Annual Report 2023

DigiWells

Sonja Moi and Amare Leulseged (photo: Helga Gjeraldstveit/NORCE)

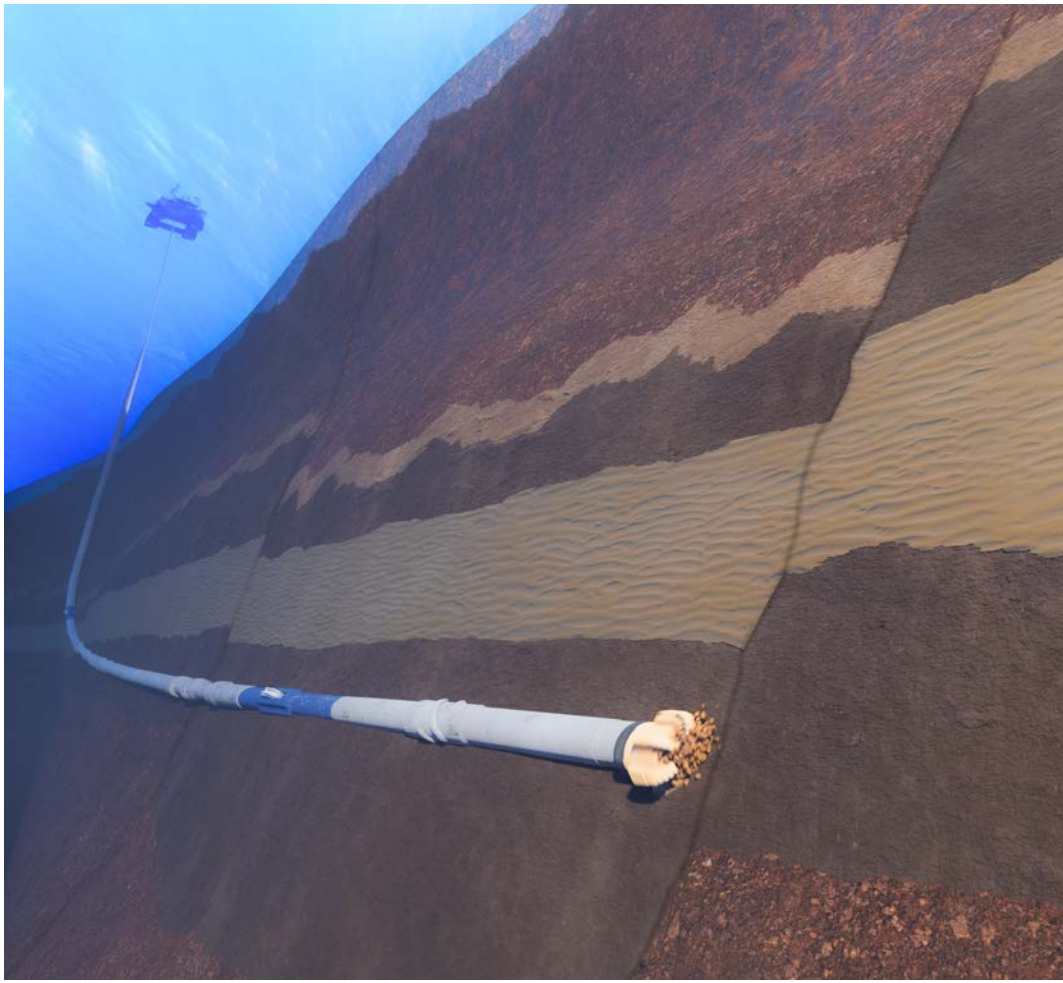
Contents

DigiWells:
Digital Well Center for Value Creation, Competitiveness and Minimum Environmental Footprint

Vision
Unlock subsurface resources through improved drilling and well technology.

Main objective
DigiWells aims to develop new knowledge, methodologies, and innovative solutions to optimize the well delivery process with special attention to challenges and possibilities at the Norwegian Continental shelf.

Subobjectives
- Develop more efficient work processes for planning the well delivery process by new workflows that addresses the uncertainties in a systematic way
- Develop techniques for fast modelling of the drilling and formation evaluation processes to enable optimization and improved decisions
- Investigate and develop solutions for automation and autonomous well delivery process
- Investigate and develop new measurement techniques that will improve process control
- Investigate and develop innovative hardware concepts to improved drilling performance based on in- depth understanding of the drilling process
- Support standardization and interoperability
- Strengthen collaboration between academic and industrial players
- Ensure industrial relevance and generate new ideas by performing case studies in collaboration with end users



The times they are-a changin’

Dear reader,

A new Annual report from DigiWells is available for you. The report is full of information about the activities in DigiWells to date. The DigiWells focus is on developing digital technologies to improve the well construction process with the aim of increasing efficiency, reducing costs, and minimizing environmental impact. DigiWells is also a valuable supplier of digital well competence to the industry through several PhDs and Postdoctoral researchers.

So, back to the heading of the article, what does Bob Dylan have to do with DigiWells? The song is from a record released in 1964. Dylan was writing the song as a deliberate attempt to create an anthem of change for the moment. I must admit I selected the name of the song as a softer alternative to a much harder slogan we use in Drilling & Wells in Aker BP: Evolve or Die. I selected the Dylan heading to avoid you choking on your coffee when reading the heading. But the reality is that we as an industry need to evolve or we will die, it is as simple as that. And one of the enablers to evolve, or change, is digitalization and the technology being developed at DigiWells.

The trend is that an increasing part of the energy in the world needs to come from renewables, due to environmental reasons. There will have to be an energy transition since the world is not able to switch over to renewables quickly. Consequently, there will be less oil and gas wells to be drilled in the future. As a nation, the majority in Norway seems to agree there needs to be a transition where the oil and gas is phased out. Norway is important for European energy supply, and we are producing some of the cleanest oil and gas in the world, but maybe not at the lowest cost.

To use the resources, found in Norway to date, one will need to produce the remaining resources to a lower cost than we are currently able to. The resource targets per well will be smaller, making future production from Norway challenging, even with low carbon emissions, we need to change. This is where DigiWells comes in with the goal to increase efficiency, reduce costs, and minimize environmental impact. For drilling and wells this means we need to spend less time, spend less money, but maintain quality and safety.

In Norway we have had very generous governmental controlled research and development programs administrated by the Research Council of Norway (RCN). This has been made possible by the enormous revenue from the Norwegian oil and gas industry. It has been a very successful collaboration system, the three-part collaboration between the government (NRC), research and academia, and the industry. The question is then if there is any room for drilling and wells technology in an industry that will be “closed down soon”? Well, as a start we must plug and abandon the thousands of wells on the Norwegian Continental Shelf safely and effectively. But in addition, many of the emerging new industries being discussed in Norway, and the rest of the world, will require effective, low cost and low carbon drilling and wells technology. CCS, underground hydrogen storage, geothermal wells, seafloor minerals and nuclear waste storage all need drilling technology.

Tron Golder Kristiansen (photo: AkerBP)

So, in the short term we need to implement all the great micro-services developed as part of DigiWells to date into our companies’ digital eco-systems. We need to help Norce influence the standardisation needed in the industry through organizations like SPE and DWiS. We also need to use the existing infrastructure, like Ullrigg, to accelerate the implementation of effective fully autonomous drilling through DigiWells and our newly started DigiWells Innovation Center. We don’t have much time!

Tron Golder Kristiansen, Board Chair

Message from the Center Director

The center has been running for just over three years, and a lot of impressive results have been achieved during this period. This is due to all the clever and hard-working scientists, PhD students, professors and support team connected to the center and not least also due to the close interaction with industry.

For 2023, four main activities have been prioritized. The main activities have been automatic well engineering, automatic drilling operational planning, automatic tripping one stand on elevator, and wrap up of the activity distributed drilling control. These activities were prioritized in dialogue with especially the end users and continues activities started initially in the center.

A lot of results have been disseminated in journals, in conference papers, and at conferences in 2023. In 2023 the most important international conference for the drilling industry, SPE/IADC Drilling Conference and Exhibition was arranged in Stavanger. A total of six papers related to DigiWells were presented at this conference. Nine PhD students and one post doc student are connected to the center and are progressing very well.

A very important activity continues to be involvement of key personnel from the center in international forums and committees to support interoperability and standardization. Scientists in the center are collaborating with the international cross-industry group, D-WIS (Drilling and Wells Interoperability Standards). Results from the center are expected to significantly impact the industry.

The two-day annual DigiWells seminar was arranged with one day for only the center partners and one day which was open also for representatives from key players outside the center including service companies, industry clusters and public authorities. This annual seminar is important for dissemination and to strengthen relations with key players.

An important goal in connection to the center is to support the establishment of spin-off projects. The spin-off projects entitled “3D geological interpretation for geosteering of wells” and “DISTINGUISH: Decision support using neural networks to predict geological uncertainties when geosteering” started in 2023.

Maturation of results towards industrialization is another very important activity connected to DigiWells. The Research Council of Norway’s Verification program is an important tool for this maturation, and one spin off project from DigiWells on development of a flowrate out measurement device is now ongoing.

The center’s focus is on developing more efficient and environmentally friendly technologies for well construction of petroleum wells, wells for CO2 storage and geothermal wells. However, we see that the work performed in the center also gives very important contributions to automation, autonomy, and artificial intelligence in general, and to other domains. An example is the new EU project under HORIZON-MISS-2023-OCEAN-01-03 call, Atlantic and Arctic sea basin lighthouse, which includes combination of new innovative

Erlend H. Vefring (photo: Rune Rolvsjord/NORCE)

Nature Based Solutions (NBS) in four demonstrations in Atlantic and Arctic basin. NORCE contributes to different work packages with a focus on Digital Twin of the Ocean (DTO), data modelling and AI for biodiversity restoration. It is a true cross-disciplinary project and methods and competence from automated/autonomous drilling will be transferred to the marine domain.

We are looking forward to an exciting 2024 with further progress on research, development, innovation, support to industrialization and collaboration.

Erlend H. Vefring, Centre Director, NORCE

About DigiWells

Digitalization, new sensors, interoperability, automation, autonomy, and improved work processes have the potential to enable a step change of the well delivery process.

