distributed over the turbines. Therefore, not all turbines in a large wind farm will reach end-of-life after 25 years of operation. Thousands of wind turbines in Europe reach this stipulated lifetime in the coming decades. Which of these turbines have shorter remaining useful life? Can we continue operating those turbines safely? These are the questions the project AIMWind (2021-2025) will strive to answer.

AIMWind is one of the many spin-off projects from SFI Offshore Mechatronics. The AIMWind project benefits from the valuable work performed on monitoring techniques in Work Package 5. The University of Agder is the coordinator of the project and the partners are NORCE, TU Delft and DNV. Prof. Kjell Gunnar Robbersmyr is the project manager of AIMW. He was the supervisor of research fellow Martin Hemmer in WP5.1.

Scientific Activities and Results

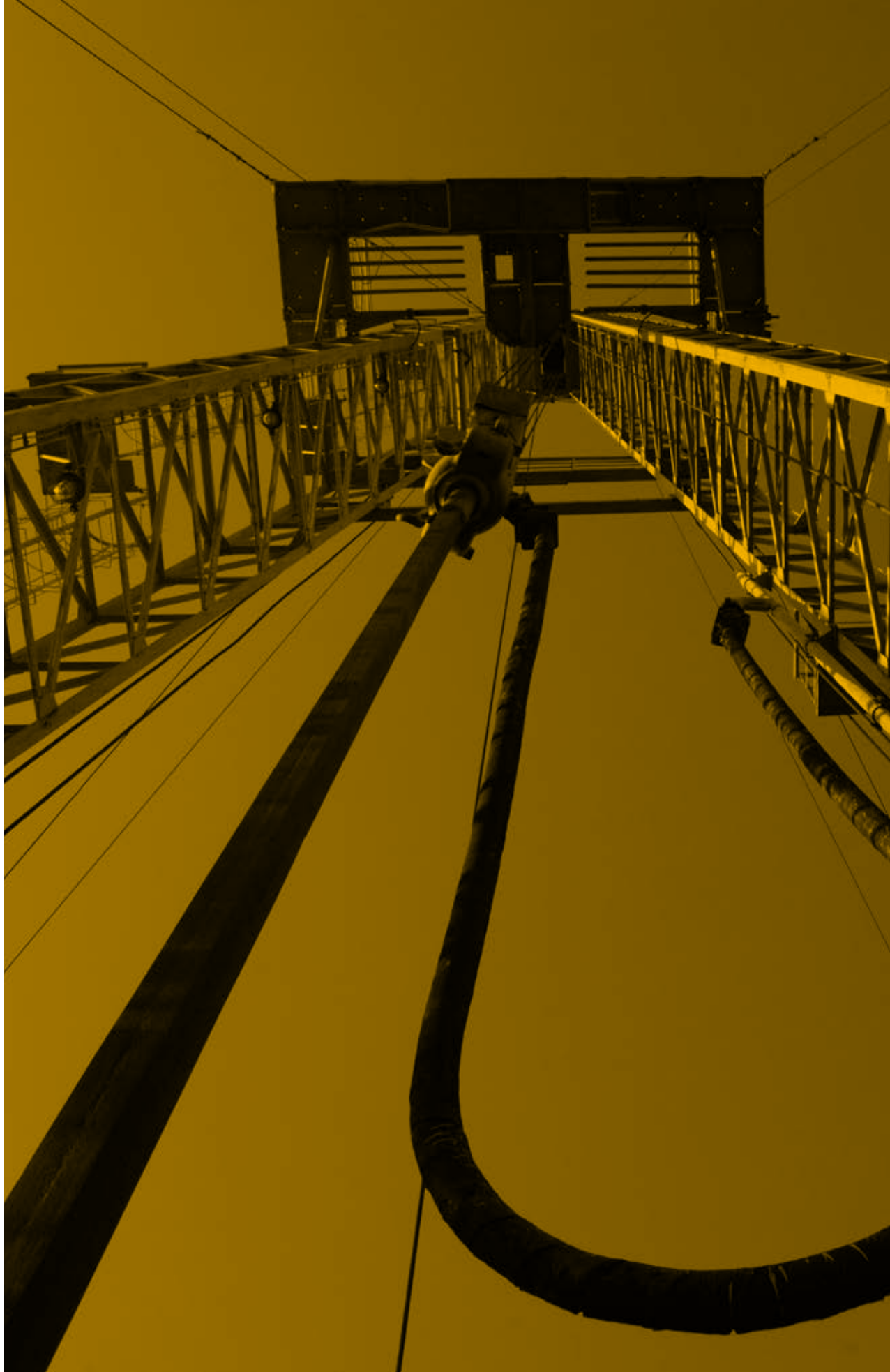
Each PhD defense is a milestone in the SFI Offshore Mechatronics centre. In 2022 seven PhD fellows defended their thesis:

