Norwegian Centre
for Research-based
Innovation

SFI
OFFSHORE
MECHATRONICS

FINAL REPORT
2015-2023

UiA University of Agder

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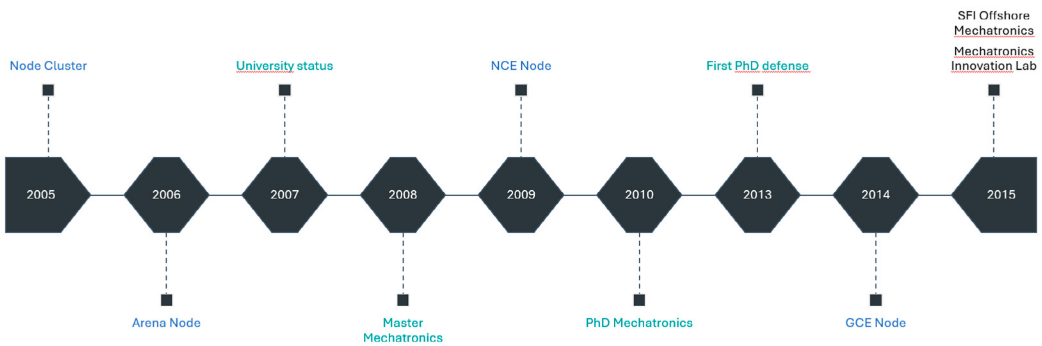
Research Environment for Innovations

By Professor Geir Grasmo, Centre Director.

Mechatronics engineering, which is the multidisciplinary intersection between mechanical, control, electronical and computer engineering, was established as a degree at the precursors of University of Agder back in 1989. It was extended towards master and Ph.D. study programmes to meet the demand from the offshore and marine industry with a stronghold in Agder.



SFI Offshore Mechatronics was the first large project that brought together the supplier industry within and around GCE NODE in Agder for a joint major visionary research, development, and innovation programme (RDI) in collaboration with the leading academic environments related to their business areas. This matched the ambitions of the University of Agder (UiA) and partners at NTNU in Trondheim and Ålesund, as well as Aalborg University. It was natural that UIA, which operates close to the industry, took on the role of coordinator. Teknova in Agder, Iris in Stavanger (both now part of NORCE) and RWTH Aachen in Germany joined the consortium as research partners. Twelve companies, including seven from Agder and GCE NODE, have been industrial partners.

The objective of the centre was the development of advanced mechatronic systems for the autonomous, safe, and efficient operation of facilities in deeper water and harsh environments along the coast and at sea. The consortium applied for funding from the Research Council of Norway, which granted 96 million NOK over eight years from 2015, the industrial partners supported with 38 million in cash, and their in-kind contribution has been more than 23 million. The remaining amount of 58 million, up to a total budget of 215 million NOK, was covered by internal in-kind priorities at the research institutions.

Beyond academic ambitions, the centre should work to improve integration and cooperation between research partners and companies, be relevant to the industry, and deliver results that the industry partners could commercialise. This was arranged for by involving the industry partners throughout the entire life of the project, from the start of the application process and kick-off to operations and now at the end, as well as laying the foundations for further engagements. There has been participation from industry at all levels in the Centre, from the steering committee with a majority of company representatives, in regular reference group meetings in each of the work packages, impact on the PhD scholarship holders' tasks, and own innovation work. Some of the Ph.D. candidates were recruited from the partner companies, and the companies also had other associated student projects at the same time.

Geir Grasmo, Centre Director

The centre has funded a total of 32 fellows and 7 postdocs, which is among the highest numbers per centre within the Research Council's SFI scheme. The centre has prioritised a high proportion of candidate production that could be made available to the industry. We are proud to have trained competent Ph.D. candidates who have acquired relevant skills that are requested by the industry and who can contribute to further development and changes in the industrial sectors both at sea and on land.

Our results have supported the industrial partners to develop innovative products and improved services. The research activities have been geared toward basic technological readiness levels (TRL 2-5), and the competing companies have been able to lift these results themselves into innovations and new products (TRL 5-9). We are very pleased to have contributed to the fact that the industrial companies in the period have been supplied with and themselves acquired competence to take on more complex and demanding developments, especially in the field of digital modelling and simulation. We are proud to have built high-quality R&D collaboration in an industrial cluster made up of competing companies and that our activities have been so relevant.

So far, we at UiA are proud to have managed the first SFI centre that UiA has hosted, and we will be particularly pleased if the centre continues with both old and new partners. We have gained a very good foundation, business has been supplied with new knowledge and competent employees, and we have infrastructure and special equipment available for further work with all the research partners, such as robot laboratories, electrical and hydraulic facilities, wave simulation lab (MotionLab), monitoring sensor technology, test equipment and project opportunities at the Mechatronics Innovation Lab, as well as computing capabilities. Most of the research partners have also been able to recruit some of our candidates as new competent employees who can continue to collaborate with the companies.

SFI Offshore Mechatronics was supported by the Norwegian Research Council, and this funded project had its closing conference in Grimstad in June 2023, but this was not the end. We will continue the cooperation in a similar way and in the same spirit, henceforth as the Centre for Offshore Mechatronics where we will seek further cooperation and support for research and innovation projects for the supplier industry and the new offshore industries that are emerging.

The Rise of Offshore Mechatronics

The commitment to mechatronics as a discipline began before our institution became a university. In 2005, in close collaboration with the newly formed NODE cluster, efforts were made to establish a study programme that could provide the supplier industry in the south of Norway with the necessary expertise. At that juncture, the industry in our region was experiencing significant growth and was a global leader in supplying equipment to the domestic and international oil and gas industry. In 2007, the university made a substantial investment in building up the field of mechatronics, effectively doubling the number of researchers within a single year. Both master's and PhD programmes were established in a matter of just a few years, as the first in Norway.

Rector and Chair of the Board, University of Agder, Sunniva Whittaker.

The emergence of mechatronics has been a concerted regional endeavour. Private and public regional stakeholders contributed funding and expertise, enabling UiA to establish a robust and internationally leading academic environment, where the industry participated in reference groups at all levels. Additional investments from Sørlandet Knowledge Foundation and Agder Regional Research Fund helped contribute to UiA's successful application for a Centre for Research-based Innovation in offshore mechatronics, in collaboration with several regional, national and international partners, in 2015.

SFI Offshore Mechatronics has been of great significance to the field, the companies partnering with the centre, the offshore industry in general, and academic collaboration across disciplines, institutions and national borders. The research and knowledge generated by the centre has been integral to facilitating the green shift. This research can be applied to areas such as offshore wind, which will be important for our region in the years ahead.

A Centre for Research-based Innovation ensures long-term and predictable funding for large-scale research and innovation collaborations. This has been of great importance, not only for the advancement of academic partners but also for an industry that had to endure both an oil crisis and a financial crisis during this period, which had severe impact on the companies. During this time, our business partners found motivation and support to better adapt to emerging challenges. As an example, one company was able to pivot towards offshore fish farming leveraging existing technology when traditional markets faltered. During the centre period, our partners successfully secured several spin-off projects with funding exceeding NOK 90 million. The ripple effects extend to the profitability of companies, the strengthening of research environments, and the expansion of the professional reach and impact of the companies and the academic institutions. The work in and results of SFI Offshore Mechatronics have left and will continue to leave a lasting mark on the regional, national and international development of both the mechatronics field and offshore industry enterprises for many years to come.

Acknowledgements

The development and success of this joint effort have depended on the visions and enthusiasm of many people involved. All GCE NODE leaders from Kjell Olav Johannessen, through Anne-Grete Ellingsen to Tom Fidjeland, were important to foster and support the establishment and execution of the SFI, supported by strong commitment from the companies involved from the industry cluster. We also thank Leif Haukom, who served as Chair of the Board and advisor to the centre management for six years.

This centre would not have been possible without the original initiative for the centre and the dedication to research and innovations of Professor Geir Hovland at UiA and Professor Olav Egeland at NTNU. They were supported by the Dean, and later Rector Frank Reichert at UiA during the establishment process. Prof. Hovland took on the responsibility as director, and Rachel Funderud Syrtveit joined to take on building the strong project administrative and organisational management system. Asle Pedersen entered as innovation officer after the midterm and took on a strong commitment to administrative leadership during the last three years. Based on this good foundation, there has been very good and open atmosphere between all scientific and industrial partners in the centre.

We are very pleased with the partner companies. Despite a significant economic downturn for the industrial partners in the middle of the last decade, the regional central industrial partners chose to complete their investment in the centre.

Summary

CULTURE FOR INNOVATION

SFI Offshore Mechatronics was the first major project that brought together the supplier industry within and around GCE NODE in Agder for a joint large visionary research, development, and innovation programme (RDI) in collaboration with the leading professional communities related to their business areas. The ambition was to improve integration and cooperation between research partners and companies with relevant topics and results that user partners should be able to commercialise.

The user partners were involved in the entire project life cycle, from application and start-up to operation and on to closure. The collaboration was secured with close involvement and a majority in the annual general meeting, quarterly steering committee meetings, regular reference group meetings, workshops and seminars, as well as bilateral contacts and side projects. The industrial partners helped define the challenges for the PhD scholars. However, we only managed to recruit five PhD candidates from the industry partners.

It became natural for the centre to organise the R&D activities at a relatively basic technology readiness level because many of the user partners are in competition with each other and did not want to open for business-critical tasks. From the R&D results, companies could then draw a basis for their innovation and development projects and activities. Along the way, industry partners have also been able to recruit good candidates who were related to the activities in the centre and its environment.

The centre's management and institutions are very grateful that the partner companies quartered in Agder have fully supported the centre throughout its project period, even though they have faced several serious market challenges along the way, which have led to financial austerity. At the same time, the results from the centre are now also useful for other market areas that the companies are addressing in the green energy shift.

TECHNOLOGY TRENDS

Mechatronics is the interdisciplinary combination of mechanical, control, electronic, and computer engineering. Within offshore, mechatronics is incorporated into the production, operation, and maintenance of equipment and installations for the marine and offshore industry. The goal of SFI Offshore Mechatronics was the development of advanced mechatronic systems for the autonomous, safe and efficient operation of facilities in deeper water and harsh environments along the coast and at sea.

For these purposes, the challenges in the centre were divided into seven work packages consisting of wave/motion compensation, actuators, robotics and autonomy, modelling and simulation, monitoring technologies, data analysis with IT integration and big data, as well as technological foresight. The user partners were originally aimed at technology supplies for oil and gas drilling and production, operation and maintenance, but the facility was of a generic nature so that the results have also become useful for other types of maritime operations, such as assembly and installation of offshore wind turbines, but also for land industry such as hydropower plants. The centre was linked to the establishment of the Mechatronics Innovation Lab on Campus Grimstad in 2017, a precursor to the Norwegian catapult scheme.

During the centre's lifetime, the rise of artificial intelligence has been exploited as a new opportunity. The original project description did not place much emphasis on artificial intelligence (AI) or machine learning (ML) techniques or tools, except for the work package on data analytics with IT integration and big data. Today, we know that AI and ML have shown unprecedented growth and adoption. The use of artificial intelligence and machine learning came to play a very important role in the project, adapted as analytical methods that had a major impact on the research results.

SCIENTIFIC RESULTS

Research at the centre has so far produced 202 peer-reviewed publications. To date, 21 PhDs have been completed, 11 remain and are expected to complete by 2024. Furthermore, 226 master's students have had related main assignments linked to the centre's theme, two of whom have gone on to establish their own companies.

Important results have been obtained.

- Motion compensation control algorithms for antisway
- Control models for wave compensation for ship-to-ship cargo handling.
- Modelling and cosimulation of ship movements and motion-compensated cranes
- Modelling of nonlinear dynamic systems
- Prediction of failure events in complex production facilities with "hidden information"
- On-the-go smooth decompression of PI industrial data with quality constraints
- Control models for digital hydraulics
- Precision control and damping of long-armed robots
- Acoustic methods for fault detection in hydraulic systems
- Three-dimensional machine vision with LIDAR scanning (patented)
- Condition monitoring and remaining life management based on machine learning of
  - Fibre ropes with optical-thermal monitoring
  - Steel ropes with acoustic monitoring
  - Large slow-moving rotating bearings with acoustic monitoring
  - Gear systems with acoustic monitoring
  - Initiation and life of fatigue of welds with multiaxial loading

INNOVATION DEVELOPMENTS

To link the research results with the innovation potential, a separate innovation manager was eventually employed, who developed a separate mapping system for innovation potential from the research results at the academic partners. In addition, the industry cluster that ran the foresight activities was engaged in active dialogue with the user partners. It became clear early on that the industrial partners themselves had to develop their own organisations to be able to interact with the R&D environments for useful dialogue and utilisation of the potentials. Similarly, academic participants had to learn to respect the framework under which competing industrial partners are subject. This drove the research towards a somewhat lower but still very satisfactory level of technology readiness. Unfortunately, the collaboration faced some difficult conditions during the years of the Covid19 pandemic.

It must be emphasised that the major advanced innovations have been developed by the industrial partners, based on results and candidates from the centre and the associated environments. Here we can mention PileGripper from MacGregor, autonomous mooring of unmanned ships, wave compensation of very large crane lifting systems, machine vision system for movement control and safety, new condition monitoring solutions, etc. Many of the results require in-depth professional knowledge, which in turn requires further knowledge enhancement from the user partners in order to utilise these. The further utilisation of the results will depend on the future commercial framework for the industry players.

EXTENDED AREAS OF USE

In addition to still being able to contribute to more efficient and safe oil and gas operations at sea with lower energy consumption, the following other very relevant industrial sectors have or may start to make use of our results.