The centre explores these possibilities by combining domain knowledge with fundamental research to accelerate the digital transformation of the well delivery process.

The centre aims to develop new work processes for planning drilling and well operations, new sensors, solutions for interoperability, solutions for automated and autonomous drilling, and decision support systems for geosteering. New solutions are planned to be demonstrated, often in spin-off projects, at the national research infrastructures OpenLab Drilling, Ullrigg and against field data from operators.

The centre supports collaboration between operators, service industry, public authorities, research institutions and academia in Norway and internationally. Results from the centre's activity enables innovation, business development, and value creation for Norwegian society. Moreover, in collaboration with universities, the centre will educate the next generation of specialists who will help implement the achieved research results.

Results from the research performed in DigiWells are disseminated to operators, service companies, public authorities, and academic partners to enable innovation and value creation.

Partners

AkerBP

ConocoPhillips

equinor

TotalEnergies

vår energi

wintershall dea

KONGSBERG

ODFJELL DRILLING

Sekal

Universitetet i Stavanger

NTNU
Norwegian University of Science and Technology

UNIVERSITETET I BERGEN

The Research Council of Norway

NORCE

EPICS

EPIC 1
Project leader:
Eric Cayeux

Automatic Well Engineering

The digital drilling program that is developed in DigiWells, can be a game changer towards the industry vision “plan a well in one day and with high quality”.

The goal for this epic, is to change the drilling program from today’s practice with one solution with possibly a couple of back-up plans, to an ensemble of possible drilling designs, using information from both the planning phase and the operational phase. The workflow consists of using multiple automatic generators for each of the possible elements of the drilling program (see Fig. 1). When having all the elements in place, the digital drilling program is the combination of constraints, uncertainties, measurement strategies, operational margins, geological risks, and engineering limits that delineate an ensemble of possible drilling designs. This gives the opportunity to take objectively assessed decisions during the planning phase, e.g., by choosing a combination of well paths, surveying programs, wellbore architectures, that give sufficient clearance to the constraints. At the operational stage, when unexpected situations occur, acceptable margins are readily available, allowing for deviating from the plan in an informed way and without recourse to qualitative judgement.

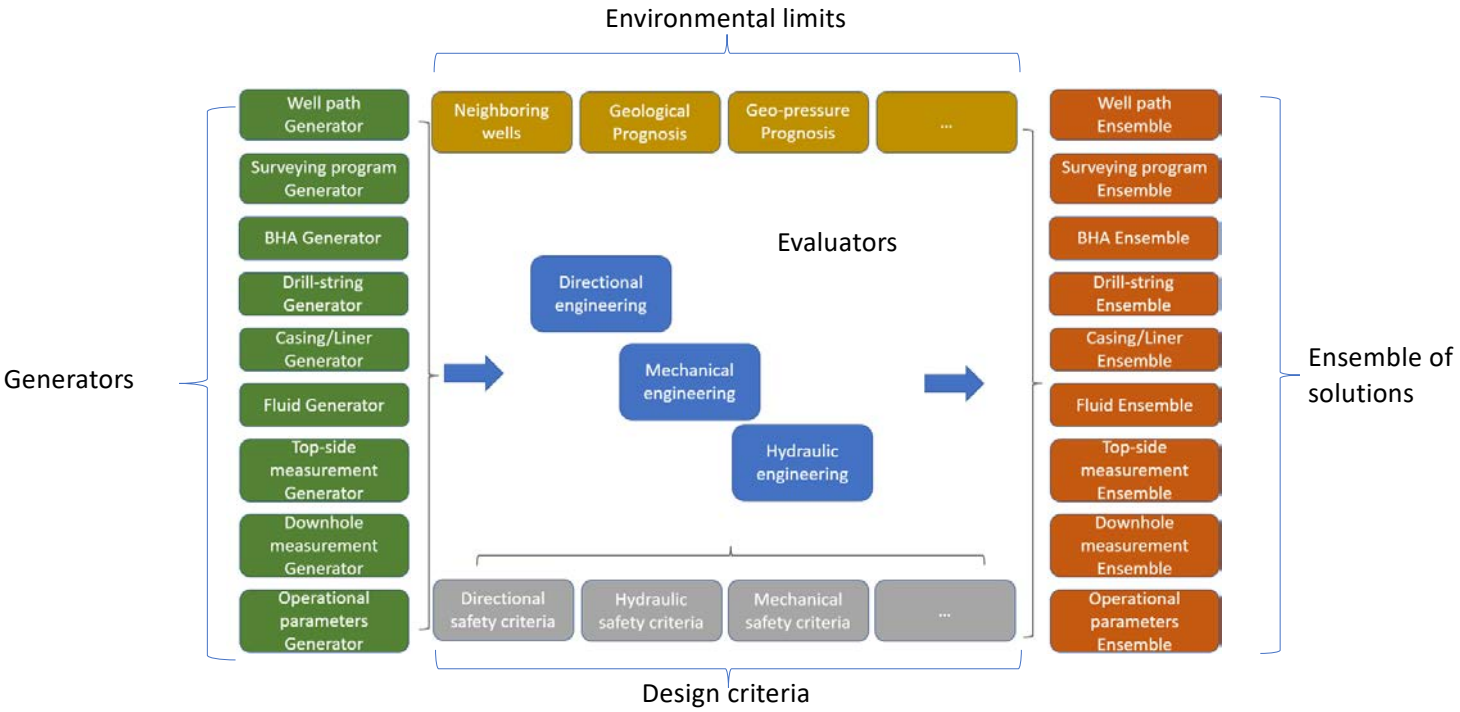


Fig. 1: Fig. 1: Evaluate multiple choices for the wellbore architecture, mud program and drill-string program amongst a library of preferred casing sizes, drill-pipe sizes, typical BHAs and drilling fluid systems, to determine a set of configurations that respects user-defined design criteria and environment limits.

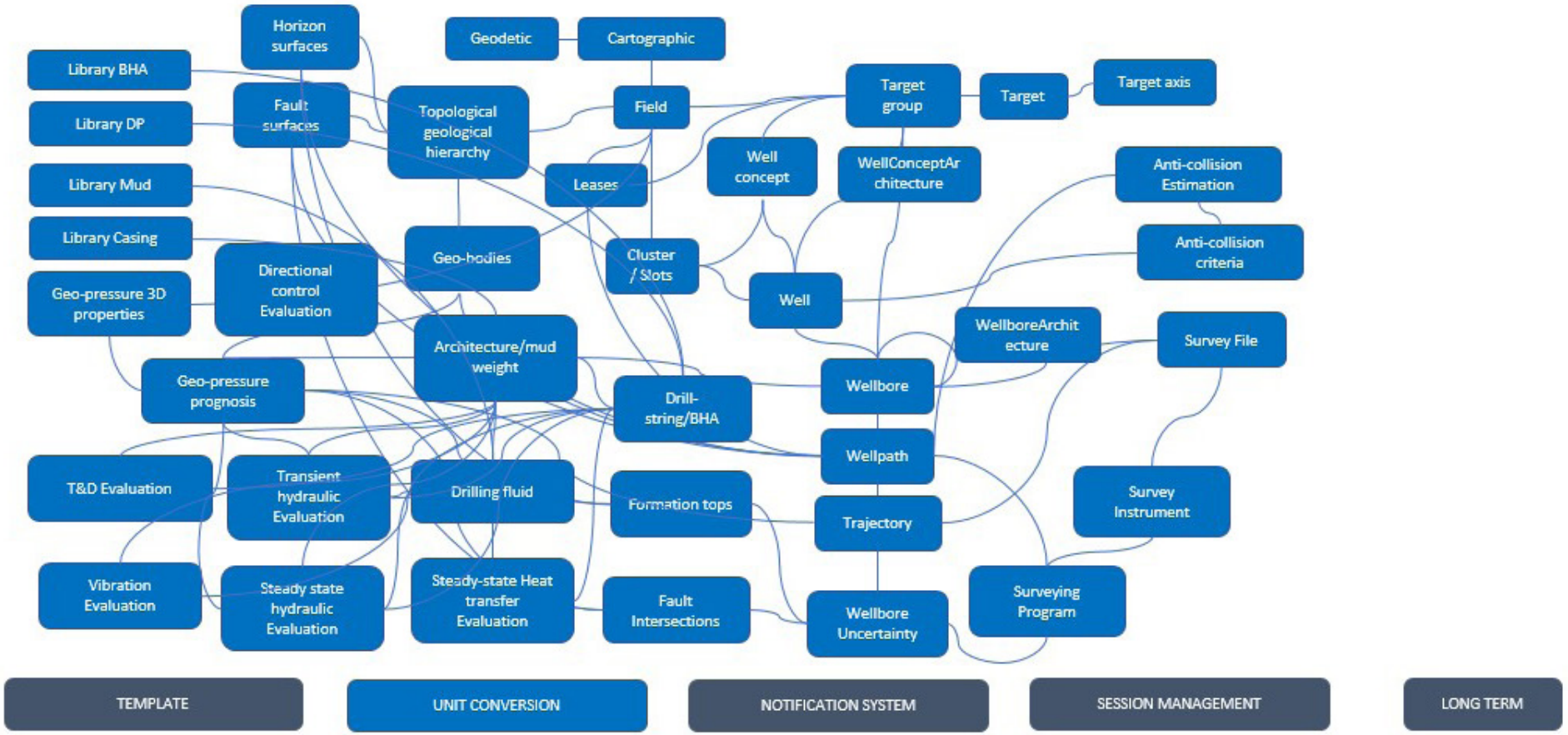


Fig. 2: Overview of the different microservices elements.

Microservice

The problem of generating ensemble of solutions in the context of automatic well engineering is complex. By using a microservice architecture, one has a versatile framework to generate such ensemble of solutions (see Fig. 2). Furthermore, microservices have the advantage of making it easier for the industry to do early testing of software developed in DigiWells. This architecture is composed of a collection of small services that are independently deployable and easily scalable by adding more instances of the necessary functionality.