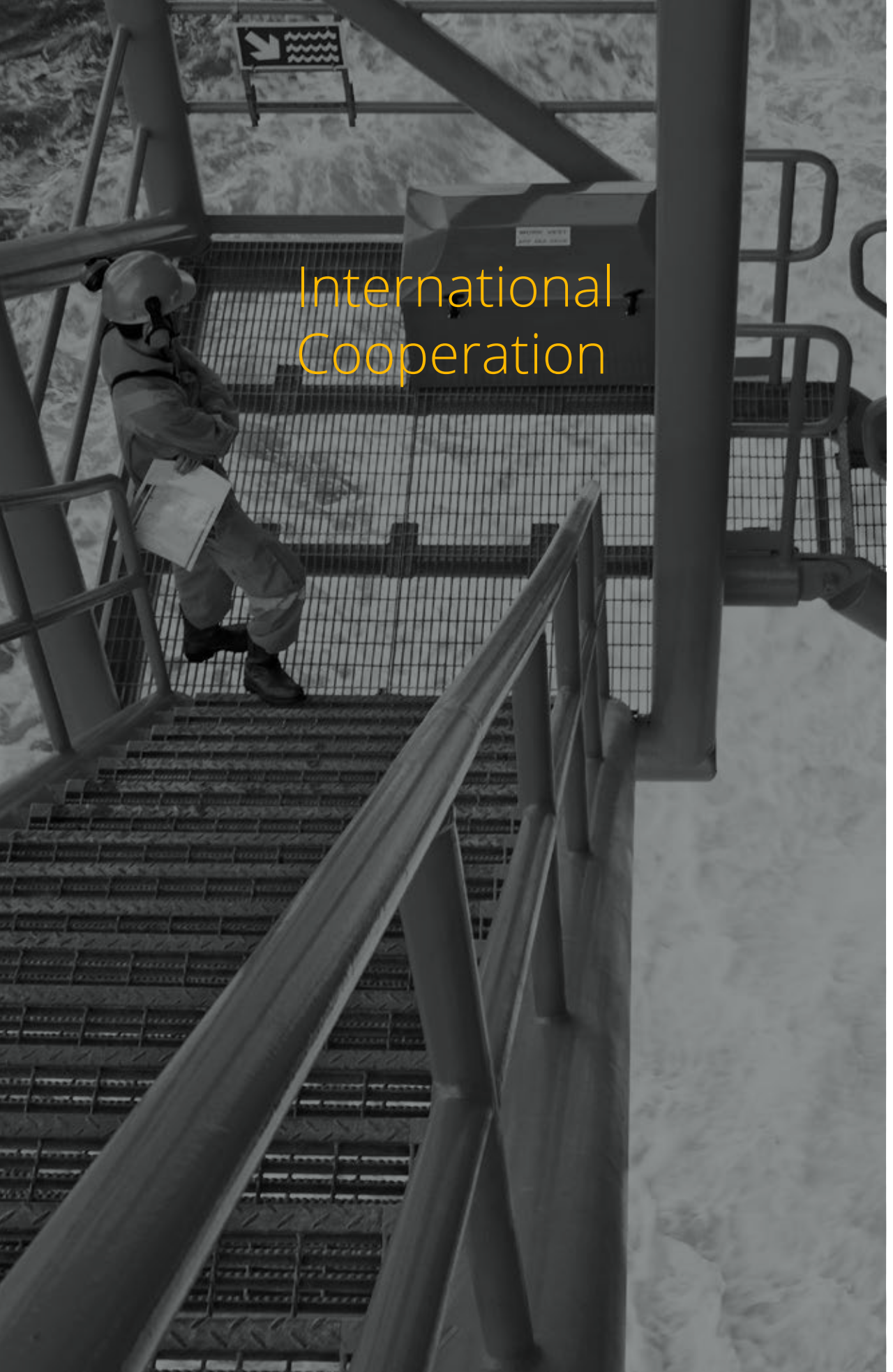
Gaute Fotland (NTNU, PhD thesis defended on June 17, 2022. Title of thesis: **Effects of Time Integration and Constraint Methods for Cable Simulations using ALE-ANCF Elements regarding Real-Time Analysis.**