- Renewable energy, in particular
  - Installation, operation, and maintenance of wind power, land and sea
  - Solar power land and sea
  - Wave power
  - Hydropower plant
- Large-scale automation of production and assembly (of marine structures)
- Unmanned land and sea transport
- Aquaculture
- Ports / harbours
- Mineral collection and extraction on the seabed
- Building and construction, infrastructure
- Process industry
- Defence equipment and facilities

INTERNATIONAL NETWORK

The centre included collaboration with Aalborg University (AAU), which also partially took over task responsibility for the activities of hydraulic actuators. There has been a very strong interaction between AAU and UiA along the way with mutual PhD guidance and courses. At RWTH Aachen, two research fellows have contributed to the project with very interesting research topics for machine system analyses and predictive control.

The international scientific advisors were active in the initial phases, but in the later years the assessment of the quality of our work was linked to the evaluation reports from the PhD disputations and the awards the publications received at scientific conferences.

We had two active foreign user partners with us for large parts of the project period who found the project very useful and put up a strong team in our events. However, these withdrew towards the end as their main areas of interest were finished earlier.

WHY WE WANT THE CENTRE TO CONTINUE.

Long-term financing of a group for a vision and a set of common goals provides unique opportunities to help ensure business and social development. When you can combine and put together many connected topics, fertile ground is provided for deep and extensive learning. The results will then be achieved on an international level. The centre has gained respect for its work within "Offshore Mechatronics", which means that there is an interest in collaborating and learning from us.

It is particularly interesting that both UiA and AAU live so closely with the industries in their regions. This provides unique opportunities for mutually beneficial support. The industries need competence in both the form of new relevant knowledge and in the form of competent candidates. Therefore, it has been important that a strong centre and associated environments contribute to lifting both RDI and the educational capacity of the institutions where the industry is located.

THE FUTURE

After a broad strategy process in the centre, during the last two years, it was concluded that the centre had many possible areas for further activities; see the areas of use mentioned above. Apart from the fact that the centre will continue to support the current user partners' new initiatives for autonomous solutions within the oil and gas sector, there are significant opportunities to contribute to the realisation of cost-effective solutions within other ocean-based industries, especially offshore wind. Therefore, UiA has taken special initiatives in the direction of mechatronics for offshore wind, while AAU has new initiatives for both offshore wind and wave power. NTNU has a long-term strong national position and obligation in all forms of renewable energy, where mechatronics will be able to contribute to significant improvements in several fields. We also see that a significantly stronger link with the Mechatronics Innovation Lab and the catapult centres together with activities related to the three existing GCEs in Bergen, Ålesund, and Agder will strengthen the ability to contribute to the industrial environment.

Sammendrag

KULTUR FOR INNOVASJON

SFI Offshore Mechatronics var det første store prosjektet som samlet leverandørindustrien innenfor og rundt GCE NODE i Agder til et felles stort visjonært forsknings-, utviklings- og innovasjonsprogram. Senteret ble etablert i samarbeid med de ledende fagmiljøene knyttet til deres forretningsområder.

Gjennom forskningsbasert innovasjon var ambisjonene å legge til rette for bedre integrasjon og samarbeid mellom forskningspartnerne og bedriftene. Senteret ble også forsterket gjennom etableringen av Mechatronics Innovation Lab på Campus Grimstad som åpnet i 2017, en forløper til den norske katapultordningen.

Brukerpartnerne var involvert i hele prosjektets livssyklus, fra søknad og oppstart og drift av senteret og videre til avslutning. Samarbeidet ble sikret med tett involvering og majoritet i årlige generalforsamlinger, kvartalsvise styringskomitemøter, jevnlige referansegruppesamlinger, workshops og seminarer, samt bilaterale tiltak og bi-prosjekter. Industripartnerne var med å definere utfordringene til PhD-stipendiatene og fem kandidater ble rekruttert direkte fra bedriftene.

Det ble naturlig for senteret å innrette FoU-aktivitetene til forskningspartnerne på et relativt grunnleggende teknologisk modenhetsnivå fordi mange av brukerpartnerne er i konkurranse med hverandre. Fra forskningen kunne så bedriftene hente resultater som kunne foredles videre innenfor utviklings- og innovasjons-prosjekter internt i bedriftene. Industripartnerne har underveis også kunnet rekruttere gode kandidater som var knyttet til aktivitetene i senteret og dets miljø.

Senterets ledelse og institusjoner er svært takknemlig for at partnerbedriftene som har hovedsete i Agder har støttet fullt opp om senteret gjennom hele dets prosjektperiode, til tross for at de har møtt flere alvorlige markedsmessige og økonomiske utfordringer underveis. Samtidig er resultatene nå også nyttige for andre markedsområder som bedriftene nå adresserer i det grønne energi-skiftet.

TEKNOLOGITRENDER

Mekatronikk er den tverrfaglige sammensetningen mellom mekanisk-, kontroll-, elektronikk- og datateknikk. Målet med SFI Offshore Mechatronics var utviklingen av avanserte mekatroniske systemer for autonom, sikker og effektiv drift av anlegg på dypere vann og tøffe miljøer langs kysten og til havs.

For å nå målene ble utfordringene i senteret delt inn i syv arbeidspakker bestående av bølge/bevegelseskompensasjon, aktuatorer, robotikk og autonomi, modellering og simulering, overvåkingsteknologier, dataanalyse med IT-integrasjon og stordata, samt teknologisk fremsyn.

Brukerpartnerne var hovedsakelig teknologileverandører til offshore olje- og gassindustrien. Forskningsutfordringene og resultatene ble imidlertid i liten grad knyttet til problemstillinger som var spesifikke for olje&gass. Derfor finner vi eksempler på anvendelser av forskningsresultatene både innenfor offshore energi som f.eks. installasjon av havvindturbiner, og innen landindustri som f.eks. drift og vedlikehold av vannkraftverk.

Med unntak av arbeidspakken om dataanalyse med IT-integrasjon og stordata, la den opprinnelige prosjektbeskrivelsen liten vekt på kunstig intelligens (KI) eller maskinlæringsteknikker (ML).

I dag vet vi at KI og ML, særlig i den siste halvdelen av prosjektperioden, har hatt en eksplosiv vekst og integrasjon. Denne utviklingen ble tidlig fanget opp og utnyttet som en ny mulighet i senteret og bruken av KI og ML har hatt stor innvirkning på forskningen, metodevalg og resultater.

VITENSKAPELIG RESULTATER

Forskningen i senteret har frem til nå gitt 202 fagfellevurderte publikasjoner. Til nå har 21 PhD-er fullført, 11 gjenstår som forventes ferdig innen 2024. Videre har 226 masterstudenter hatt relaterte hovedoppgaver knyttet til senterets tema, herav har to gått videre med egen bedriftsetablering.

Viktige resultater har vært

- Styringsalgoritmer for
  - bevegelseskompensering med anti-sving
  - bølgekompensering av skip til skip lasthåndtering
  - presisjonskontroll og demping av langarmede roboter
- Modellering og samsimulering av
  - skipbevegelser og bevegelseskompenserte kraner
  - ikke-lineære dynamiske systemer
- Predikering av feilhendelser i sammensatte produksjonsanlegg med «skjult informasjon»
- Styringsmodeller for digital hydraulikk
- Akustiske metoder for feildeteksjon i hydrauliske systemer
- Tredimensjonalt maskinsyn med LIDAR skanning (patentert)

- Tilstandsovervåking og restlevetidsstyring basert på maskinlæring av
  - Fibertau med optisk-termisk overvåking
  - Ståltau med akustisk overvåking
  - Store saktegående roterende lagre med akustisk overvåking
  - Gir-systemer med akustisk overvåking
  - Initiering og levetid fra utmatting av sveisesømmer med flerakset belastning

INNOVASJONSUTVIKLING

For å koble forskningsresultatene mot innovasjonspotensialer, ble det etter hvert ansatt en dedikert innovasjonsleder som utviklet et eget kartleggingssystem for forskningsresultatene hos de akademiske partnerne. I tillegg hadde industriklyngen som drev fremsynsaktivitetene en aktiv dialog med brukerpartnerne.

Det ble tidlig klart at industripartnerne selv måtte utvikle sine egne organisasjoner for å kunne vekselvirke med FoU-miljøene. Tilsvarende måtte de akademiske deltakerne lære å respektere de rammer som de konkurrerende industripartnerne er underlagt. Dette drev forskningen mot et noe lavere teknologomodenhetsnivå med fokus på komponenter og byggesteiner og i mindre grad sluttbrukeranvendelser og produkter. Dessverre fikk samarbeidet og ikke minst premissene for å utløse innovasjoner noen tunge betingelser under årene med Covid19-pandemien.

I prosjektperioden har flere av industripartnerne hatt pågående store avanserte innovasjonsprosjekter som har blitt understøttet av resultater og kandidater fra senteret og de tilknyttede miljøene. Her kan det nevnes bølgekompenserende pålegriper (MacGregor), autonom fortøyning av ubemannet skip (MacGregor), bølgekompensering av svært store kranløftesystemer (NOV), maskinsynsystem for bevegelseskontroll og sikkerhet (NOV), nye tilstandsovervåkings-løsninger (HMH).

Mange av de nevnte resultatene krever faglig dybdekunnskap som igjen krever ytterligere kunnskapsløft fra brukerpartnerne for å utnytte disse. Videre resultatutnyttelser vil være nært knyttet til markedsutsikter og de fremtidige kommersielle rammene for industriaktørene.

UTVIDEDE BRUKSOMRÅDER

Foruten å fortsatt kunne bidra til effektive, sikre og energieffektive olje- og gass-operasjoner til havs, så har allerede eller kan på sikt følgende industrisektorer gjøre nytte av resultater fra senteret:

- Fornybar energi i særdeleshet
  - Vindkraft installasjon, drift og vedlikehold, land og hav
  - Solkraft land og sjø
  - Bølgekraft
  - Vannkraftanlegg
- Mineralsanking og utvinning på havbunn
- Ubemannet transport land og sjø
- Akvakultur-anlegg
- Havner
- Storskala automatisering av produksjon og sammenstilling (av havkonstruksjoner)
- Bygg og anlegg, infrastruktur
- Prosessindustri
- Forsvarsutrustning og anlegg

INTERNASJONALT NETTVERK

Senteret har samarbeidet godt med Aalborg Universitet (AAU) som også delvis overtok ansvaret for arbeidspakken knyttet til aktuatorer. Det har vært en sterk vekselvirkning mellom AAU og UiA underveis med gjensidig PhD-veiledning og kursing. Ved RWTH Aachen har to stipendiater bidratt til prosjektet med meget interessante forskningstema for systemanalyser og predikering.

De internasjonale vitenskapelige rådgiverne var aktive i innledende faser. De senere år ble vurderingen av kvaliteten på våre arbeider koblet til evalueringsrapportene for PhD-avhandlingene og de utmerkelser som publikasjonene fikk på internasjonale vitenskapelige konferanser. Vi hadde også to aktive internasjonale brukerpartnere med i store deler av prosjektperioden som fant prosjektet svært nyttig og stilte opp mannsterke i våre samlinger. Disse trakk seg imidlertid ut mot slutten av prosjektet på grunn av endringer i kjernevirksomhet og ansvarsområder internt i konsernene.

HVORFOR VI VIL HA SENTERET VIDERE

Den langsiktige finansieringen av en visjonær gruppering med felles mål gir unike muligheter for å bidra til å sikre nærings- og samfunnsutvikling. Når en kan sette sammen og kombinere mange sammenhengende tema gis det grobunn for både dyp og omfangsrik læring. En vil da oppnå resultater på internasjonalt nivå. Senteret har oppnådd respekt for sitt virke innen «Offshore Mechatronics» som gjør at det er interesse for å samarbeide, men også å lære fra oss.

Det er spesielt interessant at både UiA og AAU lever så tett med industriene i sine regioner, noe som gir unike fortrinn og muligheter. Næringene trenger kompetanse både i form av ny relevant kunnskap, men også i form av kompetente kandidater. Det har derfor vært viktig at et sterkt senter og de tilknyttede miljøene har bidratt til å løfte kapasiteten for FoI og utdanning der industrien er lokalisert.

FREMTIDEN

Etter en bred strategiprosess i senteret kom en i løpet av de siste to årene frem til at senteret hadde mange mulige områder for videre aktiviteter. Foruten at senteret vil fortsette å støtte opp under de nåværende brukerpartnernes nye initiativ for autonome løsninger innen olje og gass, er det betydelige muligheter for å bidra til å realisere kostnadseffektive løsninger innen andre havbaserte industrier, da er spesielt havvind først kommende. UiA har derfor tatt spesielle initiativ i retning mekatronikk for havvind, mens AAU har nye initiativ både mot havvind og bølgekraft. NTNU har en sterk nasjonal posisjon innen alle former for fornybar energi der mekatronikk vil kunne bidra til vesentlige forbedringer på flere felt. Vi ser også at en vesentlig sterkere kobling med Mechatronics Innovation Lab og katapultsentrene sammen med aktiviteter knyttet til de tre eksisterende GCE-er i Bergen, Ålesund og Agder vil kunne forsterke nye satsinger videre.

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."