The microservices can communicate through standardized interfaces and typically adhere to the generic application programming interface (API): create, read, update, delete (CRUD). The loose connection between the microservices allows external companies to choose only some microservices from the overall solution and to incorporate them within their existing software infrastructure. A refactoring of the initial version of the microservices has been necessary to improve access to data stores in each microservices without loading the entire dataset. An overview of the different elements can be found in Fig. 2.

Deliverables in 2023

The focus in 2022 was ensemble-based well path generation solution with focus on directional drilling. In 2023 the work has moved toward a new element of the drilling program, an ensemble-based drilling engineering solutions with focus on hydraulic, temperature and mechanical engineering. The development of a generic heat-hydro-mechanical model has been started. The model makes use of the Quemada rheological behavior*. It can be configured to work in steady-state or transient mode to adapt to the necessary level of details while generating an ensemble of solutions.

The implementation of the automated digital drilling program is complex and relies on a modern software architecture. Common involvement from both software developers and well-planning experts is beneficial. To help both the industry and the academia in this process, a series of meetings has been ongoing in 2023 explaining the results packaged in micro-services included how they are open to calling calculations made by external micro-services. This has been most appreciated by the partners and will continue in 2024.

It is nice to see the involvement from the industry and this has resulted in a common publication with Equinor, TotalEnergies, Halliburton and AkerBP, together with a presentation at the SPE Annual Technical Conference and Exhibition in San Antonio, Texas, 2023.

The epic will continue in 2024 and is closely linked to the next epic Automated Drilling Operational Plan as you can read more about in the next section.

* You can read more about rheological behaviors that are relevant for characterizing drilling fluids with the use of different models as Collins–Graves, Herschel–Bulkley, Robertson–Stiff, Heinz–Casson, Carreau and Quemada in the papers: “The Effect of Thixotropy on Pressure Losses in a Pipe”, Eric Cayeux and Amare Leulseged, Energies 2020 and: “Pressure Losses Generated by a Thixotropic Fluid when Subject to an Oscillating Flowrate” Eric Cayeux and Amare Leulseged, ASME 2020

It is now possible to evaluate multiple choices for the wellbore architecture, mud program and drill-string program to determine a set of configurations that respects user-defined design criteria and environment limits.

Publications

Paper “Facilitating Directional Drilling Work to Reach the Target Entry by Calculating a Safe Operating Envelope”, L. Saavedra Jerez, UiS, E. Cayeux, NORCE, D. Sui, UiS, will be presented at the IADC/SPE International Drilling Conference and Exhibition, 5-7 March 2024, in Galveston, USA, https://doi.org/10.2118/217707-MS

Paper presented at the SPE Annual Technical Conference and Exhibition, San Antonio, Texas, USA, October 16–18, 2023: A New Paradigm for Automatic Well Path Generation Using Multidisciplinary Constraints by E. Cayeux; G. Pelfrene; R. Mihai; E. Dvergsnes; B. P. Tjøstheim; A. Baume; R. Khosravanian; T. G. Kristiansen, https://doi.org/10.2118/215021-MS

Paper presented at the SPE/IADC International Drilling Conference, Galveston, Texas, USA, March 2022, SPE-208791-MS: An Ensemble-Based Solution for Automating Drilling engineering: Application to Directional Surveying by Eric Cayeux, Erik W. Dvergsnes, Liv A. Carlsen and Rodica Mihai, https://doi.org/10.2118/208791-MS

EPIC 2
Project leader: Benoit Daireaux

Automated Drilling Operational Plan

Drilling programs should be tailored to the digitalization of the drilling process. By reinventing the drilling program, significant breakthroughs in the way automated processes are seamlessly integrated into the drilling operations can be obtained.

After summer 2023 a new epic Automated Drilling Operational Plan (DrillOpPlan) was initiated. It is closely linked to the Automatic Well Engineering epic and considers new workflows and solutions towards automated well planning, accounting for the various degrees of uncertainty inherent to the task. The workflows rely on modern software architectures, advanced numerical models developed over the last decades and detailed knowledge of the well construction process. The epic also builds on the parallel DigiWells research activities on drilling autonomy, especially the AI inspired decision-making techniques, to bridge the gap between well construction planning and execution.

The epic's objective is to deliver from the automated planning stage an execution policy that can be directly used by automated and autonomous systems to perform the well construction tasks. Furthermore, by envisioning a comprehensive digital workflow from well design, engineering, planning to construction, there is the possibility to optimize drilling operations to an extent which has previously been unattainable.

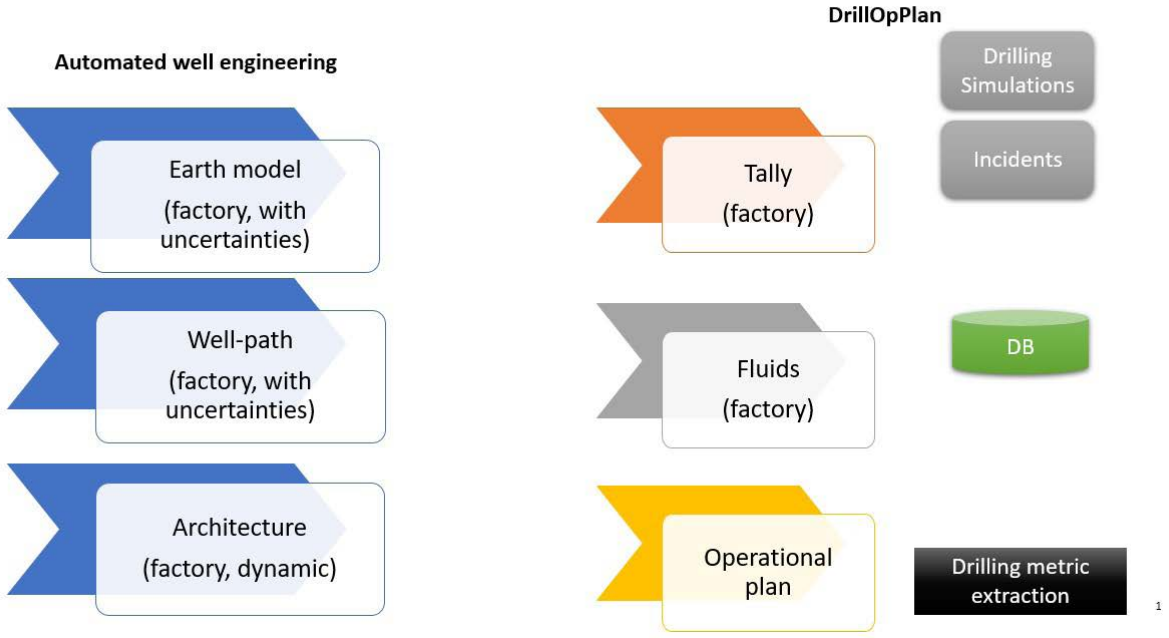


Fig 1: Workflow: Automated Well Engineering generates an ensemble of candidates, DrillOpPlan an automated evaluation of the most promising candidates.

Workflow

The Automated Well Engineering system generates an ensemble of candidates for the well plan that respect engineering constraints. In DrillOpPlan we plan to do an automated evaluation of the most promising candidates by doing analysis, plan refinement and comparisons to end up with a final choice. In 2023 a first implementation has been done of a stochastic simulation-based framework for drilling plan analysis.

The probabilistic Monte Carlo model can include elements of uncertainties in its prediction, and for DrillOpPlan Monte Carlo simulations include uncertainties in geology, trajectory, and fluid properties. Furthermore, the probability of drilling incidents occurring is considered based on models and frequency analysis of historical data.

For each candidate the system should generate a drilling strategy, i.e. an adaptive operational plan that accounts for uncertainties and risks. When unexpected events occur, the strategy re-evaluates the situation and generates an updated plan: the choice of new action is typically based on performance optimization considerations.

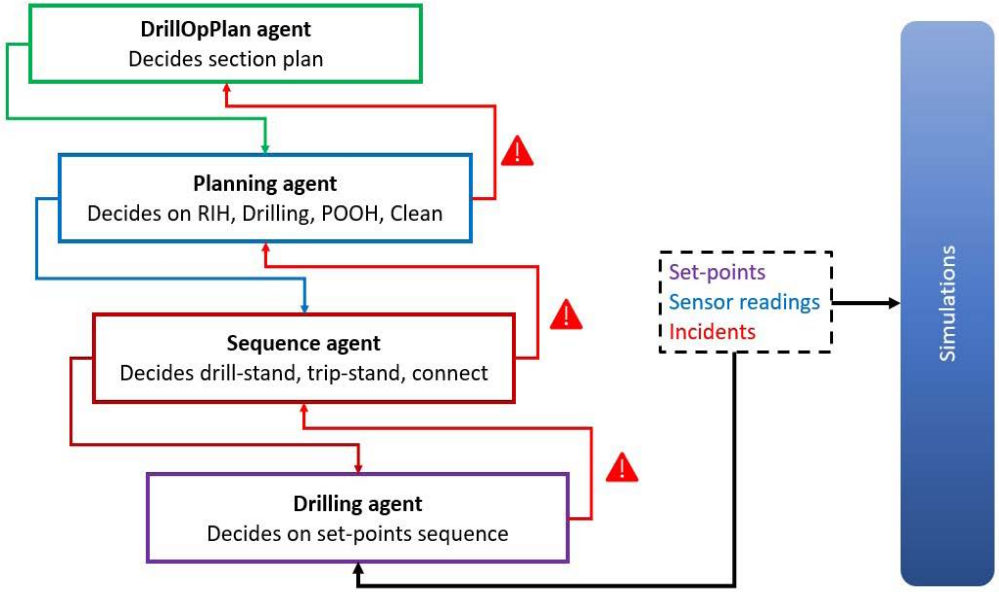


Fig 2: Simulation set-up for decision making

EPIC 3
Project leader: Rodica Mihai

Reduce drillstring vibration and improve hole cleaning

Along string elements with active control can dampen shocks and vibrations, control wobbling of drillstring to improve hole cleaning and reduce the energy requirements. By having active control of the magnetic damping elements, it is possible to optimize the damping effect with a reduced number of sleeves.