Shaun Falconer (UiA), PhD thesis defended on June 28, 2022. Title of thesis: **Condition monitoring of fibre ropes using machine learning.**

Søren Ketelsen (AAU), PhD thesis defended on August 30, 2022. Title of thesis: **Efficient Actuation of Load Carrying Applications by Electro-Hydraulic Compact Drives.**

Dipendra Subedi (UiA), PhD thesis defended on September 13, 2022. Title of thesis: **Modeling and Control of Flexible Link Manipulators.**





International Cooperation

The SFI Offshore Mechatronics centre is distributed with industry and research partners across three countries (Norway, Denmark and Germany). In addition to this the researchers in the centre utilize their extensive international networks.

The centre has a small international advisory board. It consists of the following persons: Professor Rolf Johannsson, Lund University, Sweden, Professor Ian Jennions, Cranfield University, UK and Professor Iraj Ershagi, University of Southern California, USA. This board was more active in the early stages of the centre.

Due to COVID-19, the opportunities to travel and accommodate guest researchers was very limited for a long period of time. However, most of the PhD defenses have international opponents. The written examination reports serve as valuable feedback on the relevance, quality and impact of the research in the centre. The following are a few excerpts of some very positive feedback

Professor Katharina Schmitz, Germany: "Overall the investigation is well though out, comprehensive, well executed, thorough and well documented.

Dr. Suresh Rajendran, India: The thesis is highly beneficial from an industrial and academic perspective on the modelling of an open-source multi-physical platform for ocean engineering problems which is not available so far.

Professor Ole Balling, Denmark: The quality of the PhD work is strong and the most important results are published in a prestigious and relevant journal.

Professor Robert Schulz, Germany: "A new approach for the rope industry was used. The investigations done by the candidate are interesting and surely will be of great relevance for future research in the field of fibre ropes.“

Recruitment

By the end of 2021 all final PhD and Post.Doc positions have been filled. During the project period a total of 40 researcher and technicians have been recruited. The following researchers and technicians were hired in SFI Offshore Mechatronics in 2015-2022.

NAME	POSTITION / INSTITUTION	PERIOD
Torstein Myhre	Post.Doc, NTNU	2015-2017
Geir Olav Tysse	PhD, NTNU	2015-2018
Sondre Sanden Tørdal	PhD, UiA	2015-2018
Achim Felderman	PhD, RWTH Aachen	2015-2017
Atle Aalerud	PhD, UiA	2016-2019
Andrej Cibicik	PhD, NTNU	2016-2019
Joacim Dybedal	PhD, UiA	2016-2019
Shaun Falconer	PhD, UiA	2016-2019
Daniel Hagen	PhD, UiA	2016-2019
Martin Hemmer	PhD, UiA	2016-2019
Sondre Nordås	PhD, UiA	2016-2019
Aleksander Meyer Sjøberg	PhD, NTNU	2016-2019
Aksel Sveier	PhD, NTNU	2016-2019
Thilina Nuwan Weerasinghe	PhD, UiA	2016-2019
Philipp Schubert	PhD, RWTH Aachen	2016-2019
Lothar Wöll	PhD, RWTH Aachen	2016-2019
Zbigniew Mikulski	PhD, UiA (associated)	2016-2019
Viktor H. Donkov	PhD, Aalborg	2017-2019
Thiago G. Monteiro	PhD, NTNU Aalesund	2017-2021
Savin Viswanathan	PhD, NTNU	2017-2020
Njål Tengesdal	PhD, NTNU	2017-2020
Lars Ivar Hatledal	PhD, NTNU Aalesund	2017-2020
Gaute Fotland	PhD, NTNU	2017-2020
Luis Miguel Lopez Ramos	Post.Doc, UiA	2016-2018
Søren Ketelsen	PhD, Aalborg	2018-2021
Emilio Ramiz Moreno	PhD, UiA	2018-2021
Yvonne Murray	PhD, UiA (associated)	2018-2021
Hans Kristian Holen	PhD, NTNU	2019-2022
Dipendra Subedi	PhD, UiA (associated)	2019-2022
Ronny Landsverk	PhD, UiA (associated)	2019-2022
Vignesh Shanbhag	Post.doc NORCE	2019-2021
Mohammed Yusuf	PhD. RWTH Aachen	2019-2023
Alexander Meyer Sjøberg	Post.doc NTNU	2020-2022
Kevin Roy	PhD, UiA	2020-2023
Marius Kristiansen	PhD, UiA	2020-2023
Wei Zhao	PhD, UiA	2020-2023
José Amendola	PhD, UiA	2021-2023
Savin Viswanathan	Post.doc NTNU	2021-2023
Tomas Farsakoglou	PhD, AAU	2021-2023
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Towards smarter maintenance strategies