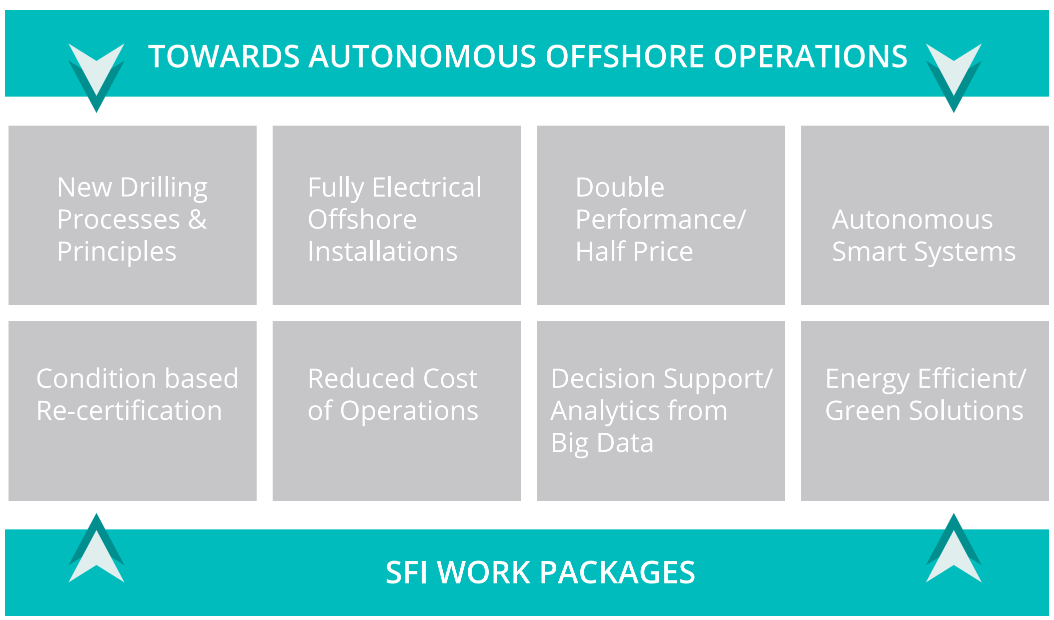
MISSION STATEMENT

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:



The vision and objectives of the centre were outlined during the first year of the project and was fixed throughout the project period. The eight grand challenges covering technical, financial, and regulatory challenges were outlined during several workshops. The aim of the grand challenges was to align the activities in the work packages with a transition into autonomous offshore operations. In general, the activities in the centre have aligned well with the grand challenges identified. Except for some work related to modelling & simulation of drill-strings, the new drilling processes & principles challenge have been covered less in the research.

To further define and adjust the activities, a foresight process was initiated which started with a trend scan workshop in June 2016.
The foresight process final report was delivered in March 2017 and outlined four strategic options. The strategic options aligned well with the grand challenges identified earlier, but to follow up on the fourth strategic option, a new PhD project was defined related to digital servitisation and business model innovation.

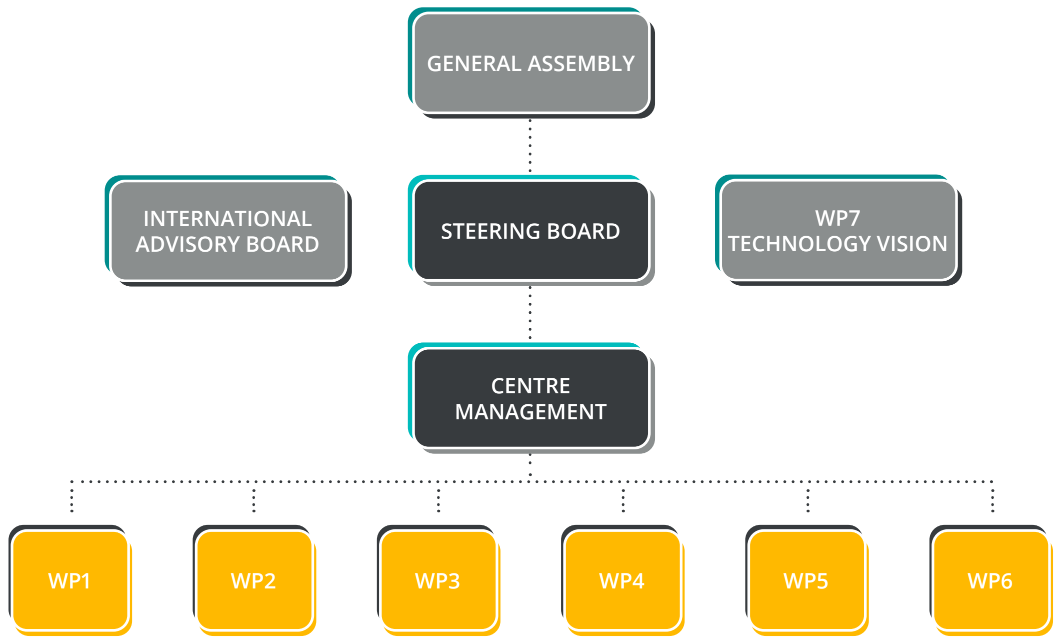
Apart from WP6 (Data Analytics & Big Data), the original application did not put much emphasis on AI or machine learning techniques or tools. At that time, AI and machine learning was yet to become mainstream. Today we know that AI and machine learning in the past 8 years has seen unprecedented growth and adoption. This development influenced the research work in the centre. Especially in the second half of the project period, the use of AI and machine learning played an important role. Especially AI and machine learning became highly integrated into the research methods and research results, especially in WP2, WP3 and WP5, in addition to WP6.

Partners

A total of 17 partners from three different countries were involved in the centre. These were represented by eleven industrial users, one industry cluster, four universities, and one research institute. Most of the partners were involved from start to finish.

University of Agder (Host Institution)	Academic	Norway	2015-2023
NTNU (NTNU and Aalesund University College until 2016)	Academic	Norway	2015-2023
Aalborg University	Academic	Denmark	2015-2023
NORCE Research (Teknova and Iris Research until 2018)	Academic	Norway	2015-2023
RWTH Achen	Academic	Germany	2015-2023
National Oilwell Varco Norway (NOV)	Industry	Norway	2015-2023
HMH (former MHWirth)	Industry	Norway	2015-2023
MacGregor	Industry	Norway	2015-2023
SLB (former Cameron Sense)	Industry	Norway	2015-2023
GCE NODE (Industry Cluster)	Industry	Norway	2015-2023
Skeie Technology Group	Industry	Norway	2015-2023
Lundin Norway (Merged into AkerBP in 2022)	Industry	Norway	2015-2023
StepChange	Industry	Norway	2015-2023
ABB	Industry	Norway	2015-2020
Bosch-Rexroth	Industry	Germany	2015-2021
Klüber Lubrication	Industry	Germany	2015-2021
Egde Consulting	Industry	Norway	2015-2022

Organisation



The centre management consisted of an academic leader in 50% position, an administrative manager also in 50% position, a part-time controller from the host institution, an innovation officer in 50% position the last four years, and six leaders of the work packages for seven work packages. The centre also had a chief technology officer at the start. The centre management reported to the centre steering board.

The centre had a small international advisory board. This board was more active in the early stages in the centre.

Industry and research partners distributed across three countries (Norway, Denmark and Germany) was a strong contribution to the international dimension of the centre. In addition to this, the researchers in the centre utilized their extensive international networks.

Centre Management

The centre management was formed of personnel from the host institution, University of Agder.


Geir Grasmo
Centre Director
(2020-2023)


Asle Pedersen
Administrative Manager
(2020-2023)


Even Skretting
Project Controller
(2020-2023)


Geir Hovland
Centre Driector
(2015-2020)

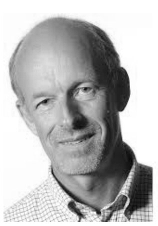

Rachel F. Syrtveit
Administrative Manager
(2015-2018)


Anne-Line Aagedal
Administrative Manager & Controller
(2019-2020)

Steering Board

A new Steering Board was appointed by the General Assembly every second year. The board consisted of seven members, and two deputy members, all attending for each meeting. The majority of the board members were from the Industry Partners (four members and one deputy member).


Tom Fidjeland
Chair of the Board
(2021-2023)


Leif Haukom
Chair of the Board
(2015-2020)

Steering Board 2015-2023

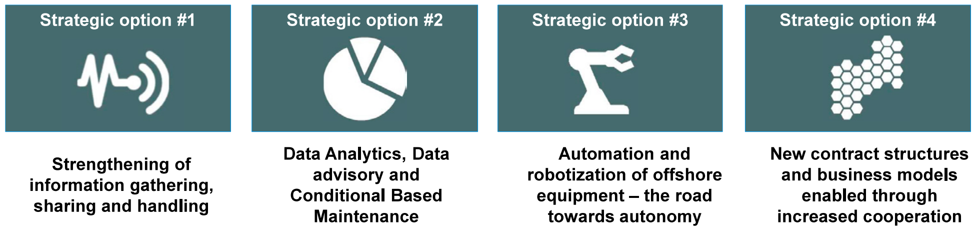
Period	Board	Period	Board
2022-2023	Chair of the Board: Tom Fidjeland (GCE Node) Deputy Chair of the Board: Peder Sletfjerding (NOV) Board Members: Sjur Henning Hollekim, (HMH) Torben Ole Andersen (AAU) Olav Egeland (NTNU) Jorunn Gislefoss, (UiA) Anstein Jorud (SLB) Deputy Board Members: Rune Schlanbusch, (NORCE) Hugo Rosano (MacGregor, 2023) Jørn Bøch (Egde, 2022)	2021	Chair of the Board: Tom Fidjeland (GCE Node) Deputy Chair of the Board: Morten Halvorsen (NOV) Board Members: Sjur Henning Hollekim (HMH) Jisha Panikar (Klüber Lubrication) Torben Ole Andersen (AAU) Olav Egeland (NTNU) Jorunn Gislefoss (UiA) Deputy Board Members: Anstein Jorud (SLB) Thomas J.J. Meyer (NORCE)
2019-2020	Chair of the Board: Leif Haukom (GCE Node) Deputy Chair of the Board Morten Halvorsen (NOV, 2020) Charlotte Skourup (ABB, 2019) Board Members: Sjur Henning Hollekim (HMH) Øyvind Mydland (StepChange) Houxiang Zhang (NTNU Aalesund) Philipp Schubert (RWTH Achen) Geir Grasmo (UiA) Deputy Board Members: Thor Arne Håverstad (NORCE) Eivind G. Stensland (MacGregor)	2017-2018	Chair of the Board: Leif Haukom (GCE Node) Deputy Chair of the Board Charlotte Skourup (ABB) Board Members: Morten Halvorsen (NOV) Arild Strand (Bosch Rexroth) Torben Ole Andersen (AAU) Thor Arne Håverstad (NORCE) Michael Rygaard Hansen (UiA) Deputy Board Members: Eivind G. Stensland (MacGregor) Torgeir Welo (NTNU)
2015-2016	Chair of the Board: Leif Haukom (GCE Node) Deputy Chair of the Board Charlotte Skourup (ABB) Board Members: Kari Nielsen (Lundin) Bjarne Sandrib (MHWirth) Jørn Vatn (NTNU) Felix Strassburger (RWTH Aachen) Rein Terje Thorstensen (UiA) Deputy Board Members: Klaus Schöffel (Teknova) Stian Myhre (NOV)		

Cooperation and Interaction

The centre was organised with the aim of strong interaction between the academic and industrial partners. The industry representatives collected and brought their challenges to the centre even before the project application was developed. They were actively involved in defining the strategy and the subjects of the tasks to be accomplished within the research.

The objectives of the centre were outlined during the first year of the project. The eight grand challenges covering technical, financial, and regulatory challenges were outlined during several workshops; see page 10. The aim of the grand challenges was to align the activities in the work packages with a transition into autonomous offshore operations. In general, the activities in the centre have aligned well with the identified grand challenges.

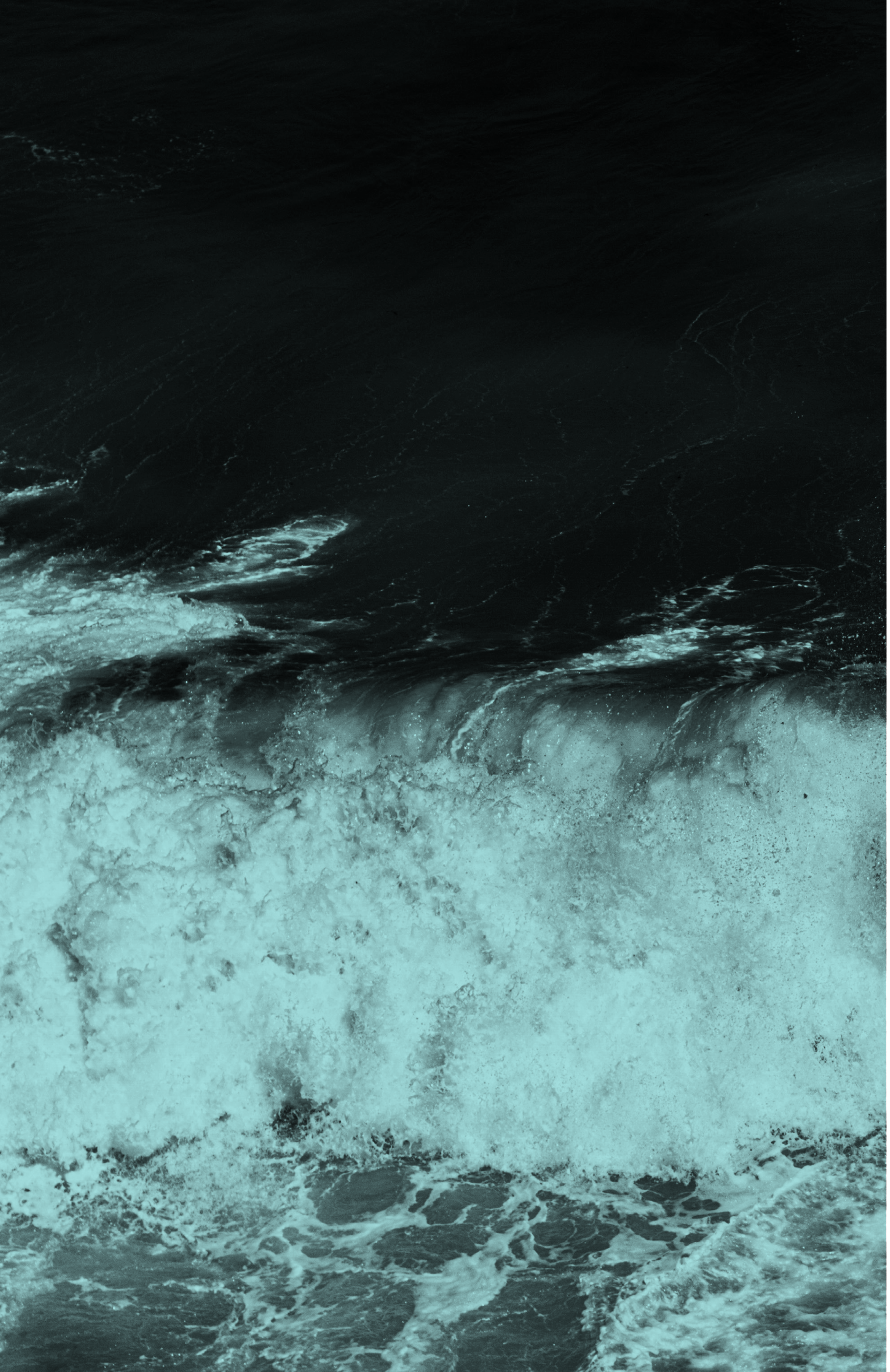
To further define and adjust the activities, a foresight process was initiated, which started with a trend scan workshop. A final report on the foresight process was delivered in March 2017 and outlined four strategic options. The strategic options aligned well with the grand challenges identified earlier, but to follow up on the fourth strategic option, a new Ph.D. project related to digital servitisation and business model innovation was defined.