Achieving optimal performance during drilling of complex well trajectories is often hindered by downhole drill string vibrations and stick-slip. These can lead to drill bit and downhole tool damage, drill string wear possibly leading to a twist-off, or formation damage. Recent advancements in drill string vibration interpretation show that the sources of excitation are not only at the bit but anywhere along the string.

An innovative concept that uses distributed along-string damping elements based on magnetic damping is being developed in this DigiWells project. The experimental work has been described in the 2022 annual report.

Active control of the sleeves

Passive damping has good results, but relatively large number of sleeves are required to achieve the desired effect. At the same time, slipping of the sleeve on the borehole can be a source of trouble. However, the design of the damping subs can allow for active control of the damping strength. Based on this, it has been a focus in the project on how to reduce the number of sleeves by employing distributed control algorithms. Initial simulations show that it is possible to achieve dampening of shocks and at the same time reduce the number of sleeves, by actively controlling the damping effect on the sleeves along the drill-string in a distributed fashion. At the same time, PhD student at NTNU, Pauline Nüsse, has worked on active control of one sleeve to cope with slipping of the sleeve on the borehole.

Furthermore, active control of the sleeves can facilitate cutting transport. In addition to high flowrate and rotational speed, lateral oscillations of the drill-string on the low-side of inclined wells will improve hole cleaning. However, the drill-string lateral oscillations are usually not controlled in any way. Active control of the distributed damping subs represents a solution to trigger the lateral movement of the drill-string at certain positions which can open the possibility to control wobbling of drill-string. A simulation environment including a transient stiff-string torque and drag model which accounts for axial, torsional and lateral displacements has been set up with a well configuration from a field case. The viscous damping subs are included in the model at defined locations along the drill-string. Two different series of simulation with active control of the lateral movement of the drill-pipes have been done. The first series of simulated experiments were focused on

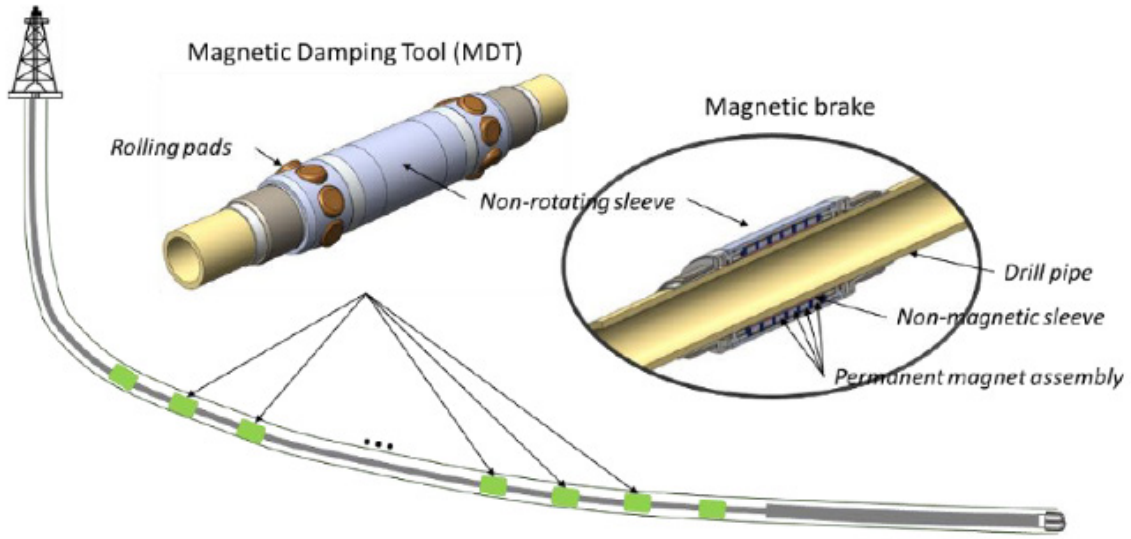


Fig: The innovative magnetic damping tool has demonstrated the ability to damp out stick-slip at discrete intervals along the drillstring where stick-slip originates. Active control of the sleeves has reduced the number of necessary sleeves and enhanced the cuttings transport for inclined wells.

controlling the amount of viscous damping for all subs simultaneously with the same magnitude. It was observed that the effect on the lateral movement in this case was minor. In a second approach, subs placed at different locations had different damping strengths that were varied at specific time steps. Controlling the damping in a distributed fashion had a stronger effect on the local lateral movement and it was possible to create different localized movement patterns along the drill-string. The simulations show that it is possible to trigger different movement patterns in the drill-string by varying the damping effect of the sleeves, and therefore enhance hole cleaning. At the same time, torsional oscillations are damped out.

Reduction in CO2 emissions

The damping subs reduce the overall required torque at the top-drive and facilitate weight transmission to the bit. Simulations have shown that torque reduction can reach more than 50 percent. A more modest 30 percent decrease is assumed to account for the fact that the tools will not always be lying in part of the well where contacts are significant. This decrease in friction directly affects the electrical energy consumption of the top drive. When drilling long lateral sections, the savings in cost and CO2 emissions can be significant.

All directional wells will benefit from reduced vibration and reduced friction along the drill-string. Hence, the solutions developed here can bring value to most of the wells at the Norwegian Continental Shelf. For deep geothermal wells drilling in hard formation and a growing need to deploy multi-lateral well architectures, stick-slip and energy transfer are well-known issues. Finally, also P&A operations benefits from mitigate stick-slip, reduce friction, and thereby minimize their cost.

Publications

Paper IADC/SPE-217675-MS “Improving Hole Cleaning by Using Distributed Damping Subs to Control Lateral Oscillations of the Drill-String”, R. Mihai, NORCE, A. Ambrus, NORCE, E. Cayeux, NORCE, DOI 10.2118/217675-MS will be presented at the IADC/SPE International Drilling Conference and Exhibition, 5-7 March 2024, in Galveston, US

“Self-Attenuation of Drillstring Torsional Vibrations using Distributed Dampers”, E. Cayeux, A. Ambrus, NORCE, SPE Journal, 2023. https://doi.org/10.2118/214675-PA

“Experimental Verification of Vibration Mitigation Through a Viscous Damping System Along the Drill String” SPE Drilling conference 2023, A. Holsaeter, E. Cayeux, A. Ambrus, R. Mihai, S. Moi. DOI: 10.2118/212521-MS

«Modelling and Analysis of Non-Rotating Damping Subs for Removing Torsional Vibrations in Drilling”, A. Ambrus, Ulf Jakob Aarsnes, E. Cayeux, R. Mihai, NORCE, ASME 2022. https://doi.org/10.1115/OMAE2022-78339

Status from NTNU

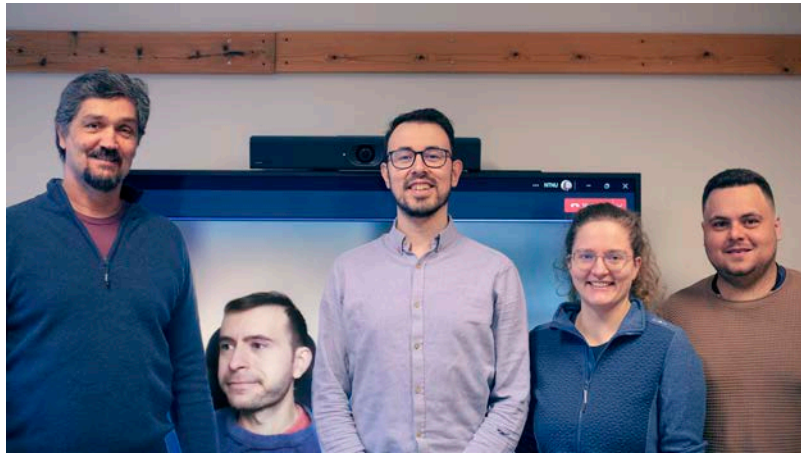
NTNU currently has two PhD students (Pauline Nüsse and Marios Gkionis) and one half-time post-doc (Nils Christian Aars Wilhelmsen) within DigiWells. Pauline and Nils Christian are developing algorithms for active control of subs for damping of drill string vibrations. They are supervised jointly by NTNU (Ole Morten Aamo) and NORCE (Adrian Ambrus), and the photo below is taken during one of our bi-weekly status meetings. Pauline is approaching the finish line of her PhD, with results published in the high-quality journal Geoenergy Science and Engineering1 and to be presented at the 2024 IADC/SPE International Drilling Conference and Exhibition2 in Galveston, USA, and at the 43rd International Conference on Ocean, Offshore & Arctic Engineering3 in Singapore. She also has a joint publication with Nils Christian in preparation for a journal4.

Pauline: « I work on controllers for the distributed sleeves to reduce vibrations in the drill string. My latest addition was an anti-slip logic to prevent the sleeve from slipping too frequently in the borehole. This works as a saturation on the damping coefficient such that the damping force is smaller than the friction force keeping the sleeve stationary. »

Nils Christian: « My recent work has focused on modelling and detection of slip in damping subs. For optimal functioning it is imperative that the subs do not slip on the borehole wall during operation. A simple mathematical model describing the motion of the subs in the wellbore, useful for simulation, algorithm design and analysis purposes has been derived. Subsequently, a scheme for detecting when slip occurs using signals from inertial measurement units placed within the sub has been developed. A publication containing these results is under preparation. »

Marios is developing algorithms for multitask learning in neural nets. He is supervised jointly by NTNU (Ole Morten Aamo and Bjarne Andre Grimstad) and NORCE (Ulf Jakob Aarsnes), and has one and a half year to go in his PhD research.

Marios: « In my thesis topic, my attempts are currently focused on analytically describing certain complex behaviours that are exhibited in Multitask Learning. Deep Learning has been used extensively during the last decades; however, its inner mechanisms have recently started becoming analytically understood. We have been busy exploring formulations, as well as ideas on how to utilize the state-of-the-art knowledge on Deep Neural Network behaviour, to devise better strategies to train them. We are focusing this effort on certain challenges of Multitask Learning. »



Bi-weekly status meeting at NTNU. From left: Ole Morten Aamo, Adrian Ambrus (remotely from NORCE), Marios Gkionis, Pauline Nüsse and Nils Christian Aars Wilhelmsen.