WHAT IS THE PROBLEM?

Reduced costs and increased productivity without compromising health, safety and environmental requirements is critical for sustainable and competitive offshore operations. To improve machine availability and reliability, the offshore industry is actively exploring opportunities to make the transition from periodic maintenance planning to other maintenance strategies such as condition-based maintenance, risk-based maintenance strategies or to put it simply – smarter maintenance.

In the harsh and remote offshore environment, maintenance and repairs are highly constrained by multiple factors such as ongoing operations, weather windows, access to spare parts, skilled personnel and required infrastructure such as vessels and cranes. Unplanned downtime can be costly, not only because of the challenging repair and maintenance conditions, but hampering operations leads to potentially high production losses.

WHY IS IT HARD?

In the traditional periodic maintenance strategy, the risk is that machines are maintained too early or too often, resulting in elevated costs, or too late resulting in unplanned downtime. Machine health and the need for maintenance is impacted by multiple factors, including machine usage and operating conditions such as loads and weather conditions. Another challenge is that wear issues can be hard to identify by visual inspection and would in most cases require downtime due to the need for disassembly to access components and parts.

But what if we could identify problems at a very initial stage, in time to operate the machine securely and reliably until the next feasible maintenance opportunity? This is the type of question addressed by the SFI Offshore Mechatronics work-package on condition monitoring techniques (WP5). Based on feedback from the industry partners, condition monitoring of hydraulic cylinders was identified as a relevant research topic. Hydraulic cylinders are used in a broad range of machines in the offshore industry, such as clamping units, skidding systems, tensioners, cranes, and heave compensation. Robust and affordable solutions for condition monitoring of hydraulic cylinders would therefore be of high value.

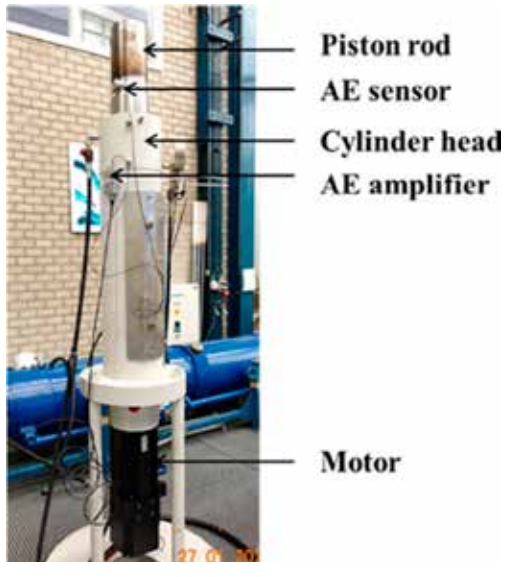
HOW IS IT DONE TODAY AND WHAT ARE THE LIMITS OF CURRENT PRACTICES?

Monitoring of rotating machinery such as electrical motors, pumps and gearboxes is commonly solved by bolting vibration sensors on the machine. The vibration data is recorded, and once analyzed it can indicate if maintenance is needed. A drawback of vibration sensors is that they are not performing well with non-rotating machinery such as hydraulic and electro-mechanical cylinders and reciprocal machines using pistons to induce motion. But what type of sensor would be a good fit for monitoring cylinders?

For a moment, let us go back to the very early start of the SFI Offshore Mechatronics. In 2015, Senior Researcher Rune Schlanbusch started his research on monitoring of large diameter steel ropes and welds using Acoustic Emission (AE). At the same time, but on the opposite side of the world, Vignesh Shanbhag started his PhD at Deakin University, Australia. Vignesh used AE techniques in his research on measuring tool wear in metal forming processes. An advantage of AE-based condition monitoring is that AE signals are sensitive to damage on microscopic level. Another advantage is that the effect of environmental noise or machine vibrations are severely limited for AE-signals due to the high frequency.