Plans were updated and approved at annual general assemblies and progress was followed at regular steering board meetings four times a year. The work package leaders were regularly invited to the steering board meetings in an alternating schedule.

The research was carried out in seven work packages with 40 tasks mostly filled with Ph.D. fellows (32), postdocs (7) and a few researchers in addition to academic supervisors and work package leaders. The tasks were distributed in time slots, and the fellows partly worked in parallel and partly interactionally, and thus gained both deeper and broader understanding and higher momentum, giving relevant high-level research results. Fellows and postdocs shared open landscape offices with up to 6-8 fellows each. The fellows were enrolled in Ph.D. programmes of their host institutions and fulfilled their local obligations on coursework, research regulations, internal participation, dissemination in faculty, etc.

Close interaction was secured across the centre through high frequency of in-person bilateral meetings, reference group meetings and annual conferences. The partners were represented with relevant technical and R&D personnel at these events. Reference group meetings in the work-packages took place 2-4 times a year. These meetings were an important opportunity to disseminate results, contribute to discussions, and get valuable feedback from the industrial partners. The reference group meetings were internal and exclusive to the consortium members.



Work Packages WP1 – WP7

The research was 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 Integration and Big Data
- Work-Package 7: Technology Vision

WP1

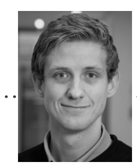
WP1 LEADER 1
Morten Kjeld Ebbesen, UiA
Sup. WP1.4 and WP1.6.
Co-sup. WP1.2, WP1.3 and WP1.7.

WP1 LEADER 2
Torben Ole Andersen, AAU
Sup WP1.2 and WP 1.7,
Co-sup. WP1.4 and WP1.6

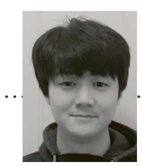
WP1.2
Sondre Nordås
UiA

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
Sup. WP2.1-4, WP2.7-8, Co-sup. WP2.5.

Geir Hovland
UiA
Sup. WP2.5

Dirk Abel
RWTH Aachen
Sup. WP2.6

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
Sup. WP3.7

Geir Hovland
UiA
Sup. WP3.1, WP3.2.
Co-sup. WP3.6,
WP3.7

Olav Egeland
NTNU
Sup. WP3.3

Frank Y. Li
UiA
Sup. WP 3.5

Ilya Tyapin
UiA Sup. WP3.6,
Co-sup. WP3.7

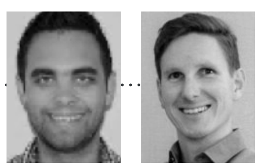
David Anisi
UiA / NMBU
Sup. WP3.8

Knut Berg Kaldestad
UiA
Researcher

Charlotte Skourup
ABB
Co-sup.WP3.4

Linga Cenke-ramaddi
Co-sup. WP3.9

Ajit Jha
UiA
Sup. WP 3.9



WP3.1
Joacim Dybedal
UiA

WP3.2
Atle Aalerud
UiA

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
Sup 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 University

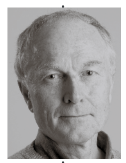
WP 5.1	WP 5.2	WP 5.3	WP 5.4	WP 5.5	WP 5.6
"Big tapered roller bearings"	"Big steel ropes"	"Big fiber ropes"	"Winch Lifetime predictions"	"Welded joints fatigue predictions"	"Hydraulic Cylinders"

Tor Inge Waag
Task leader, NORCE

Rune Schlanbusch
Task leader, NORCE

Ellen Nordgård-Hansen
Task leader, NORCE

Stephan Neumann
Task leader, Aachen IME



Tom Lassen
Task leader, UiA

Kjell Gunnar Robbersmyr
UiA
Sup. WP5.1

WP51
Martin Hemmer
UiA

WP5.3
Shaun Falconer
UiA

Geir Grasmo
UiA
Sup. WP5.3

WP5.4
Mohammed Yusuf
Aachen IME

WP5.5
Zbigniew Mikulski
UiA

WP5.6
Vignesh Shanbhag
NORCE

WP6

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

Daniel Romero
UiA
Co-sup. WP6.1

Jing Zhou
UiA
Co-sup. WP6.2

Øyvind Mydland
UiA, Liaison

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

WP6.2
Emilio Ruiz Moreno
UiA

WP6.3
Kevin Roy
UiA

WP7

WP7 LEADER 1
Christian von der Ohe, GCE NODE

WP7 LEADER 2
Ellen Nordgård-Hansen, NORCE

Thor Helge Aas, UiA
Sup WP7.1

Jan Helge Viste, GCE NODE
Industry liaison WP7.1

WP7.1
Marius T. Kristiansen
UiA

WORK-PACKAGE 1: DRIVES

Timeline 2015–2023 (quarters 1–4)

- WP1.2 Sondre Nordås (PhD, UiA)
- WP1.6, Wei Zhao (PhD, UiA)
- WP1.4 Daniel Hagen (PhD, UiA)
- WP1.3 Viktor H. Donkov (PhD, Aalborg)
- WP1.7, Thomas Farsakoglou (PhD, Aalborg)
- WP1.5 Søren Ketelsen (PhD, Aalborg)
- WP1.8, Mohit Bhola (Post.Doc, Aalborg)

WORK-PACKAGE 2: MOTION COMPENSATION

Timeline 2015–2023 (quarters 1–4)

- WP2.1 Geir Ole Tysse, (PhD, NTNU)
- WP2.2 Torstein Myhre, (Post.Doc, NTNU)
- WP2.3 Andrej Cibicik, (PhD, NTNU)
- WP2.7, Hans Kristian Holen (PhD, NTNU)
- WP2.4 Alexander Meyer Sjøberg, (PhD, NTNU)
- WP2.8, Alexander Meyer Sjøberg (Post.Doc, NTNU)
- WP2.5 Sondre Sanden Tørdal (PhD, UiA)
- WP2.6 Philip Schubert, IRT, (PhD, RWTH Aachen)

WORK-PACKAGE 3: ROBOTICS AND AUTONOMY

Timeline 2015–2023 (quarters 1–4)

- Researcher, Dr. Knut Berg Kaldestad (UiA)
- WP3.1 Joacim Dybedal, (PhD, UiA)
- WP3.2 Atle Aalerud, (PhD, UiA)
- WP3.3 Aksel Sveier, (PhD, NTNU)
- WP3.5 Thilina Nuwan Weerasinghe (PhD, UiA)
- WP3.6 Dipendra Subedi, (PhD, UiA)
- WP3.7 Ronny Landsverk (PhD, UiA)
- WP3.8 Yvonne Murray, (integr. master/ PhD, UiA)
- WP3.9 WP6.5 Jose Amendola, (PhD, UiA)

WORK-PACKAGE 4: MODELLING AND SIMULATION

Timeline 2015–2023 (quarters 1–4)

- WP4.1 Savin Viswanathan (PhD, NTNU)
- WP4.2 Njål Tengesdal (PhD, NTNU)
- WP4.3 Lars Ivar Hatledal (PhD, NTNU Aalesund)
- WP4.4 Gaute Fotland (PhD, NTNU)
- WP4.5 Savin Viswanathan (Post. Doc NTNU)

WORK-PACKAGE 5: MONITORING TECHNIQUES

Timeline 2015–2023 (quarters 1–4)

- WP5.1 Martin Hemmer, (PhD, UiA)
- WP5.2 Rune Schlanbusch - NORCE
- WP5.3 Shaun Falconer (PhD, UiA)
- WP5.4 Achim Feldermann and Lothar Wöll, (PhD, IME - Aachen)
- Mohammed Yusuf, (PhD IME Aachen)
- WP5.5 Zbigniew Mikulski, (PhD, UiA)
- WP5.6 Vignesh Shanbhag - NORCE

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

Timeline 2015–2023 (quarters 1–4)

- WP6.1 Luis M. Lopez-Ramos (Post.Doc, UiA)
- WP6.2 Emilio Ruiz Moreno, (PhD, UiA)
- WP6.3 Kevin Roy, (PhD, UiA)
- WP6.4 Luis M.Lopez-Ramos, (Post.Doc, UiA)

WORK-PACKAGE 7: TECHNOLOGY VISION

Timeline 2015–2023 (quarters 1–4)

- WP7.1 Marius Kristiansen (PhD, UiA)

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).

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 Modelling 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.

WP7.1 The management of digital business model innovation

Financing and results

FINANCING THROUGH THE LIFE OF THE CENTRE

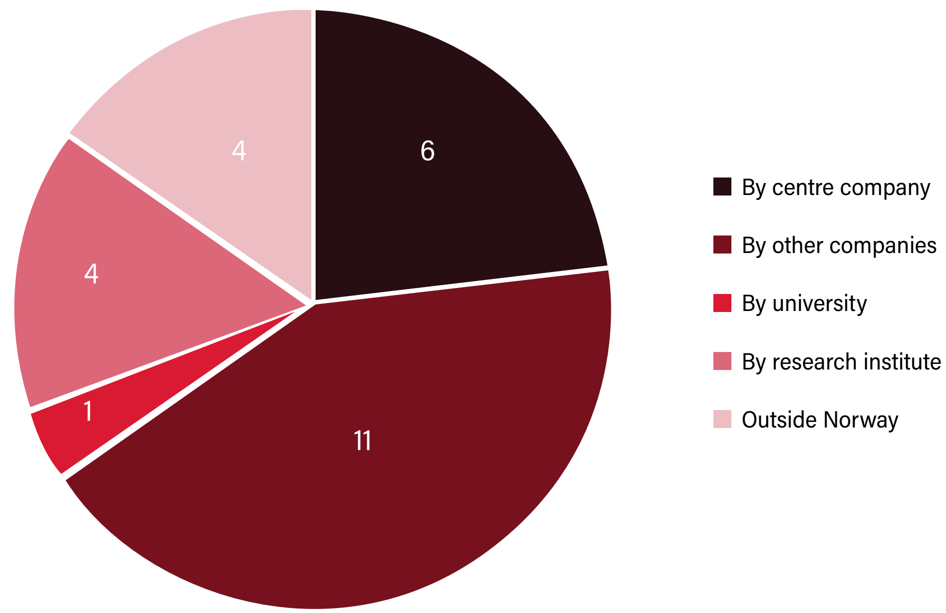
Contributor	Cash	In-kind	Total
Host	-	22,8	22,8
Research partners	-	30,3	30,3
Companies	37,4	25,5	62,6
Public partners	-	-	-
RCN	96,3	-	96,3
Sum	133,7	78,3	211,9

DISTRIBUTION OF RESOURCES

Type of activity	NOK million
Research projects	178,4
Common centre activities	20,3
Administration	13,3

Equipment rental is included in the research project costs. In addition, the partners have invested more than 5MNOK in required equipment which have been made available to the research projects.

EMPLOYMENT OF PHD CANDIDATES



Eleven candidates (eight with financial support from the centre) have not yet completed their PhD. Out of the four employed Outside Norway, one was hired by a centre partner company, two by other companies and one by a university.

RESULTS - KEY FIGURES

	2015	2016	2017		2018	2019	2020	2021	2022	2023	Total
Scientific publications (peer reviewed)		16	29		33	40	44	19	13	10	202
Dissemination measures for users	12	5	6		23	19	14	17	11	4	111
Dissemination measures for the general public	1	15	15		2	5	1	3	2	7	51
PhD degrees completed						1	7	7	4	2	21
Master degrees		20	38		77	16	23	18	26	8	226
Number of new/improved methods/models/prototypes finalised		1			4	2	1	3	1		12
Number of new/improved products/processes/services finalised			1						1	2	4
Patents registered						1					1
New business activity		1	1		1	1	1	0	2	0	7

Research

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 were several competing companies in the centre which operates in the same business segments, it was decided to focus on enabling technologies and technological building blocks, rather than working too closely with product specific development.

The work was organized into seven work packages (WP1-WP7) that addressed important challenges for the offshore industries.