Publications

Evaluation of distributed damping subs with active control for stick-slip reduction in drilling", Pauline Nüsse, NTNU; Adrian Ambrus, NORCE, Ulf Jakob Aarsnes, NORCE and Ole Morten Aamo, NTNU, Geoenergy Science and Engineering, 2023. https://doi.org/10.1016/j.geoen.2023.212255

Paper IADC/SPE-217676 "Decentralized Active Control of Distributed Damping Subs for Stick-Slip Reduction in Drilling", P.M. Nüsse, NTNU, A. Ambrus, NORCE, O.M. Aamo, NTNU, DOI 10.2118/217676-MS , will be presented at the IADC/SPE International Drilling Conference and Exhibition, 5-7 March 2024, in Galveston, US

Paper "Active Control of Distributed Subs With Anti-Slip Logic for Torsional Vibration Damping in Drilling'', P. M. Nüsse, A. Ambrus, O.M. Aamo, will be presented at OMAE 2024.

Towards a framework for optimization of tripping

A two-steps procedure to trip one stand is already available. Motivated by the achieved time savings, we now investigate multistep tripping of one stand to optimize time and minimize hydraulic and mechanical risks on a short-term perspective.

Earlier, NORCE has developed a functionality to trip one stand in a two-step procedure to minimize time per stand and stay within acceptable limits for swab and surge. The functionality is available through DrillTronics, an automated drilling control solution used by the driller and commercialized by Sekal. Installed on more than 20 rigs, DrillTronics has shown to increase the tripping speed in a safe way.

To further increase the tripping speed, we have established a framework for multistep tripping optimization of one stand. The framework allows for inclusion of multiple parameters affecting downhole estimations for tripping optimization. As mechanical, hydraulic and heat effects directly influence downhole pressure, the tripping optimization method needs to cope with transient behavior such as:

- Hydraulic transient effects that are required to be captured in the model for the accelerations and decelerations phases
- Transient torque and drag model which is needed because of elasticity of the drill-string
- Heat transfer model which is needed as the fluid density and the rheological behavior are influenced by the temperature

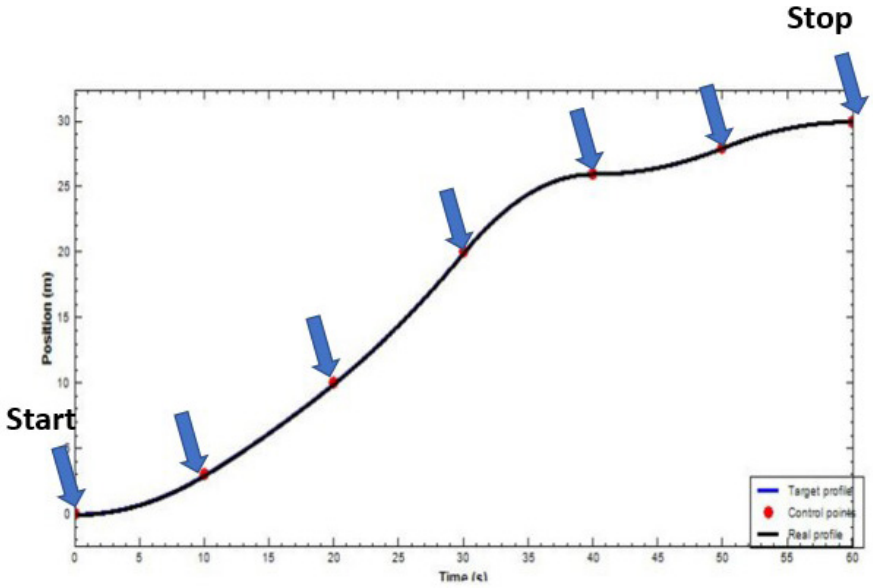


Fig 1: Tripping optimization framework with piece-wise constant acceleration

To optimize the tripping speed for one stand in a safe way, it is important to investigate and do risk estimation of scenarios such as surge & swab and stuck pipe. To manage this in a proper way, it is needed to consider uncertainty estimation of downhole conditions including temperature, mud properties, cuttings accumulation, and static and kinetic mechanical friction.

The approach considered in this work, uses piece-wise constant accelerations as shown in Fig 1. At the same time, the approach considers a constraints characterization which includes machine constraints, process constraints, user defined constraints and other constraints such as smoothness and continuity. By this approach is then possible to compute accelerations and velocities that optimize tripping and which respect the aforementioned constraints.

Successful demonstration of DDHub

Digitalization of the drilling industry is progressing rapidly. DDHub makes different players exchange information in an automatic and consistent manner.

The characterization of drilling real-time signals can happen through differentiating their names or by associating them with metadata. However, combinatorial explosion tends to limit agreement on the number of practical standardized tag names or metadata attributes. DDHub is an alternative solution to this problem. The framework defines a vocabulary of standard terms that are useful to describe facts about drilling signals. Behind this new solution, we find semantic description of real-time drilling signals in a computer readable format. DDHub allows different software solutions to discover drilling data whenever available and how they relate in terms of uncertainty propagation.

The use of semantic networks to describe the relationships among elements of data allows for transparency of information. That transparency reduces misunderstanding and allows for multiple digital parties, with different reference frames, to exchange information in a way that reduces risk in critical operations. Semantic networks should be seen as a framework reducing confusion in data analytics and machine learning, and drilling systems automation, and any task or product that utilizes digital data in drilling operations. Indeed, useful data is seen as the first and most important step in developing a true digital drilling operation. Data-driven design, facilitated by semantic networks, is a solid way to mitigate risk. It enables the reuse of data sources and provides valuable information that can provoke creative ideas in the stages of design and planning. This not only leads to innovative solutions but also ensures the efficient use of data and resources, further minimizing risk.

Benoit Daireaux and Eric Cayeux (photo: Sergey Alyaev/NORCE)

D-WIS
Drilling and Wells Interoperability Standards
INDUSTRY GROUP

Picture: D-WIS is a group of industry professionals interested in data interoperability to enable the exchange of data and facilitation of drilling automation at the rig site and beyond.

To achieve an international recognition of DDHub and a possible standardized way to exchange data, the two NORCE Chief Scientists, Eric Cayeux and Benoit Daireaux, work together with the international cross-industry group, D-WIS (Drilling and Wells Interoperability Standards). Some of the results will be presented by Cayeux at the next drilling conference in Galveston March 2024: “The Role of Semantic Networks in mitigating Risk During Data Exchange in Multi-Disciplinary Well Construction”. The work is a joint effort with an impressive international co-author list, see overview of publications. You can read more about D-WIS and other International Forums and Committees at DigiWells website.

Demonstration of DDHub using OpenLab

Drilling operations rely on the collaboration of many participants, and the efficiency of this collaboration depends on timely exchange of information. The complexity and variability of this information make

it difficult to achieve interoperability between the involved systems. By using DDHub as an effective collaboration framework, it was demonstrated consistent and automatically exchange of data between Sekal's and Halliburton's software solutions in real-time.

"The Drilling Data Hub (DDHub) approach is well aligned with Halliburton 4.0 Well Construction programs. Our philosophy with open architecture and data liberation fits well with DDHub to enable seamless data flow between systems; both internally and externally. Now we need to keep the momentum by expanding on the semantics vocabulary for the DDHub program going forward. This is important to reduce point to point solutions, and it is also well aligned with D-WIS efforts.", says Oddbjørn Kvammen, Halliburton.

DDHub can play an important role for speeding up automated drilling

When rigs take automated drilling into use, the drilling control systems (DCS) accept advice from external apps that includes calculations of what happens downhole. Before this can happen, extensive work on integrating apps in a safe way must be done. Different DCS vendors have different solutions for interfacing, and every rig is different. Vendors are changing, and we can easily foresee that the work necessary to configure and adapt the DCS and the external apps, can slow down the deployment of automated drilling solution because of workload and cost. By using DDHub as an intermediate layer, once implemented, the manual work is replaced by an automated solution accommodating the different service providers with unambiguous signals. It is a flexible solution that not only handles the current picture, but also takes into account changes of vendors and measurements in the future. DDHub can potentially facilitate for more efficient deployment and further use of automation solutions.

The live demonstration with Sekal and Halliburton was given by Benoit Daireaux in OpenLab (photo: Helga Gjeraldstveit/NORCE)

Publications

Paper SPE-217668 "The Role of Semantic Networks in mitigating Risk During Data Exchange in Multi-Disciplinary Well Construction" E. Cayeux, NORCE Norwegian Research Centre, Stavanger, Norway; B. Daireaux, NORCE Norwegian Research Centre, Oslo, Norway; J. Macpherson, Baker Hughes, Houston, Texas, USA; C. Damski, Genesis Petroleum, Perth, Australia; P. Annaiyappa, Independent Consultant, Houston, Texas, USA; J. Carney, NOV, Stavanger, Norway; W. Ziadat, Cor-va.ai, Houston, USA; P. Harbidge, Expro, Kuala Lumpur, Malaysia; M. Edwards, Edwards Energy Innovation Consulting, Houston, Texas, USA; H. Bolt, Depth Solutions, London, U To be presented at the IADC/SPE International Drilling Conference and Exhibition held in Galveston, Texas, USA, 5 – 7 March 2024

SPE Drilling & Completions: "Connecting Multilayer Semantic Networks to Data Lakes: The Representation of Data Uncertainty and Quality", Cayeux, E., Damski, C., Macpherson, M. Laing; P. Annaiyappa; P. Harbidge; M. Edwards; J. Carney, https://doi.org/10.2118/208754-PA

SPE Energy Stream: https://streaming.spe.org/spe-live-interoperability-as-a-key-factor-to-better-drilling-automation

Paper SPE-212472-MS "Interoperability of Real-time Drilling Signals at the Rig Site: An Example Based on Mechanical Specific Energy" presented at the SPE/IADC Drilling Conference in Stavanger, Norway, March 2023, https://doi.org/10.2118/212472-MS

Paper SPE-212565-MS "Drilling Systems Automation: Fault Detection, Isolation and Recovery Functions for Situational Awareness" presented at the SPE/IADC Drilling Conference in Stavanger, Norway, March 2023, https://doi.org/10.2118/212565-MS

Paper SPE-212537-MS "A General Framework to Describe Drilling Process States" presented at the SPE/IADC Drilling Conference in Stavanger, Norway, March 2023, https://doi.org/10.2118/212537-MS

Method is described in paper SPE-208754-MS «A Framework to Capture the Relationships in Drilling Data and the Propagation of Uncertainty» presented at the SPE/IADC Drilling Conference in Galveston, TX, USA, March 2022, https://doi.org/10.2118/208754-MS

Paper SPE-208732-MS "Best Practices to Improve Accurate Time Stamping of Data at The Well Site" presented at the SPE/IADC Drilling Conference in Galveston, TX, USA, March 2022, https://doi.org/10.2118/208732-MS

Presentation "Drilling Data Quality and Uncertainty" at the SPE-WPTS ISCWSA conference (virtual) April 14, 2021,

Presentation "The Role of Software Interoperability to Improve Performance and Quality of Service in Drilling Operations" at the SPE Virtual Workshop Asia Pacific Digital Week – "enhancing the energy value chain through Innovation and digital ecosystem", 9-11 Nov. 2021.