OUTLINE OF THE RESEARCH

Subtask WP5.6 was established with the aim of using AE to identify oil leakage from hydraulic cylinders at very initial stages. Vignesh Shanbhag was recruited into WP5.6 as a PostDoc researcher at NORCE Research under supervision of Rune Schlanbusch, and he started his work in late 2019. Specific wear conditions such as piston rod wear, spindle wear and seal-wear were considered. The scientific results of the performed research on hydraulic cylinders and spindles are published in several journal papers, a majority on the highest scientific level (Level 2).



WHO CARES AND WHAT'S NEXT?

In his research Vignesh Shanbhag presents robust AE-based condition monitoring techniques, that can be used in industries to monitor multiple faults in hydraulic cylinders at the same time.

The results have been presented to the industry partners, but development of sensor systems is not in their core business. They are foremost users of such systems and rely on vendors to supply commercial products and services. Non-technical barriers such as business models and lack of incentives are also part of the consideration.

The technology demonstrated in the research is well positioned within emerging trends such as digital vessel classification services, asset integrity management, asset performance management and digital twins. However, the sensor system used in this research is bulky and expensive lab equipment (Technology Readiness Level - TRL 3-4). To be considered for larger investments and industrial implementation TRL 7-9 is expected.

For these reasons, NORCE has decided to proceed with a separate spin-off project to reach a higher technology readiness level. In 2021 a pre-project with funding from the Research Council Norway FORNY program was granted. In early 2023 a FORNY main project with 5MNOK funding was granted. The project will prepare for commercialization of the AE technology. A spin-off company to industrialize and bring the technology to the market will be considered as part of this process.

More details on the research results can be found in the publication "Defining acoustic emission-based condition monitoring indicators for monitoring piston rod seal and bearing wear in hydraulic cylinders" [1].

[1] Shanbhag, V. V., T. J. J. Meyer, L. W. Caspers and R. Schlanbusch (2021). Defining acoustic emission-based condition monitoring indicators for monitoring piston rod seal and bearing wear in hydraulic cylinders. The International Journal of Advanced Manufacturing Technology, May 2021.

Communication and Dissemination Activities

After two years of postponements and cancellations, we finally managed to proceed with our annual conference. The conference was hosted as a physical conference with almost 40 attendees and with good representation from the industry partners and the centre board members. The conference took place on 19.-20th of May and the venue was the Department of Energy at Aalborg University, Denmark.

SFI Offshore Mechatronics has a web page (sfi.mechatronics.no) for news and general information about the Project. The web site is both for partners and the general public. All information about the organization, activities and results that are not sensitive is published here. From the web site there is generated a monthly newsletter, with over 350 subscribers.

Dissemination Activities

PUBLICATIONS

JOURNAL PAPERS

Dipendra Subedi, Teodor Nilsen Aune, Ilya Tyapin and Geir Hovland, **"Static Deflection Compensation of Multi-Link Flexible Manipulators Under Gravity"**, IEEE Access, 2022.

Yvonne Murray, Martin Sirevåg, Pedro Ribeiro, David A. Anisi, Morten Mossige, "**Safety assurance of an industrial robotic control system using hardware/software co-verification"**, Science of Computer Programming, Volume 216, 2022, 102766, ISSN 0167-6423.

Zbigniew Mikulski, Tom Lassen, **"Probabilistic models for the fatigue resistance of welded steel joints subjected to constant amplitude loading"**, International Journal of Fatigue, Volume 155, 2022 (Level2)

Falconer, Shaun; Krause, Peter; Bäck, Thomas; Nordgård-Hansen, Ellen Marie; Grasmo, Geir (2022). **Condition Classification of Fibre Ropes during Cyclic Bend over Sheave testing Using Machine Learning**. International Journal of Prognostics and Health Management. ISSN: 2153-2648.

Smith, Torbjørn; Egeland, Olav. (2022) **Dynamical Pose Estimation with Graduated Non-Convexity for Outlier Robustness**. Modeling, Identification and Control. vol. 43.

Tysse, Geir Ole; Cibicik, Andrej; Tingelstad, Lars; Egeland, Olav. (2022) **Lyapunov-based damping controller with nonlinear MPC control of payload position for a knuckle boom crane.** Automatica. vol. 140. (Level2)

Viswanathan, Savin; Holden, Christian; Egeland, Olav; Sten, Ronny. (2022) **A Co-simulation Methodology for Risers Tensioned with Direct Acting Tensioners.** International Journal of Mechanical Engineering and Robotics Research (IJMERR). vol. 11.