WP1
DRIVES

- Reliable and energy-efficient drives
- Drive topologies

WP2
MOTION COMPENSATION

- Operation in deep water and harsh conditions
- Crane control and damping of crane load pendulum motion

WP3
ROBOTICS AND AUTONOMY

- Cost-effective and safe autonomous operations
- 3D perception and computer vision algorithms

WP4
MODELLING AND SIMULATION

- Co-simulation and integrated simulation models
- Multi-physics simulation

WP5
MONITORING TECHNIQUES

- Remaining Useful Life estimation and decision support
- Condition based re-certification

WP6
DATA ANALYTICS & BIG DATA

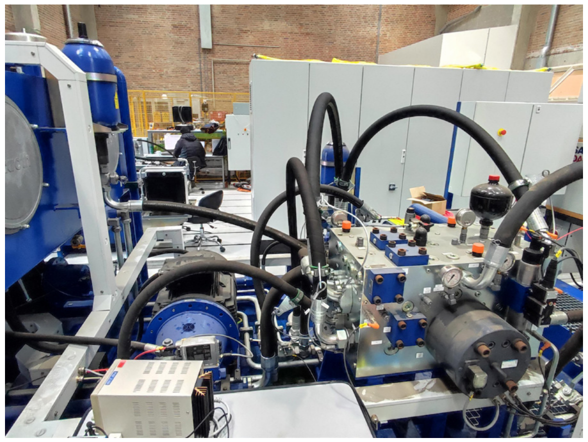
- Decision Support and Early Warning
- Data-driven optimisation of processes

WP7
TECHNOLOGY VISION

- Business model innovation
- Digital Servitisation

WP1 – Drives

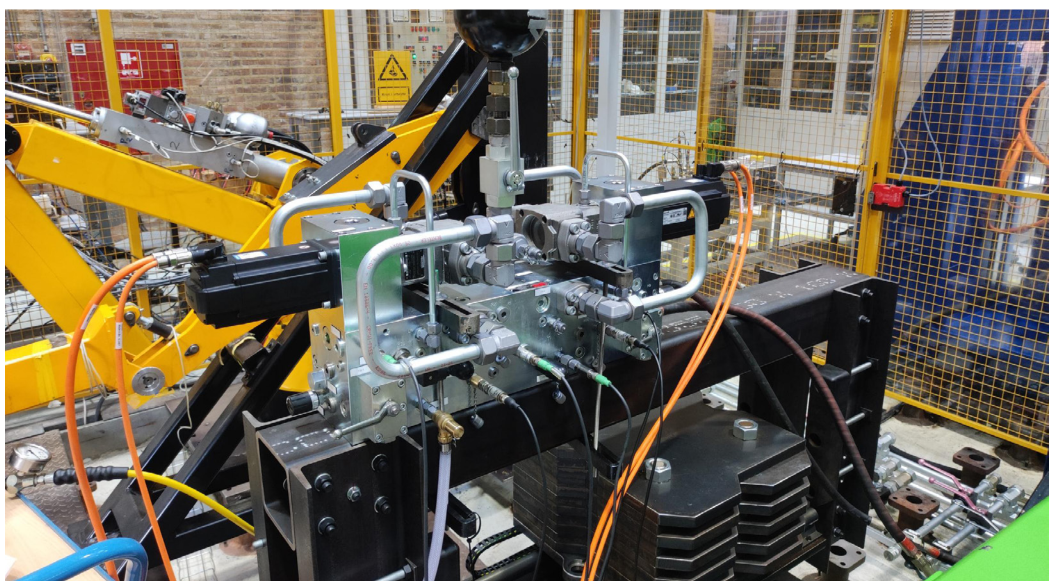
The activities in Work Package 1 have focused on topologies for drives to reduce the power consumption and/or simplify installation when maintaining satisfying performance. Both linear and rotary drives have been considered.



Attention has been given to the development of different concepts for autonomous drives with a closed hydraulic system that only requires electrical supply and a control signal. Attention has also been given to research related to the use of digital hydraulics for both rotary drives for winches and linear drives for cranes. The overall aim has been to obtain drives with significantly better energy efficiency while maintaining the control performance.

The work in the package was organized in seven subtasks – six PhD-projects and one postdoctoral researcher. All have utilized modeling and simulation of hydraulic and mechanical systems, and significant resources have been put into experimental setups for test and verification purposes.

13 representatives from seven different companies were active in the reference group. WP-leaders were professor Torben Ole Andersen (AAU) and Associate Professor Morten Kjeld Ebbesen (UiA).

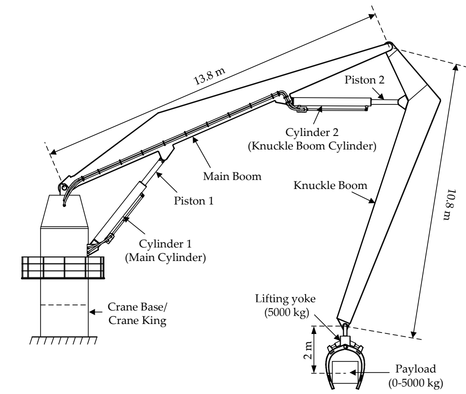


Reliable and Energy Efficient Drives

Offshore applications have demanding safety and performance requirements such as high force, passive load-holding, and four-quadrant operation. For decades, hydraulic cylinders have been the preferred choice to meet these tough requirements.

In conventional hydraulic systems, the hydraulic fluid is supplied by a central hydraulic power unit (HPU). The major downside of using a conventional HPU is poor system energy efficiency, and high energy usage, even under light loads.

A self-contained cylinder, also referred to as integrated cylinder, and electro-hydraulic compact drive (ECD) is an alternative approach with significant energy saving potential. ECD is a promising design, but to meet the demanding offshore requirements, more research and development was needed.



Søren Ketelsen was PhD-candidate in Work Package 1 and was enrolled at Aalborg University 2018-2021. He worked on the development of autonomous drives. He made a very systematic review of the work done in the field so far and classified the already known topologies.

His review paper based on this work published in 2019 has gained large interest in the community. A medium sized knuckle boom crane was used as a theoretical case study. Ketelsen proposed a new topology for a drive including the possibility of energy regeneration in case of assistive loads and an indirectly controlled hydraulic lock for load holding functionality. At the centre annual conference in 2019 Søren was awarded with the centre Innovation Award for his invention.

“The lock ensures that the cylinder is hydraulically locked in case of power loss or hose burst but may be unlocked by properly controlling the internal pressure states”, says Søren.

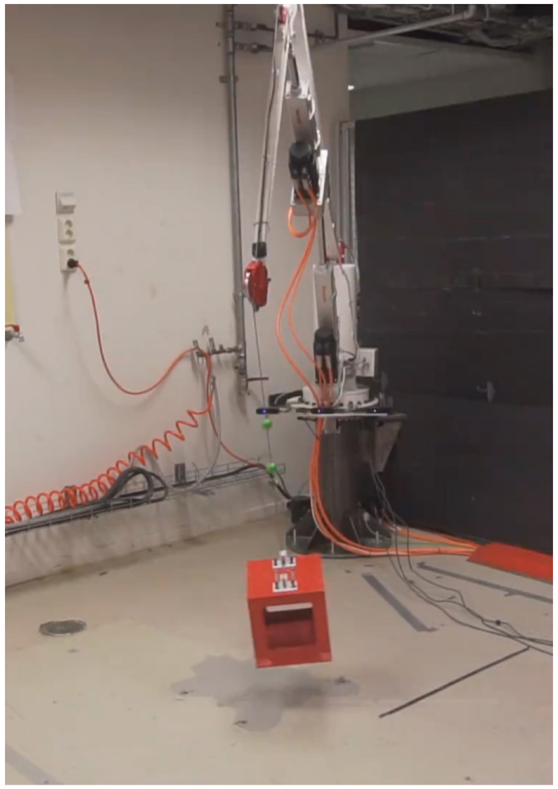
“By simulating a realistic motion cycle of the crane, a reduced energy consumption of 58 % to 75 % compared to a valve-controlled system is found, while good motion tracking performance has also been established.”, he says.

The design of a test-bench for experimental validation of the proposed drive was an additional valuable contribution of his work. The linear hydraulic test-bench has since been built and used by his successor in the project. Complemented by a rotary hydraulic test-bench this forms a solid infrastructure, which is ready and available to be used in new projects and initiatives.

WP2 – Motion Compensation

Activities within Work Package 2 have been well aligned with the vision of autonomous offshore operations and the grand challenges identified such as autonomous smart systems.

Traditionally the motion compensation of equipment has been performed in a human-machine interaction. For example, heave compensation is widespread in offshore vessels, but swing compensation have to a large extent required manual compensation by the crane operator. To succeed with the vision of autonomous offshore operations more research into automated motion compensation is important.



The work package was organised in eight subtasks of which six were covered by PhD positions and two by PostDoc positions. Operations such as vessel to platform and vessel to vessel have been considered.

The contributions from the work-package have also included theoretical work with a high number of papers published in level 2 journals.

Three of the companies have been very active in the reference group. Due to highly related activities several of the reference group meetings have been jointly with WP3 and WP4. WP-leader was Professor Olav Egeland (NTNU).

Highly relevant competence

Sondre Sanden Tørdal at the University of Agder was employed by the centre industry partner MacGregor Norway, even before he handed in the final version of his PhD thesis in mechatronics.

Sondre successfully defended his PhD thesis on March 19, 2019. The title of the thesis was: “Real-Time Motion Compensation in Ship-to-Ship Load Handling”. A main contribution from the research is a new assistance system which the crane operators can use when they are loading containers between ships in high wave-conditions off-shore.

So-called "ship-to-ship" load handling usually requires a special crew with a lot of experience and expertise in safety and other dynamic factors. In his work Sondre made use of advanced control theory, sensor testing and sensor fusion, and sensor fusion for real-time motion estimation.

During his project Sondre was also a key contributor to the build-up of MotionLab, a concurrent project supported by INFRASTRUKTUR (Norwegian Research Infrastructure funding initiative). This infrastructure made it possible to test and verify the technology developed during his PhD project.

Sondre decided to pursue his dreams, and in mid 2020 he set up his own company, MotionTech.

“I studied mechatronics, which in itself is mainly technically aimed at mathematics and physics. Now that I run my own company, I get a lot of benefit from this knowledge in the form of selling cutting-edge expertise in areas where precisely mathematics and physics are absolutely fundamental to creating good solutions for the customer.”, Sondre says.

MotionTech deliver software solutions within the field of robotics and vision applications for real-time industrial problems. Their speciality is solving complex problems within robotics, vision, AI, and ML using mainly open-source tools combined with Agile development methods.

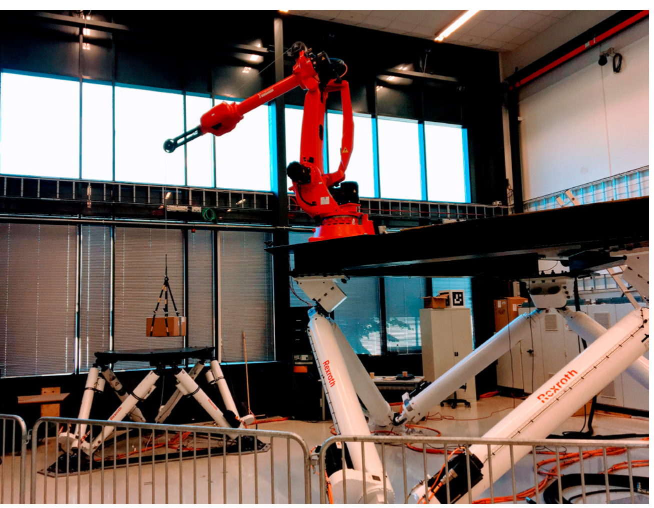
MotionTech has grown into a profitable company with two full time employees and a lot of exciting customer projects, in Norway and abroad.

WP3 – Robots and Autonomy

Activities within Work Package 3 have been well aligned with the vision of autonomous offshore operations and the grand challenges identified such as autonomous smart systems.

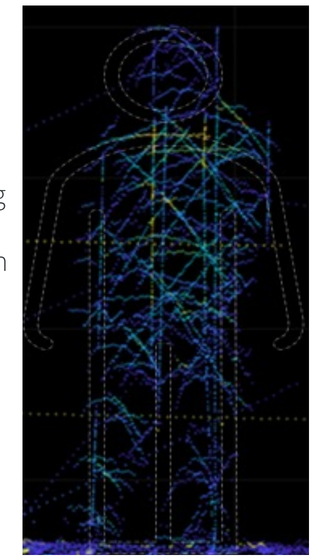
The work package was organised into eight subtasks with one corresponding PhD position in each subtask. Enabling technologies such as computer vision algorithms and 3D sensors have been parts of several of the subtasks. Other activities include research on long-reach, light-weight robotic arms enabling applications such as autonomous mooring or operations in offshore aquaculture. Enabling technologies for autonomous operations such as Ultra Reliable Communications (URC) for 5G Networks have also been part of the research.

More than 20 representatives from six companies have been active in the reference group. In the period 2015-2020, the WP-leader was Professor Geir Hovland (UiA) followed by Professor Jing Zhou (UiA) in the period 2021-2023.



Towards autonomy with robust object detection and classification

A 3D sensor is used to capture images, each consisting of hundreds of thousands of measurements, which is commonly referred to as a point-cloud. Computer vision algorithms can use the point-cloud to identify and classify objects and estimate metrics such as speed, velocity, and pose of the objects.



Sensor performance requirements depends on the application, but generally high levels of automation and autonomy require robust algorithms coupled with high performance sensors.

Different 3D sensor technologies each have their strengths and weaknesses. The offshore environment poses challenging lighting conditions and weather conditions such as snow, rain and fog, and aerosols such as dust and sea salt. This puts high demand on the robustness and performance of 3D sensors.

Light Detection And Ranging (LiDAR) is a type of 3D sensor making use of lasers to measure the distance to objects within a defined Field of View (FOV). The FOV of a spinning LiDAR is typically fixed at 360° horizontally and between 22.5° and 90° vertically. If your application requires omnidirectional 360° horizontal FOV, then a spinning LiDAR gives a good fit. However, if the applications require less than 360° horizontal FOV, using the spinning LiDAR directly will be inefficient.