DigiWells' Ph.D. candidate develops a chatbot for oil and gas data

At Aker BP, we started testing Microsoft Copilot integrated as a virtual assistant, which you can chat with in the Teams app. It can, for example, prepare an action list after a Teams meeting or find and summarize relevant documents in your Sharepoint. However, finding and summarising technical information is not that simple. Even more so, the current AI struggles to make sense of data across multiple databases and formats, says Tomasz Wiktorski, Data Delivery Manager at Aker BP and Professor at UiS.

ChatGPT started receiving tremendous attention at the end of 2022. The Atlantic named ChatGPT and other large language models (LLMs) in the "Breakthrough of the Year" article in 2022. Lately, LLMs excelled in answering general questions, writing code, and transforming and translating text. However, using LLMs for domain-specific factual responses poses a challenge.

AI for drilling data

– We wanted to develop a custom question-answering bot that can help drilling personnel make informed decisions promptly. Developing the chatbot started as a side project but has quickly become a significant part of my Ph.D. within machine learning for drilling, says Felix James Cardano Pacis, a Ph.D. candidate at the University of Stavanger and DigiWells.

Pacis is currently developing the chatbot with Tomasz Wiktorski, Sergey Alyaev, a senior researcher from NORCE, and Gilles Pelfrene, also a senior researcher from NORCE.

–Felix started working on a data filtering and visualization dashboard before he started his Ph.D. He showed the first chatbot functionality with it at the DigiWells Seminar in 2022. That was before ChatGPT took the world by storm, says Alyaev, Deep-Learning-epic leader and Pacis's Ph.D. co-supervisor.

– We got a lot of interest from the consortium and encouraged Felix to dig deeper into the problem. That was very much in the spirit of DigiWells' agile fashion. We definitely could not foresee this when we announced the Ph.D. position, he adds.

Pacis was on an extended research stay at the Colorado School of Mines in 2023 with an initial plan to explore data-based rate-of-penetration optimization. Simultaneously, he was improving the chatbot prototype for the upcoming conference. The chatbot project was so exciting that he decided to return earlier, as the group in Colorado did not have the right competence in LLMs.

Rigorous evaluation of available LLMs on industry jargon

– We used a zero-shot learning technique that relies on an LLM's ability to generate responses for tasks outside its training, explains Pacis.

In machine learning, zero-shot learning occurs when an AI model is given tasks that were not part of the training and needs to make an inference about these tasks. This generally works by providing context information together with such a task. For example, an AI model trained to recognize horses can recognize a zebra given the context: "Zebras look like striped horses."

Felix Pacis during a DigiWells collaboration visit to Aker BP (photo: Sergey Alyaev/NORCE)

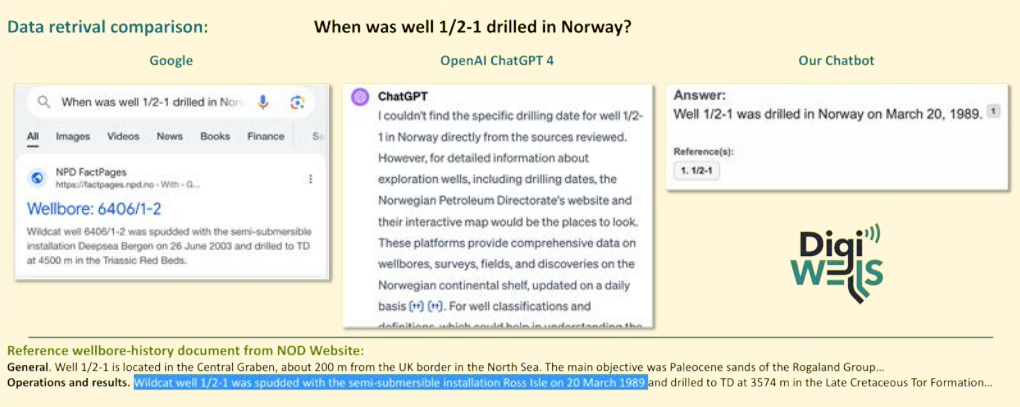


Figure. Three-way comparison between Google search, Open AI ChatGPT-4, and DigiWells chatbot. Performed in Feb. 2024.

The chatbot team visiting the Norwegian Offshore Directorate (photo: Sergey Alyaev/NORCE).

For the recent study, Pacis implemented a controlled zero-shot learning "in-context" procedure that sends a user's query augmented with text data to an LLM as inputs.

– This implementation encourages the LLM to take the answer from the data while leveraging its pre-trained contextual-learning capability. And we documented the pre-trained LLMs' ability to provide correct answers and identify petroleum industry jargon from the collated dataset, says Pacis.

DigiWells researchers gathered and collated text data from publicly available databases, such as the Norwegian Offshore Directorate, annual reports of different companies, and the petroleum glossary. They used the dataset to create a domain-specific benchmark of multiple-choice questions. Their study, published at the SPE AIDC conference, evaluates seven commercial and open-source large language models (LLMs) on this benchmark. The results of the LLM evaluations aided the researchers in selecting the best-performing components for the petroleum chatbot.

Towards a fully functional chatbot

– We tailored the algorithm for drilling documents and made it preferable over Google and ChatGPT. Unlike our chatbot, ChatGPT and Google search could not provide specific and direct answers to industry-specific questions, says Pacis.

The work on the chatbot continues with the development of the ranking model. The researchers are also working to identify specific cases where the bot excels or needs improvement.

– We are including more data, increasing the response rate, and performing further testing and validation. We are also generating artificial data through simulated interactions with the chatbot as supplementary data, explains Pacis.

The DigiWells researchers also work with several public and private partners.

– We started working with the Norwegian Offshore Directorate on a new extensive dataset of all their public data. We'll use it to train LLMs for offshore data exploration based on open-source offline models. We sorted out "in-context" question-answering in our SPE study. Now, for the full chatbot, we need an improved ranking model that finds the correct context document from any large knowledge base. We think this model can also be an LLM, says Sergey Alyaev.

The large language models are here to stay.

– What started as a PhD sub-project is gaining momentum. There will already be spin-off activities in DigiWells in 2024. We are discussing applications of Felix's methodology with several of NORCE's industrial partners. Maybe this summer we'll get funding to apply it outside drilling, fingers crossed, concludes Alyaev.

Reference

Pacis, F. J., Alyaev, S., Pelfrene, G., and T. Wiktorski. "Enhancing Information Retrieval in the Drilling Domain: Zero-Shot Learning with Large Language Models for Question-Answering." Paper presented at the IADC/SPE International Drilling Conference and Exhibition, Galveston, Texas, USA, March 2024. doi: https://doi.org/10.2118/217671-MS

Case study on drillstring vibration causing casing wear in a vertical section

For an operator on the Norwegian Continental Shelf (NCS), it was important to have an evaluation for how long and where the casing had been exposed to side forces due to drillstring vibration. A transient, stiff-string torque and drag model were used by NORCE to study this case.

A transient, stiff-string torque and drag model that calculates axial, torsional and lateral deformation of the drillstring has newly been developed by the researchers in DigiWells. The model is a combined hydro-mechanical model where the hydraulic forces are included in the lateral dynamics and buoyancy calculation. It includes a drillstring-wall contact model and the drillstring can move axially along the casing/borehole. Verification of this 4n-degrees of freedom transient torque and drag (4nDOF TT&D) model with high frequency downhole measurements from field cases showed very good agreement in complex conditions (Ambrus, Cayeux, & Shor, 2024).

Simulations have been performed using this 4n DOF TT&D model on a case from the NCS to evaluate lateral vibrations and contact loads on the casing.

Simulations

Dynamic simulations considering drilling with an average ROP of 10 m/h and a variable surface RPM have been performed on the case described in Fig 1. Original and processed survey data were used for the well trajectory that was given as input to the model. Four different scenarios and drilling from three different bit depths have been simulated. The operator was especially concerned about the casing wear in a region around 500m MD where the casing shifts from 10 ¾" to 9 7/8" outer diameter (OD).