CONFERENCE PAPERS

Thomas Farsakoglou, Henrik C. Pedersen and Torben O. Andersen (2022): **"Review of offshore winch drive topologies and control methods"**. The 13th International Fluid Power Conference 13, IFK, March 21-23, 2022, Aachen, Germany.

Dipendra Subedi, Ilya Tyapin and Geir Hovland, **"Control of Redundant Flexible Manipulators with Redundancy Resolution"**, The 8th Intl. Conf. Mechatronics and Robotics Engineering, Munich, Germany, February 10-12, 2022.

Nadia. S. Noori, Vignesh. V. Shanbhag, Surya. T. Kandukuri and Rune Schlanbusch (2022). **"Data Driven Seal Wear Classifications using Acoustic Emissions and Artificial Neural Networks"**. 7th European Conference of the PHM Society, July 6.-8., Turin, Italy.

Vignesh. V. Shanbhag, Jørgen. F. Pedersen and Rune Schlanbusch (2022). **"Forecasting piston rod seal failure using the acoustic emission features in ARIMA model"**. 7th European Conference of the PHM Society, July 6.-8., Turin, Italy.

K. Roy, L. M. Lopez-Ramos, B. Beferull-Lozano, "**Joint Signal Estimation and Nonlinear Topology Identification from Noisy Data with Missing Entries"**, IEEE Asilomar Conference on Signals, Systems, and Computers, 2022.

K. Roy, L. Miguel-Lopez, B. Beferull-Lozano, **Joint Learning of Topology and Invertible Nonlinearities from Multiple Time Series,** IEEE International Conference on Machine Learning, Optimization, and Data Science (ISMODE), 2022.

Student Projects

UIA:

Jennie Braaten Andersen
Real-Time People Tracking using Reflected LiDAR Data (NOV)

Daniel Råmundsen
Radar/Lidar (Xdar) based dynamic 4D pose estimation of monopile for robust offshore wind-turbine installation (UIA/Ajit)

Silje Wetrhus Hebnes
Deep Aruco: AI/ML-based Real-Time Marker Pose Tracking (MotionTech)

Lene Therese Baardsen Skiftenes
Environmental footprint (NOV)

Henrik Hoang, Kevin Hermann Skaar, Rodion Solheim
Collision Prediction System for Collaborative Robots (UiA/Jing)

AAU:

Stefan Siray, Niklas Simonsen, Frederik Peter Kløvborg
"Automated Pressure Control Loop Tuning" (Digital Displacement Pump (DDP), Danfoss/Artemis, Edinburgh)

Aachen:
RWTHNagarjuna Avula (Stralsund University) "Load Distribution and Lifetime Analysis of an Offshore Winch Drivetrain"

NTNU:

Henrik Grüner
Implicit Regularization of Convolutional Neural Networks with Mirror Descent

Eirik Berg Samuelsen
Pose Estimation and Attitude Estimation with IMUs using Machine Learning

Thilogen Thambirajah
IMU filtering with Kalman filter and machine learning

Fabian Vakhidi
Attitude estimation with convolutional neural networks

Kasper Kallseter
Machine learning for elimination of reflections in laser scanning for robotic welding

Else Amalie Holm Berg
Machine learning for elimination of reflections in laser scanning for robotic welding

Sigmund Hennum Høeg
Learning Robotic Manipulation

Jørgen Haaland
Development of Automatic Ferry Charger

Ludvik Kasbo
Robotic Grasping: Closing the Sim-To-Real Gap by utilizing Point Clouds as Sensor Information

Petter Rasmussen
Placement of a RGBD camera in robot manipulator system: How it can effect Deep Reinforcement Learning grasping performance

Ole Jørgen Gether Rise
Placement of a RGBD camera in a robot manipulator system: How it can effect Deep Reinforcement Learning grasping performance

Mustafe Ismail Yusuf Kahin
Robot Telemanipulation for Remote Maintenance

Irfan Suvalija
Robot Telemanipulation for Remote Maintenance

Irfan Ljevo
Pose estimation of aquaculture crane using IMUs

Espen Marsteng Nilsen
Dynamic Modelling and State Estimation of a Shipboard Crane

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