With an aim to increase the efficiency of spinning LiDAR sensors, back in 2017, SFI Offshore Mechatronics alumni Atle Aalerud (WP3.2) and Joacim Dybedal (WP3.1) came up with an interesting concept. The basic idea was to reshape the field of view from a spinning LiDAR while also maintaining high resolution and refresh rate. Such an invention would enable increased performance at a lower cost.

"In a camera the FOV can be easily adjusted optically by pairing an image sensor with an appropriate lens. The invention uses a similar approach, wherein a spinning LiDAR is paired with an appropriate reflector matching the desired FOV.", Atle says.

The reflector invention is a typical example of technology which is wanted by the industry partners, but development of sensor systems is outside their core business. They are primarily users of such systems and rely on vendors to supply commercial products and services.

For this reason, University of Agder initiated a process to secure IPR rights. The invention has been granted with a European patent and exploration into how to commercialize the concept is still ongoing.

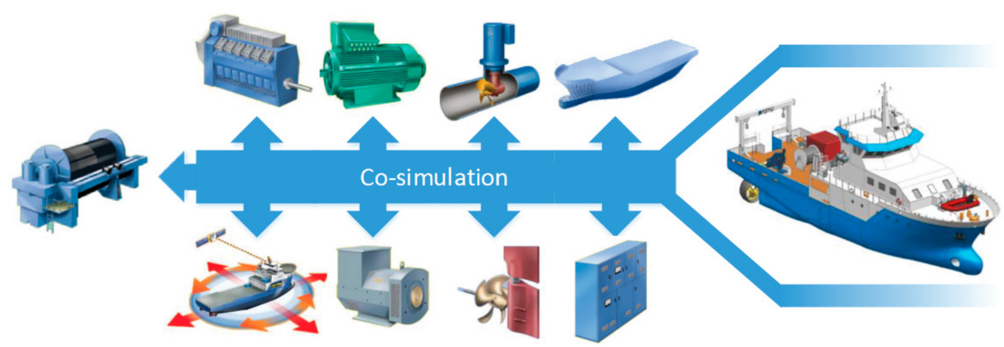
WP4 – Modelling & Simulation

Activities within Work Package 4 have been well aligned to support the vision of autonomous offshore operations and the grand challenges identified such as autonomous smart systems.

Advanced modelling and simulations are required to support the design of new products and services targeting high levels of automation and autonomy. The increased complexity and higher degrees of integration between systems such as handling equipment and vessel control is demanding in terms of modelling and simulation.

The work package was organised into five subtasks of which four were covered by PhD positions and one by a PostDoc position. Activities in the subtasks have been concerned with methods and software for multi-physics simulation, co-simulation and integrated simulation models.

Representatives from three different companies have been very active in the reference group. WP-leader was Professor Olav Egeland (NTNU).



Papers with Code

Scientific publication accompanied with software made available to support the reproduction of the results, is often referred to as "Papers with Code". This is an important contribution to reproducible and reusable research.

Most of the software which are results from the work in the centre is accessible as open source with liberal licenses such as the MIT license. Most of the software is available via GitHub hosted repositories (https://github.com/SFI-Mechatronics). In total there are 28 public and 10 private repositories.

Some software are tools that can be used stand-alone by end-users and some are components, libraries and modules that can be used by other software developers. In the spirit of open source software some of the software is also "forked", reused and further developed in relation to other projects and with contributions from other developers.

WP4 have been concerned with modelling and simulation and naturally software has been part of the research and results.

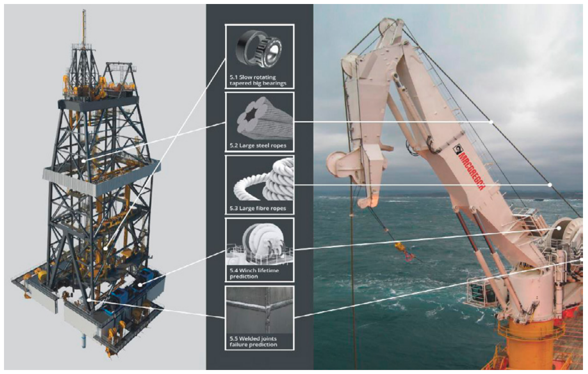
Lars Ivar Hatledal completed his PhD in 2021 as part of WP4.3 at NTNU Ålesund. The title of his thesis was "Protocols and standards for integration of simulation models and co-simulation". Lars Ivar Hatledal is an active contributor and maintainer of several open source software projects related to the co-simulation, many of which are a result of his work in WP4.1. Some of the projects are PythonFMU, FMU-proxy, FMI4j, and VICO.

Savin Viswanathan completed his PhD in 2021 as part of WP4.1 at NTNU and he continued as a PostDoc in WP4.5. The title of his thesis was "Integrated simulation of multi-physical systems in offshore operations". As a result of his work, Savin has also developed several software projects related to offshore and ocean engineering. His main contributions are Ocean Engineering Library for OpenModelica and OMHyD.

OMHyD is an open-source software with a Python based implementation of the 3D Boundary Element Method, applicable to wave-body interaction problems *. In its current version, it demonstrates the basic principle behind the working of a frequency-domain hydrodynamic analysis package. This provides a steppingstone towards in-house development of such software and alternatives to commercial frequency-domain hydrodynamics software like WAMIT, ANSYS-AQWA and DNV-GL Sesam HydroD/WADAM modules.

* Savin Viswanathan, Christian Holden, Olav Egeland and Marilena Greco, "An Open-Source Python-Based Boundary-Element Method Code for the Three-Dimensional, Zero-Froude, Infinite-Depth, Water-Wave Diffraction-Radiation Problem", Modeling, Identification and Control, 2021, Vol 42, No. 2, pp. 47-81

WP5 - Condition Monitoring Technologies



Work package 5 was organised into six subtasks, each based on industrial cases where maintenance operations served as significant cost drivers and were traditionally guided by subjective human judgment.

Through in-depth exploration of sensing technologies, we have successfully engineered diagnostic and prediction algorithms that supplant human judgment with online condition monitoring technologies. This ground-breaking approach proactively identifies maintenance requirements weeks in advance of potential failures, and estimation of remaining useful lifetime.

The accumulation of our scientific findings represents a crucial milestone in establishing a knowledge hub that has garnered national and international acclaim. The profound impact of this hub extends to industry and classification companies, compelling them to embrace transformative changes in their maintenance regimes, owing to the introduction of innovative technologies and methodologies.

In total, 19 scientists have been involved in WP5. 30 engineers from 6 different companies have taken part in 26 reference group meetings. In the period 2015-2020, the WP-leader was Dr. Thomas J. J. Meyer (NORCE Research) and Dr. Rune Schlanbusch (NORCE Research) in the period 2021-2023.

Towards smarter maintenance strategies

Reduced costs and increased productivity without compromising health, safety and environmental requirements is critical for sustainable and competitive offshore operations. What if we could identify problems in machinery at a very initial stage, in time to operate the machine securely and reliably until the next feasible maintenance opportunity?

Monitoring of rotating machinery such as electrical motors, pumps and gearboxes is commonly solved by bolting vibration sensors on the machine. A drawback is that vibration sensors are not performing well with non-rotating machinery such as hydraulic and electro-mechanical cylinders.

ACOUSTIC EMISSION

Work Package - WP5.6 was established with the aim of using Acoustic Emission (AE) to identify oil leakage from hydraulic cylinders at very initial stages. AE has been identified as a potential monitoring technique for non-rotating machinery. 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 due to the high frequency of the AE signals.

Vignesh Shanbhag has been working as a PostDoc researcher at NORCE Research under supervision from Rune Schlanbusch. Specific wear conditions such as piston rod wear, spindle wear and seal-wear have been considered. 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 scientific results of the research on hydraulic cylinders and spindles are published in several journal papers, a majority on the highest scientific level (Level 2).

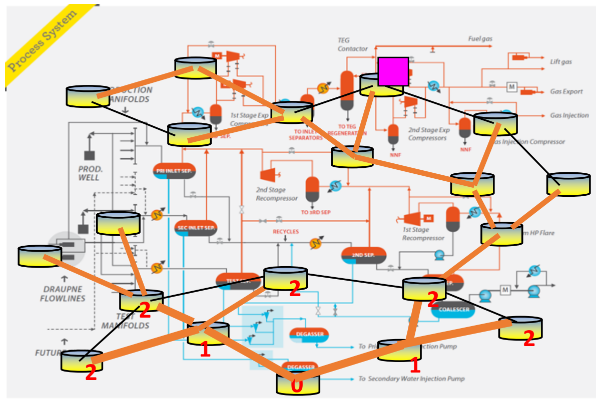
IMPLEMENTATION AND INNOVATION

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 the research experiments is bulky and expensive lab equipment (Technology Readiness Level – TRL 3-4). The results have been presented to the industry partners which have shown an interest to use AE based sensor systems once they have reached a higher TRL.

To mature the technology, NORCE decided to proceed with a separate spin-off project. A pre-project with funding from the Research Council Norway FORNY program was granted in 2021., followed by a main project with 5MNOK funding in 2023.

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.

WP6 - Analytics & Big Data



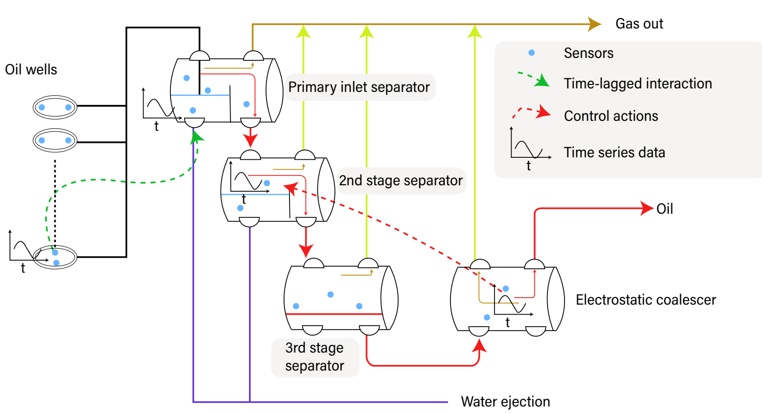
Work package 6 was organised into four subtasks, each based on industrial cases where maintenance operations and process optimization served as significant cost drivers and were traditionally guided by subjective human judgment. Two PhD positions and two Post Docs positions have been integrated into the subtasks.

The majority of activities in the work package were in the field of real-time graph signal processing and automated machine learning. The research has covered a broad range of challenges such as online reconstruction of multi-variate time-series, topology estimation to learn causal dependencies in processes, anomaly detection, denoising, missing data imputation and data reduction.

We have formalized and developed a family of algorithms that can reconstruct streaming data (e.g., multivariate time series nonuniformly sampled and quantized) smoothly and with virtually no delay.
This technology can be used to decompress PI data smoothly on the go or to generate and plan safe trajectories in real-time.

Use cases were selected in close collaboration with the industry partners Lundin Norway and HMH (MHWirth). The methods can be used in forecasting of events causing production stops or performance degradation, e.g. build-ups in oil and gas separators, or improving data quality The results include software to demonstrate the methods and a high number of papers have been published in level 2 journals.

6 representatives from 4 different companies have been active in the reference group. WP-leader was Professor Baltasar Beferull Lozano (UiA)



"AI discovers hidden connections"

As part of Work Package - WP6.3, Kevin Roy has developed an algorithm that is able to discover causal relationships among different parts of a complex system.

"The algorithm analyses the signals captured by a network of sensors monitoring an industrial process," he says.

The advantage of an AI system that discovers hidden connections is that the offshore industry can improve and streamline its systems.

"To simplify, you can say that the sensors monitoring temperature, water level, pressure and other variables might co-operate with each other in a way humans cannot but the algorithm can. For instance, if a sensor breaks down, we are able to go back to the algorithm and see how it correlated with other sensors and why it broke down," he says.

A POSSIBLE TOOL FOR SEVERAL SECTORS

The algorithm was proven to be successful when tested with signals from sensors monitoring an industrial process, but Roy points out that its use can be extended to other fields as well.

"The algorithm can be used in any field where there is a need to understand large-scale dynamic systems, such as the financial and health sectors," he says.

A significant contribution from this research is that the algorithm has improved accuracy and demands less computational resources and data as compared to what you would normally need when you use other standard algorithms in AI.

"In addition, our method is explainable, which traditional AI methods such as deep learning are not," he says.

BEST PAPER AWARD

Kevin Roy received a best paper award for his work presented at the IEEE International Seminar on Machine Learning, Optimization, and Data Science (ISMODE) held in Jakarta, Indonesia in 2022.

Roy emphasises that the prize-winning paper has been created in collaboration with his supervisor and leader of Work Package – WP6, Professor Baltasar Enrique Beferull-Lozano, co-supervisor Luis Miguel Lopez Ramos and other colleagues at UiA.

Roy and Beferull-Lozano are both happy for the contributions from industry partners Lundin Energy, and MHWirth Norway (now HMH) for providing them with data from the oil and gas plant to carry out this research.

WP7 – Technology Vision

The main purpose of work package 7 was to align a good understanding between the industry partners and their vison for their future need for development and technology.

The activities in WP7 have spanned across work packages and across industry and academia. Note some of the relevant goals and activities achieved in WP 7:

- Strategy revisions adapting to market trends and available new technologies.
- Ensure a dynamic organization that knows the offshore industry well, enabled through a foresight study.
- Monitoring technical progress and priorities and suggest spin off projects.
- Ensure up-to-date industry consensus on technology priorities, enabled through annual 1:1 meetings with the main industry partners.
- Ensure high relevance of project results for project partners, enabled through 1-page result dissemination from the technical WPs to the industry.
- Contribute to an increased synergy effect between the WP tasks, enabled through participation in all WP reference group meetings.

The foresight process initiated in 2016 and followed up in 2022 was organised by WP7, and during the project period WP7 has organised a large number of workshops and seminars covering both technology, market conditions, innovation, and business models.