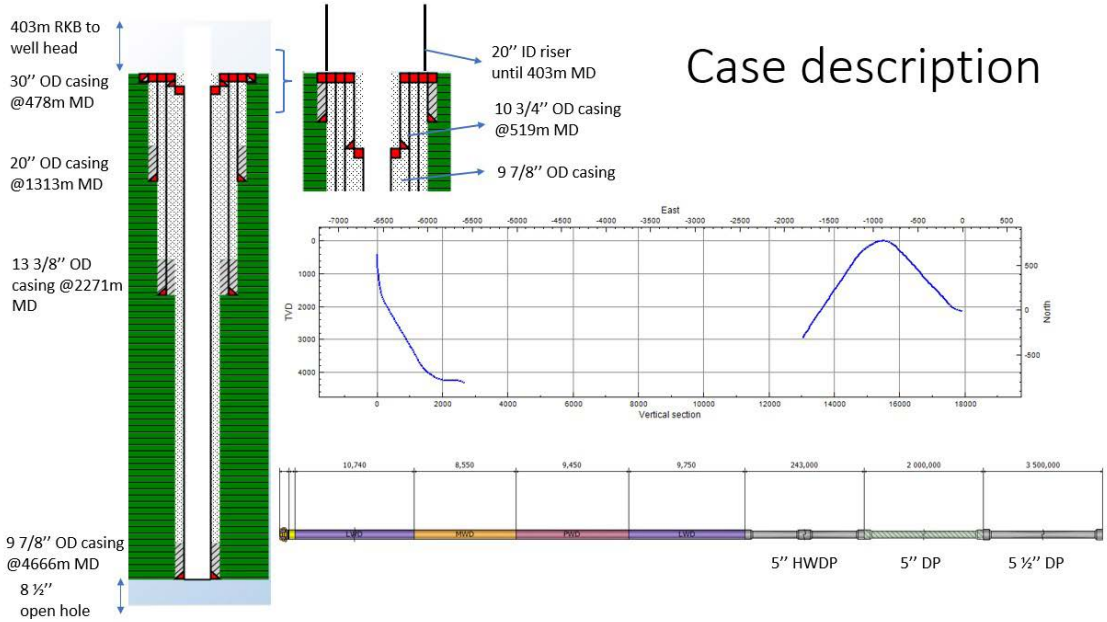


Fig 1: The case description for the simulations. The region of most interest is where the casing shifts from 10 ¾" to 9 7/8" OD.

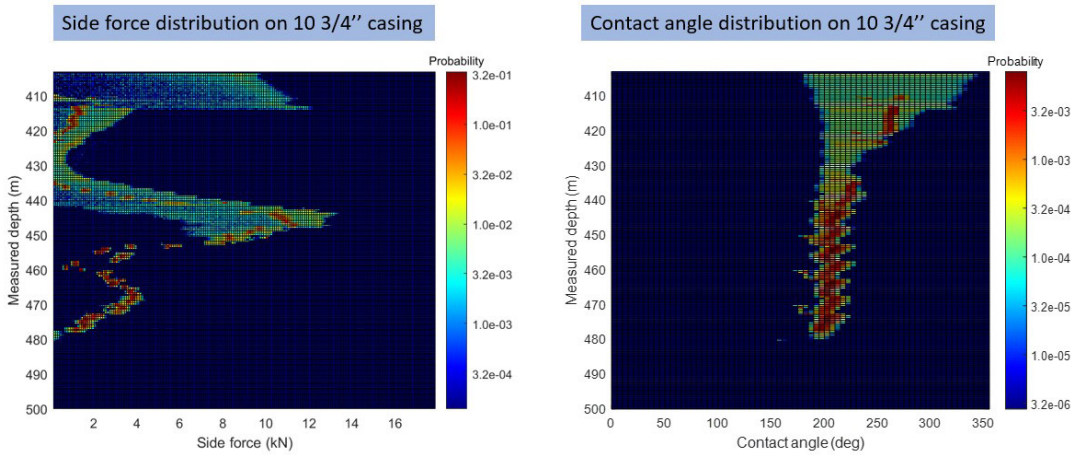


Fig 2: Side forces and contact angle distribution on 10 ¾" casing from 410 m MD to 500 m MD. Red and orange points show higher probability at a particular depth, while green and blue points show lower probability. A wide distribution is equivalent to whirling and a narrow distribution is equivalent to wobbling movement.

To estimate a probability distribution for how long and where the casing had been exposed to side-forces, the calculated side force and angle of contact were recorded for each tool joint in contact with the casing. The contact angle is based on the lateral displacement of the tool joint inside a cross-section of the wellbore, and its trend over time can indicate forward and backward whirling, or a more gentle wobbling movement. As tool joints move axially while drilling or hoisting the drillstring, heat maps of the side forces and contact angles on an entire portion of the casing can be constructed. For this purpose, the wellbore was discretized into equally spaced angular sectors and depth intervals. Fig. 2 shows the side forces and the contact angle distribution on the 10 3/4" casing for one of the simulated cases.

Conclusion

Simulations with a 4nDOF model have showed that full whirling can occur in the part of the vertical section of most interest, and that the occurrence of whirl depends on top drive RPM and wellbore tortuosity at shallow depths. The contact force distribution and contact angle can vary significantly over a short depth interval and this has potential implications on casing wear.

Reference

Ambrus, A., Cayeux, E., & Shor, R. (2024). Investigation of field scenarios using a 4n degrees of freedom transient torque and drag model. Geoenergy Science and Engineering, 233, 212563.

Photo: Helga Gjeraldstveit

SFI DigiWells annual seminar

In November we gathered for our annual seminar. Experts from industry, academia, and authorities came to discuss new research and relevant issues within digitalization, automation and autonomous drilling.

At the seminar industry, researchers and regulatory authorities came to share their knowledge. Arvid Østhus from the Norwegian Offshore Directorate talked about Value creation at the Norwegian Continental shelf, Antonin Baume talked about digital transformation within Total Energies, and Tron Golder Kristiansen from AkerBP talked about Experiences from Drill Well on the Simulator Concept.

DigiWells researchers presented some of their latest research, within subjects such as, well planning, geosteering, interoperability and automation.

The taxonomy of Autonomous drilling

One of the topics of the seminar were the different perceptions of what autonomous drilling is, and the need for a common understanding.

– At Equinor we talk about different levels of automation and autonomy, where every level requires less operator control. We use the same classification as the automotive industry. There is quite a big step to reach the highest level – full autonomous drilling. There are technical, organizational and regulatory hurdles to overcome before we get there, said Erlend Wersland from Equinor.

Chief scientist Eric Cayeux and senior researcher Rodica Mihai in DigiWells have written a paper on how one can define autonomous drilling – the taxonomy for autonomous drilling. The paper is written together with industry experts John de Wardt, John Macpherson, Pradeep Annaiyappa and Dimitrios Pirovolou.

– Many factors collectively decide if a system is autonomous, for example, if it makes decisions and implements decisions, how uncertain and complex the system in which the system operates is, if it learns from experience and if it manages risk to achieve its goal. Independence is a crucial factor. An autonomous system can interact with other agents, but it decides independently whether or how it will use external advises, explained Eric.

The paper (SPE-215021-MS) will be presented at the Drilling Conference in March 2024.

Centre director Erlend Vefring together with Aina Berg, acting excecutive vice president at the Energy and Technology division at NORCE.

Antonin Baume from TotalEnergies

Top: From the left: Eric Cayeux Chief Scientist at NORCE and Harald Nevøy from ConocoPhilips.
Bottom: From the left: Ivar Kjøsnes and Erlend Wersland from Equinor.

Top: From the left: Tron Golder Kristiansen, DigiWells' board chair from Aker BP and Erlend Vefring.
Bottom: Rodica Mihai, senior researcher at DigiWells.

Photos: Ida Sollesnes/NORCE

What differentiate a fully automatic system from an autonomous one?

There has been inflation in the use of the word autonomous in the drilling industry. To avoid confusion there is a need to define and include autonomous behavior in the taxonomy of drilling systems automation. A possible reference paper is now published.

The NORCE researchers Eric Cayeux and Rodica Mihai has together with an international group collaborating under the SPE DSATS (Drilling Systems Automation Technical Section) investigated how various industries and disciplines characterize an autonomous system. There is no single definition, but the most important traits of an autonomous system were identified:

(a) goal oriented
(b) adaptable
(c) perceives its environment
(d) makes decisions
(e) takes actions
(f) learns from experience
(g) has strategic and tactical abilities
(h) is independent
(i) collaborates
(j) is self-contained
(k) manages uncertainty
(l) assess risk
(m) is self-governing
(n) has fallback-mechanisms
(o) is self-sustaining
(p) is responsible

Most of these traits are interrelated. Furthermore, autonomous operation must respect a certain number of constraints like acceptance, verification, validation, transparency, ability to explain its decisions, legal compliance, ethics, time constraints and limited perception.

An autonomous system needs to meet a certain minimum of the traits and constraints to be classified as autonomous, and these will not be the same for different industries and disciplines.

An additional challenge for the drilling industry, is the sparse availability of data, which is often delayed in time and associated with uncertainty. It is far more complicated than for e.g. self-driving cars given the available signals. Another two challenges for drilling, is the subsurface uncertainty and to know the current state of the drilling operations. The autonomous system needs to know if the operation has challenges with cutting transport, if the downhole pressure stays within the geopressured window, if the well is on the right track to reach the pay zone, and so on to be able to take the right decisions. Due to the complex nature of this high-risk environment, there will be some grade of uncertainties related to the answers. It is therefore not relevant to lift an existing taxonomy or definition to be used for well construction, and the approach in the paper is to define traits that an autonomous drilling system must exhibit, see Table 1.

Autonomous drilling system

Notice from Table 1 (p. 27) that an autonomous system has decreased dependence on human interaction, but it is not about having no human intervention. If having an autonomous system, it can interact with other agents (e.g. different players in an offshore drilling operation), but the system itself decides what it uses. It adapts to the current situation and balances the performance and the levels of risks, and it decides if additional operations are necessary in the context of available signals. It is a self-learning system that estimates unexpected downhole drilling conditions deviations and formation rock drillability.

An autonomous drilling system takes the responsibility of strategic decisions in a multi-horizon time perspective.

Curios about learning more?

Recommend reading the paper "Taxonomy Describing Levels of Autonomous Drilling Systems: Incorporating Complexity, Uncertainty, Sparse Data, With Human Interaction". Additional information can also be found in DigiWells Annual report from 2022.