One PhD position have been integrated into the work package since 2020. The PhD position is related to digital servitisation and business model innovation and is with supervision from Professor Thor Helge Aas, at UiA School of Business and Law and co-supervised by Jan Helge Viste, at GCE NODE.

In the period 2015-2018, the WP-leader was Anne Grete Ellingsen (GCE NODE) followed by Marianne Engvoll (GCE NODE) from 2019 to 2020. Christian von der Ohe (GCE NODE) took over the responsibility from 2021 to 2023. The work package has also been extensively supported from NORCE Research, with Øyvind Haugen and Ellen Nordgård-Hansen.

Digital Servitisation

New contract structures and business models enabled through increased cooperation

To align activities and priorities in the centre, a Foresight Process was initiated, and the final report was ready in March 2017. The report outlined four strategic options and the fourth option was driven by an increased attention to offering smart digital services in addition to products, often referred to as "Digital Servitisation".

Examples from other industries demonstrate how to transition from product sales into new digital and service-oriented business models. One notable example is "power-by-the-hour" championed by Rolls Royce.

The key distinction between services such as maintenance programs or digital products such as a digital handbook, is that Smart Digital Services are based on data generated from the product in use. Getting data from the products require timely measurements using appropriate sensors, which is covered in WP5 (Monitoring Techniques). Making sense of the data requires big data analysis and machine learning, which is addressed by WP6 (Big Data and Analytics).

To follow up on the fourth strategic option related to business model innovation, a new PhD project was defined under Work Package 7. In September 2020 Marius Kristiansen started as a PhD student at UiA School of Business and Law. In his work Marius addresses how to succeed with digital servitisation.

In one of his case studies, Marius has used the notion of legitimacy to explain the perspectives of the different stakeholders in service innovation processes.

"The findings suggest that companies who succeed with digital servitisation manage to pass 'legitimacy thresholds' during the development of the new service. Different stakeholders emphasise different aspects of the service in order to view it as legitimate (accept it).", Marius says.

A customer might emphasise the pragmatic legitimacy aspect before accepting to pay for the new service, focusing on the cost/benefit of the solution. A supplier or partner might emphasise the moral legitimacy in supporting the vision and wanting to be a part of the solution that is proposed, without knowing the exact cost or benefit they will receive. A regulator or media might emphasise the cognitive legitimacy, that they understand what the new service is a part of or why it is important (i.e. digitalization), without needing to know the details of its operation.

“In relational service-sales a higher sensitivity to the customer’s and the partner’s motivations and situation is required. Understanding what makes the company’s offering legitimate in their eyes is helpful when designing the value proposition and communicating it to the ecosystem.”, he says.

Communication and Dissemination

The regular reference group meetings have been the main communication and dissemination channel. The annual conference has been the main common event for dissemination across the project. The conference took place every year of the project except in 2020 and 2021 due to COVID-19. The conference has attracted between 50 and 80 participants from the industry and academic partners. The final annual conference in 2023 was also partly open to external participants.

For external communication, the website sfi.mechatronics.com has been used. The centre had accounts and presence in social media and professional networks such has LinkedIn, but the activity was limited. The news stories on the website were periodically communicated via a newsletter with more than 300 recipients.

Centre activities and upcoming events such as new hires, PhD defences, and highlights from the research results are examples of stories featured on the website and in the newsletter. As an internal project coordination and communication platform the project have used ProjectPlace.

The centre has co-hosted several public events such as Science Meets Industry, Ocean Technologies workshop and events during Arendalsuka. During the Covid-19 pandemic webinars were actively used to disseminate results from the centre. The webinars were also used to have invited external guests presenting topics of interest to both academic and industry partners.

In the project period more than 200 papers have been published in journals and at conferences. Less than 15 percent of the papers are published in non open-access journals. Github was used as an open source repository and Dataverse.no was used as a repository for datasets. This is in line with the FAIR principles to improve the Findability, Accessibility, Interoperability, and Reuse of digital assets.

AWARDS

WP	Year	Award	Details
WP3	2023	Best Student Paper Award	The paper "Embedding Clustering using Lightweight Contrastive Learning For Cross-Modal Classification" by José Amendola, Linga Reddy Cenkaramaddi, A. Jha was awarded with Best Student Paper Award at the The 8th International Conference on Computer and Communication Systems (ICCCS 2023).
WP6	2022	Best Paper Award	The paper "Joint Learning of Topology and Invertible Nonlinearities from Multiple Time Series" by Kevin Roy; Luis Miguel Lopez-Ramos; Baltasar Beferull-Lozano was awarded with Best Paper Award at the IEEE International Seminar on Machine Learning, Optimization, and Data Science (ISMODE 2022)
WP3	2021	Runner-up Best Journal Paper Award	The paper "Priority Enabled Grant-Free Access With Dynamic Slot Allocation for Heterogeneous mMTC Traffic in 5G NR Networks" by Thilina N. Weerasinghe; Vicente Casares-Giner; Indika A. M. Balapuwaduge; Frank Y. Li was awarded runner-up Best Journal Paper IEEE ComSoc – CSIM (Communications Systems Integration and Modeling (CSIM) Technical Committee) Journal 2021 Edition
WP3	2020	Best Presen-tation Award	The presentation by Dipendra Subedi based on the paper "Modeling and Analysis of Flexible Bodies Using Lumped Parameter Method" by Dipendra Subedi; Ilya Tyapin; Geir Hovland was awarded with Best Presentation Award in Session 2: System Control and Management Engineering at the 2020 IEEE 11th International Conference on Mechanical and Intelligent Manufacturing Technologies
WP3	2018	Best Application Paper Award	The paper "Visual Marker Guided Point Cloud Registration in a Large Multi-Sensor Industrial Robot Cell" by Erind Ujkani, Joacim Dybedal, Atle Aalerud, Knut Berg Kaldestad and Geir Hovland received the Best Applications Paper Award at the IEEE/ASME International Conference on Mechatronic and Embedded Systems and Applications (MESA).
WP2	2016	Best Session Presen-tation Award	The presentation by Sondre Sanden Tørdal based on the paper "Testing of Wireless Sensor Performance in Vessel-to-Vessel Motion Compensation" by Sondre Sanden Tordal; Per-Ove Løvsland; Geir Hovland was awarded with best session presentation award at the 42nd Annual Conference of the IEEE Industrial Society (IEEE-IECON 2016).
WP1	2015	Best Presen-tation Award	The presentation by industrial PhD candidate Witold Pawlus based on the paper "Drivetrain Design Optimization for Electrically Actuated Systems via Mixed Integer Programing" by W. Pawlus, D. Frick, M. Morari, G. Hovland and M. Choux was awarded with Best Presentation award at the IECON 2015 conference in the session "TS-140 Electrical Drive Applications".

Coopetition and Innovation

Coopetition is a term coined to describe cooperative competition. Via their engagement in the NODE cluster, the partner companies had already been introduced to collaboration with competitors. The inclusion of competitors into the centre was thus both natural and deliberate. Even so, the intrinsic worry that their competitive advantage could be compromised was apparent. To mitigate potential pitfalls of the coopetition-approach, several measures were incorporated into the consortium agreement, non-disclosure-agreement, and the overall strategy of the centre.

The companies were generally much more open to collaboration when working with building blocks such as 3D machine vision, sensors, and the lower end of the technology readiness level scale (TRL 1-4). The companies preferred internal R&D or in bilateral projects with the research partners when dealing with TRL 4 and above.

For this reason, it was decided that the research should focus on enabling technologies and technological building blocks. The overall research strategies and grand challenges were defined in a collaborative effort between all the partners and governed by the steering board.

Each industry partner selected which work-package to engage with based on their interest, internal capacity, and resources. The resulting distribution was considered fair and with few overlaps between major competitors.

Regardless of all the measures and strategies, the industry partners remained quite conscious of the competing environment and cautious in their disclosure of both interests and non-interests. To mitigate the cautiousness of the industry partners, bilateral meetings and collaboration was a solution.

From the centre management the worry was that the research would fail on relevance and that the coopetition approach would turn into an innovation barrier. However, in hindsight the conclusion is that coopetition was a good constraint and innovation happened regardless.

The approach by the industry partners were good in the sense that the researchers could focus on longer term fundamental research and building blocks rather than short-term needs related to specific product and services. The caution feedback from the industry enabled the researchers with an opportunity to be more experimental and explorative in their research. It also enabled them to use their intuition and make some bold guesses with regards to anticipating relevance and interest to the industry.

It was also good in the sense that a separation of concern was established between the research partners and the industry partners. The main responsibility of the research partners was to indirectly contribute to innovation by offering interesting and relevant research results. The main responsibility of the industry partners was industrial implementation and innovation.

Industry-driven spin-off projects enabled additional funding to reach a higher TRL levels and to shape new concepts. These projects were organised differently in terms of partners, IPR and contracts. The centre management made efforts to keep track of the spin-off projects. They were categorized as either direct spin-offs or indirect spin-offs. Projects in the direct spin-off category were initiated in collaboration with the academic partners. Indirect spinoffs were within the thematic areas of the research in the centre but initiated independently by the industry partners. The total external funding for the spin-off projects exceeded 250MNOK, of which half of the projects were direct spin-offs.

Defining, mapping and following-up research results with innovation potential was a core activity in the centre. To support this work, a tool called Research Impact Canvas was developed. The canvas is comprised of seven key questions which serves as an executive summary of a research project. The canvas includes questions related to problem statement, today's practice and limitations, alternative solutions, expected results, competitive advantages, and IPR. The process to populate the canvas involved using highlights from an interview with the respective PhD students. The canvas process enabled the PhD students to reflect about IPR, use-cases and impact. Follow-up with the industrial partners and submission of an invention disclosure are examples of follow-up activities and actions initiated based on the canvas process. Especially the canvas was an efficient format to communicate expected results and potential use-cases to the industry partners.

From Research to Product

NOV is successful with new offshore crane technology created in collaboration with SFI partners

During the SFI-project, NOV has developed advanced crane technology for safer and more efficient boat loading in all kinds of weather.

“Crane operators carry out thousands of lifts between supply boats and oil rigs every year. The new crane technology reduces the swinging motion of the load and makes it possible to rotate the load 360 degrees.”

This is what Peder Sletfjerding says. He is the department manager for Robotics and Automation at NOV. The offshore company has been part of the SFI-project since the beginning in 2015.

The crane technology is an algorithm. It was developed and tested on a smaller crane that was built in a lab at the Norwegian University of Science and Technology (NTNU). Based on this research, NOV developed the technology that now helps reduce crane oscillations during cargo loading onto ships.

“Before, the deck crew would rotate the load using push poles and tag lines, but with the new technology, the crane operator is able to rotate the load, and the deck crew can stay safely out of reach,” says Sletfjerding.

The technology is patented and called anti-sway rotator. The PhD students Andrej Cibicik and Geir Ole Tysse at NTNU were the ones who developed the algorithm.

With the new crane technology, the crane operator can rotate the load 360 degrees while the deck crew stays safely out of range (Screenshot from Transocean's YouTube video about the technology).

“The PhD students initially developed it, and we have since refined and adapted it to suit our cranes. It provides a more secure system and expands the use of the crane,” says Sletfjerding.

The crane technology is now in use at NOV and Transocean.

Peder Sletfjerding coordinated NOV's involvement in the SFI project.

KNOWLEDGE EXPANSION

The SFI project has carried out research in areas such as hydraulics, robotics, automation and condition monitoring of machinery. NOV was involved in many of these, including projects on motion compensation, robotics and automation.

They see that the project is adding value to the industry in the region. Sletfjerding believes that NOV has benefitted substantially from the SFI collaboration. In addition to developing the new crane, the company has also initiated several development projects, and the employees involved have enhanced their skills and knowledge in various areas.

“We’ve gained new expertise, especially in camera technology and simulation. There is a lot going on in such collaborative projects, both formally and informally, between us and the students involved, and between us, UiA and other collaboration partners,” he says.

HMH has made quantum leaps in software and digitalisation

HMH's vice-president for innovation is pleased with the company's innovative power. "We are constantly working to develop and improve our products and services, and the establishment of Node cluster and UiA's Centre for Research-based Innovation (SFI) has been important for us and the rest of the supplier industry in Agder."

Nicolai Nilsen, vice-president for innovation at HMH.

That is what Nicolai Nilsen, vice-president for innovation at HMH, says.

According to Nilsen, HMH has made quantum leaps in its services in the digital and software fields. However, he does not attribute this solely to the collaboration with the SFI.

"It's not that input from research leads to a new and clever twist on our products. It's more about creating an environment where we collaborate and are open to new ideas that can develop and provide new products and solutions in areas other than originally intended," says Nilsen.

MONITORING AND STREAMLINING

"HMH works to improve drilling operations by increasing the use of automation and digitalisation. The goal is always safer and more efficient solutions," says Nilsen.

He highlights the products DrillPerform and Activity Visualizer as examples of innovative products.

DRILLPERFORM FOR OPTIMAL DRILLING

"Simply put, DrillPerform is a data analysis tool that analyses offshore drilling operations," says Nilsen.

The goal is to detect when operations are most effective so that one can attempt to replicate this at all times to create the most efficient and safe drilling operation possible.

He emphasises that the product belongs to HMH, while the data belongs to the customers.

ACTIVITY VISUALIZER

Activity Visualizer has also been developed to optimise drilling processes. It allows you to see the entire operation on the drilling deck in a physical 3D representation.

"The solution displays completed drilling operations. It allows us to visually compare, making it easier to understand where the bottlenecks are," Nilsen says.

DOCTORAL THESIS ON CONDITION MONITORING

Nilsen also highlights Martin Hemmer's doctoral thesis as a contribution to the development of new products and services from HMH.

Hemmer was a PhD student at UiA who was recruited from HMH, and his doctoral work was funded by HMH and SFI Offshore Mechatronics. It should be noted that test facilities at HMH were used, and a special test rig was constructed at UiA during the doctoral research.

"We have built upon insights from that thesis. Today, we use it in connection with monitoring and data analyses that help us maintain and streamline operations on oil rigs," Nilsen says.

Motion Compensated Pile Gripper

Motion Compensated Pile Gripper is an excellent example of a direct spin-off project from the centre. The project “Increasing Operational Efficiency by Retrofitting Sensor-Based Anti-Swing Technology on Offshore Cranes” was initiated by MacGregor in collaboration with University of Agder. The project was granted funding from the Research Council of Norway Maroff-2 program.

The scientific challenges in the spin-off project are closely related to research in the SFI Offshore Mechatronics such as wave compensation and control systems. The spin-off project has actively used the Motion Lab infrastructure at UiA to perform experiments.

The results from the project will greatly support a new solution innovation from MacGregor in collaboration with Kongsberg Maritime called Motion Compensated Pile Gripper. The motion compensated pile gripper will be used for installation of offshore wind towers foundations.

Motion Compensated Pile Gripper Static pile gripper frames are well known in the industry and are traditionally used for jack-up vessels. With the Offshore Wind market trends, wind farms being installed further offshore and the requirement of handling much larger monopiles, legacy jackup vessels are not capable of handling the job.

Therefore, the market demanded for an innovative approach for installing monopiles by means of a floating vessel, with the pile gripper frame capable of compensating for the vessel motions. One example of this is the use of next generation wind foundation installation vessels as OHT Alfa Lift, combined with a 3000t crane from Liebherr and MacGregor motion compensated pile gripper.

It is the combination of multiple innovative elements that makes the solution unique and new compared to existing solutions, but certainly the integration to the vessel control system is the way to increase efficiency, operability, and safety of the overall installation operation.

"To begin with it was challenging for us to understand the research going on in the centre. Throughout the project period we have vastly improved our own capacity to absorb the research and make use of the results.", says Eivind Gimming Stensland, Director of Engineering, Technology and R&D at MacGregor.

This is a good example of how the centre have influenced the internal RD&I processes within the partner companies.

How the supplier industry and UiA became a success story

ENTREPRENEURS OFTEN WORK MORE THAN THEY TALK. FURTHERMORE, THEY COMPETE AND REFRAIN FROM REVEALING THEIR INNOVATIONS TO OTHERS. A NEW STUDY EXPLAINS THE SUCCESS OF THE SUPPLIER INDUSTRY IN AGDER.

By Atle Christiansen

During the 1960s, only one or two entrepreneurial companies in Agder were involved in cranes and equipment. Over time, their numbers grew. By the 1980s, there were many. By the turn of the century, they had become significant players. The largest among them were National Oilwell Varco (NOV), Aker Solutions, and Cameron.

Yet, hardly anyone discussed them in the newspapers or the local councils. Public discourse did not revolve around the supplier industry.

In the 1980s, there were serious discussions about the decline in industry and the post-industrial era ahead. The process industry in Agder was what captured the attention of politicians and newspaper discussions.

HUSHED VOICES BEHIND THE SCENES

No one openly discussed college and university either. However, things were happening behind the scenes. They talked about engineering school. College, they said. Eventually, university was also mentioned, although in hushed tones. An engineering school, a college and a university were all realised over time. However, well into the 1990s, it was fairly quiet around the supplier industry.

A STUDY ON THE SUPPLIER INDUSTRY

All of this is revealed in a study on the pioneering work that led to job creation and innovative products in the supplier industry in Agder.

This study was conducted by researchers from UiA: Roger Normann, Mikaela Vasstrøm, and Hans Christian Garmann Johnsen. They examined the development of business and industry in Agder from 1955 to 2015.

The study shows how a small region achieved significant objectives when researchers and business leaders agreed on shared goals.

"A central feature of this development has been that entrepreneurs from both business and academia came together, agreed on common goals and steered development in the same direction," says Roger Normann from the School of Business and Law at the University of Agder (UiA).

He points out that UiA eventually had representatives from regional businesses on its board, while businesses, in turn, had UiA staff on their boards.

UNDER THE RADAR

"The supplier industry did not emerge in complete silence, but it developed under the radar. The industry isn't mentioned in public documents at the municipal or county level from 1969 and well into the 2000s," says Normann.

"The industry became a national player in the 1980s, almost in parallel with the rest of societal development," says Professor Hans Christian Garmann Johnsen. The development of the college in Agder and later the university also took place in a separate sphere outside of other societal developments, or as the researchers call it, the 'academic field.'

"In the 1970s and 1980s, they were closed and separate societal areas. People would go on 'field trips' to businesses, as it were. But there was no close or real collaboration on research, development, and innovation," says Associate Professor Mikaela Vasstrøm.

MILESTONES

But then there are certain milestones that changed the rules of the game, raised voices, and put the supplier industry on the map.

Here, we could mention several key individuals, but the researchers have anonymised their sources from academia, business and politics in their study.

We could also mention the entrepreneur Bjarne Skeie, who was already building hydraulic cranes in the 1960s. Some call him the godfather of Agder's supplier industry. Or we could write a few words about the engineer and academic Knut Brautaset. He played a pivotal role in establishing Agder Regional College of Technology in 1967, Agder Regional College in 1969, and the University of Agder in 2007. Some call him the pioneer of higher education in Agder.

The mechatronics education is also noteworthy among the milestones. Mechatronics was already being taught in colleges in Agder. Since its establishment in 2007, UiA has been the sole provider of bachelor's and master's programmes in mechatronics, a diverse field that encompasses mechanics, electronics, computer science and artificial intelligence.

NODE AND THE WORLD MAP

We should also dedicate a few paragraphs to Kjell O. Johannessen. He had a loud voice and was the driving force behind the establishment of the Node business cluster in 2005.

Since 2005, the region's supplier industry was on the map. And now we're not just talking about the map of southern Norway, or the map of Norway. We're talking about the world map.

Node founder Kjell O. Johannessen could eventually drop his mantra that we were better known in Houston, Texas, than in Oslo and the rest of Norway.

By the late 2000s, the over 70 supplier companies (as of 2016) in Node were internationally recognised as innovative and outstanding contributors to the global oil and gas industry.

CO-CREATION IS KEY

However, the researchers refrain from singling out one event or environment. The point is that multiple events contributed to the success.

And the main point is that it is no longer about going it alone and in separate spheres (or fields). Now, it's about co-creation. Different environments come together, communicate, and agree on shared goals.

"Several fields have merged and collectively developed industry, workplaces, research and development projects, as well as new products," says Garmann Johnsen.

This collaboration led to Node being designated as a National Centre of Excellence in 2010. In 2014, Node, along with UiA and its member companies, was designated a Global Centre.

The University of Agder had GCE NODE and the entire supplier industry in Agder on the team when UiA's SFI Offshore Mechatronics obtained the status of a Centre for Research-based Innovation in 2014.

BLUEPRINT FOR SUCCESS FOR OTHERS?

The UiA researchers' study focuses on economic and industrial development. They have examined barriers, drivers and successful collaborative projects that led to success.

The researchers nevertheless hesitate to claim that the study provides a blueprint for how to succeed in industrial development.

"This growth is difficult to replicate with political decisions elsewhere. In addition, development occurs in specific locations with unique conditions and their own cultural and industrial experiences," says Normann.

"But perhaps Agder can repeat the success in another field?"

"There is reason to be optimistic. If you've succeeded once, you can succeed again," says Normann.

Source: Roger Normann, Mikaela Vasstrøm and Hans Christian Garmann Johnsen: 'Field analysis of industrial development in a peripheral region of Norway' published in Norwegian Journal of Geography (2022). The key sources in the study are 15 in-depth interviews with stakeholders from business, academia, and the public sector in Agder. The participants have been anonymised. The study shows how mechatronics and the supplier industry emerged and became the main driver of regional growth in Agder over a 50-year period from 1955 to 2015.

What's next?

This question was put on the agenda at every board meeting, work-package leader meetings, and reference group meetings, since 2021.

The aim of the discussions was to gain insight into small and large unresolved problems in the industry and relevant research that can help to solve it. In addition to the technology monitoring activities in WP7 (Technology Vision), the discussions where supported by additional analysis and market research. The analysis identified opportunities based on stakeholders, market drivers, key societal challenges, sustainability goals, competing initiatives, collaboration opportunities, available funding schemes, industry commitment and more.

Throughout the process various onshore technologies and market opportunities were assessed, however the consensus was that offshore mechatronics is our stronghold and that future prospects should be closely related to offshore operations.

The offshore environment is a gateway to abundant natural resources and opportunities, especially related to energy and food. E.g. offshore wind resources are stronger, and blow more consistently than land-based wind resources. But the offshore environment is also naturally challenging due to the remoteness of the locations, ocean depths and the harsh and changing weather conditions.

The consortium companies have put a lot of resources into developing new advanced technologies that will be a key enabler in the energy transition. The research results have made an impact by lowering the technology risks, however the financial risks due to changing market conditions is also a major challenge. At the time of writing this report, offshore oil & gas investments are again picking up, and at the same time several offshore wind projects are put on hold due to rising costs.

In the long-term perspective, we are confident that offshore mechatronics will be in high demand also in the next decades. Reduced costs and increased productivity without compromising health, safety and environmental requirements will remain key drivers of innovation.

Short-term and in the present volatile market conditions, it is more challenging than before for companies to commit to long-term research projects. Ultimately, each company will need to decide if and how they want to proceed and get involved in new initiatives.

Final Reflections

The centre has successfully served as a platform for comprehensive R&I for the offshore mechatronics area, where it has been possible to cover a broad range of challenges.

The success of this centre is based on the strong integration of collaboration between the research environment of the universities and research institute, and the industrial partners. This environment includes not only research and innovations, but also education and student projects. The research partners achieved very good alignment with the user partners within their expectations and boundary conditions as partly competing companies. This gave a basis for a relevant environment and results that contribute to innovative solutions and commercial products.

With academic partners in six distant locations, regular communication and interaction was very important for the management. The centre management met with the seven work package leaders eight times a year and the work packages met with the user partners in regular reference meetings. There was a constant focus on relevance and interaction with the partners. We were lucky to have a rather lean but stable management group with only a few reassignments. The few changes were filled by centre personnel. The new centre director from 2020 was recruited from the steering board.

The size of the centre was appropriate for continuous collaboration and involvement for relevant research, efficient management, and communication. We tried to improve the interaction between distant research partners after the first couple of years, but the COVID-19 pandemic pushed us toward digital remote events, which somewhat impaired the interaction in the centre. The project website and newsletter were actively used, with frequent news and updates, however we admit that our outreach efforts could have been more visible.

The industry has built internal capability and skills for research-based developments. They have improved the knowledge base for more advanced mechatronics control and safety and enhanced their ambitions on R&D-based innovations. Spin-off projects for more advanced and complex technologies was initiated and more advanced products have been brought to market. New business models are now also being considered.

The academic partners in the centre not only aspired to collaboration with the industrial partners, but also co-creation, but this was mostly too difficult due to the competitive characteristics of the industrial partners. The research thus aimed for TRL

2-5, and the results have been offered to the user partners to harvest appropriate results, enabling them to innovate and develop their new products.

In the centre we have managed to unify high industrial relevance with high academic ambitions. We are proud that 23% of the journal articles from the centre have been published in Level 2 journals. The total publication rate was and is still as expected. The reports from the Ph.D. evaluation committees during defences have given us valuable feedback demonstrating that the quality of the research has been relevant and on high levels. The centre provided a large number of Ph.D. and associated M.Sc. candidates that matched the need of the industry for recruitment. This is one of the best ways to provide competence.

The mutual and collective collaboration between the research partners NTNU, AAU, NORCE and UiA have been very good and fruitful. In the project we also learned that the PhD education and training in Germany have a different approach and schedule than what we are familiar with in the Nordic model.

In long-term projects, it is vital to account for new challenges and opportunities. The consortium managed to deal with unforeseen issues in a coherent and cooperative manner with the aim of minimising impact and negative consequences for centre activities. In particular, the centre industry partners faced a significant financial downturn in the middle of the last decade, but the centre was largely shielded regarding resources and financial contributions.

On the other hand, the rise of artificial intelligence was exploited as a new opportunity for the centre. Apart from the work package on Data Analytics & Big Data, the original application did not put much emphasis on artificial intelligence (AI) or machine learning techniques or tools (ML). At that time, AI and ML had not yet become mainstream. Today, we know that AI and ML in the last 8 years have seen unprecedented growth and adoption. This development influenced the research work at the centre. The use of artificial intelligence and machine learning played an important role, became highly integrated as analytical methods and algorithm design, and had a high impact on research results.

It was recognised underway that the innovation potential of research results had to be addressed, and an innovation officer was thus hired to manage and strengthen these efforts. We still see that there is a need to strengthen the culture of 'disclosure of invention' within university environments. However, we have experienced that the volume of significant innovative work was done by the industrial partners.

The centre also aimed to promote spin-off research projects. Estimates have shown that the grants to spin-off projects by far exceed the total cost of the centre. The research partner NORCE has been invited to Horizon Europe projects on condition-based control on transport systems based on capabilities developed at the centre. It is more challenging to approach Horizon Europe with key competence in offshore mechanics aimed at oil and gas industries, as this is not a priority area of interest for the EU. But now both research and industrial partners are approaching new arenas such as offshore wind, wave energy, ocean farming, deep-sea mineral mining, and autonomous marine operations. This includes also building new partnerships for new RCN funded projects and centres.

In December 2022, a review of the strategic options developed in the early phase was made and to what extent the recommendations from that process had been followed and to what extent they were still valid. The review concluded that all strategic options were followed in terms of work package activities and results, as well as spin-off projects. The review also concluded that all strategic options are still very much valid within a broad range of offshore operations.

As the centre is vital, we aim to continue the collaboration and extend the partner base to pursue new opportunities as the Centre for Offshore Mechatronics.

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