Publication

"Taxonomy Describing Levels of Autonomous Drilling Systems: Incorporating Complexity, Uncertainty, Sparse Data, With Human Interaction", J. P. de Wardt, DE WARDT AND CO, Elkhart Lake, Wisconsin, USA; E. Cayeux and R. Mihai, NORCE, Stavanger, Norway; J. Macpherson, Baker Hughes, Houston, Texas, USA; P. Annaiyappa, Independent Consultant, Houston,Texas, USA; D. Pirovolou, Weatherford, Houston, Texas, USA, presented at the IADC/SPE International Drilling Conference and Exhibition, Galveston, USA, 5.-7. March 2024. https://doi.org/10.2118/217754-MS

Trait	An autonomous drilling system must …
Risk	…actively manage at least one risk and it must manage all risks with clarity. The more risks an autonomous system can manage with clarity, the better it is.
Mission	…complete a drilling mission, evaluating progress with a quantifiable objective function. Hierarchy of missions is from at least procedural to enterprise.
Situational Awareness	…demonstrate a depth of understanding of at least one current state of the drilling process. The more states it addresses the higher the level of autonomy.
Decision Making	…be able to make decisions, by estimating root cause, estimating seriousness of the current situation, decide on a course of action, and then monitor progress. Ranking is on number of topical problems addressed: material transport, string mechanics, string hydraulics, annulus hydraulics, open-hole integrity, cased-hole integrity, directional, and productivity.
Dynamic Planning	…have an ability to generate dynamic plan that addresses multiple time horizons, and it must be able to assess the uncertainty associated with the plan as a function of the time horizon.
Execution	…execute a dynamic plan protected by the necessary SOE and FDIR, with SMM, that are relevant for safe execution.
Learning from Experience	…be capable of learning from experience, which may include offset data, self-calibration of the internal models used in the decision-making process, based on the current run or previous runs
Human Dependence	…have decreasing dependence on human interaction with an increasing level of autonomy. Human interaction accepted for autonomy, and mixed mode, human-system interaction recognized.
Environmental Complexity	…handle environmental complexity such as uncertainty, observability, and lack of consistency. The lower the predictability of the environment, the higher the complexity of the environment.
Problem Complexity	…handle complex problems, preferably two or more of material transport, string mechanics, string hydraulics, annulus hydraulics, open-hole integrity, cased-hole integrity, directional, and productivity.
Interaction with Agents	…interact with external agents and this collaboration can contribute to better decision-making. A system can be autonomous at the lowest level of autonomy and not exhibit this trait.
Harmlessness	…have the principle of harmlessness, which includes trust, ethics, transparency and explainability. A system can be autonomous at the lowest level of autonomy and not exhibit this state.

Table 1: An overview of traits important for an autonomous drilling system

Many potential usages for AI techniques from drilling

AI techniques are changing the drilling industry. But the techniques have high transfer value to other fields as well.

Senior researcher at NORCE, Rodica G. Mihai, leads the drilling automation and autonomy work package at DigiWells, and has been working on artificial intelligence (AI) in drilling for years.

– We have shown that artificial intelligence techniques can be used to achieve higher levels of automation in drilling and consequently reduce costs and make drilling for oil and gas safer and more efficient. The AI techniques we have used in drilling automation and particularly, autonomous drilling can have big potential within other fields as well, says Mihai.

Several factors influence how relevant a field is for technology transfer from drilling automation. According to the EU classification of AI systems[1], autonomous drilling comes under high-risk AI (critical infrastructure).

– When addressing autonomous decision making in drilling, one needs to account for the complexity and high-risk nature of the environment. The drilling process deals with uncertainties and observability challenges. It is a fragmented process where many different suppliers are involved and need to collaborate to ensure a safe drilling process. This raises several challenges when it comes to stability of such a complex distributed system, tells Mihai.

Other subsurface and drilling fields

An obvious usage of the AI techniques from autonomous drilling in oil and gas, is within other drilling operations, such as geothermal drilling, drilling for CO2 injection wells and drilling for hydrogen storage or production
Mihai particularly points to geothermal drilling.

Rodica G. Mihai

– Our previous research on autonomous drilling is a good basis for further research that can make Norway a winner within deep geothermal drilling. The transfer of knowledge from autonomous drilling, already demonstrated for oil and gas and currently in the industrialization phase, can lead to a substantial cut in costs and increased efficiency in geothermal drilling, particularly within deep drilling for district heating. By building on existing research on autonomous drilling with further research enhancements to include specific challenges of the geothermal case, it may be feasible to scale up the geothermal operations through boosting the number of wells that the same team can manage, explains Mihai.

Geothermal district heating is when geothermal energy is used for space and water heating, for both private households and for industry, through a distributed network.

Environmental monitoring and energy systems

Also in different sectors, there are great possibilities for the usage of the AI techniques developed in DigiWells. Two relevant examples are environmental monitoring and monitoring of energy systems. In a newly awarded EU project, currently in the GAP Phase, under HORIZON-MISS-2023-OCEAN-01-03 call, Atlantic and Arctic sea basin lighthouse –, Mihai will work together with colleagues from NORCE Environment and a large European team on addressing climate change & human threats to marine biodiversity. NORCE will contribute with methods and knowledge from drilling such as digital twin, data modeling and other AI techniques. Going forward, energy systems will be even more variable, characterized by production at different sites, at different times and involving multiple providers. Hence, managing the overall energy system will increase in complexity. The AI techniques from autonomous drilling can come to good use when monitoring and steering the energy system at large under variable and uncertain conditions, says Mihai.

Subcommittee on verification and validation of DSATS

In drilling automation, usually, several automation solutions from different providers need to seamlessly work together to ensure safe drilling operations. This raises several challenges when it comes to the stability of such a multi-agent system.

SPE-Drilling Systems Automation Technical Section (DSATS) recognizes these challenges and started a subcommittee to advance collaboration on these aspects.

– The Verification and Validation subcommittee of DSATS is focusing on how to address the verification and validation of the interplay in a multi-agent architecture of drilling automation systems, with multiple providers, says Mihai who leads the subcommittee.

Spin-off project: “3D-GIG”: 3D Geological Interpretation for Geosteering of wells

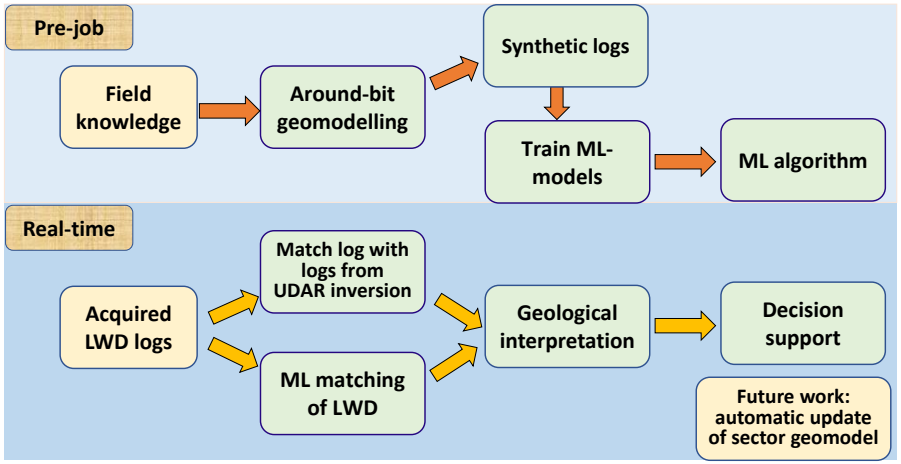


Figure: Planned workflow: Top: pre-job phase with model construction and training of geosteering personnel. Bottom: real-time phase with geosteering decisions supported by around-BHA geological interpretation. In the future, the sector geomodel could be automatically updated to enable decision support based on automatic ahead-of-bit geological forecasts.

The primary objective of the 3D-GIG project is to establish and verify a workflow for automatic, real-time, around the bit 3D geological interpretation of LWD logs for optimal well placement decision support while drilling in complex formations. The format of the interpretation will support future automatic updates of standard probabilistic geomodels.

The secondary objectives are:

Around the wellbore geomodelling. Develop and test a methodology for automatic generation of around-BHA geomodels

Probabilistic 3D inversion. Robust, accurate and computationally effective ensemble-based inversion of UDAR logs to quantify uncertainties

ML-based methods for real-time geological interpretation to complement and expand on the analytical methods

The project will be an important step towards a workflow for automatic, real-time around-bit 3D geological interpretation of LWD logs, including deep sensing Electro-Magnetic (EM) logs for optimal well-placement decision support while drilling in complex formations.

Project partners: NORCE, University of Stavanger, University of Texas at Austin, AkerBP, ConocoPhillips, Equinor, TotalEnergies and WintershallDEA

Project webpage: https://geosteering.no/3d-gig

Project leader: Nazanin Jahani, NORCE

Technical meeting in 3D-GIG project. (Photo: Sergey Alyaev/NORCE)

Spin-off project “DISTINGUISH”: Decision support using neural networks to predict geological uncertainties when geosteering

Following the newest trends in subsurface work flows, a geosteering workflow of the future shall capture and update uncertainty in an ensemble of geomodels. The most advanced ensemble methods are the core of closed-loop reservoir management (EnCLRM), the new standard for optimizing the development of petroleum fields. However, EnCLRM is not adapted for real-time operations.

An important objective of SFI DigiWells is to develop ensemble-based decision support that balances drilling risk and recovery, emphasizing the drilling-program constraints.

In DISTINGUISH we plan to address another critical real-time challenge: the geomodelling complexity. We do so by developing new Generative-Network (GN) geomodels. GN-geomodels “learn geology” before the operation and have sub-second performance. They unlock next-generation data assimilation and new predictive decision-support AI. DISTINGUISH will develop and combine these technologies into a next-generation workflow that proposes a new way of thinking: substituting “depth of detection” with “distance of prediction” and probabilistic decision support.

GN-geomodels and the new decision-support workflows can strengthen DigiWells’s research and enhance applicability for geologically complex NCS fields. These developments address well-placement research challenges from an Oil-&-Gas-21 machine-learning report. According to the report, better well placement may lead to additional discoveries on the Norwegian Continental Shelf, an increased net present value from drilling, and significant CO2 emission reductions.

Project partners: NORCE, University of Bergen, University of Stavanger, Heriot-Watt University, Aker BP, Equinor

Project webpage: https://geosteering.no/distinguish

Project leader: Sergey Alyaev

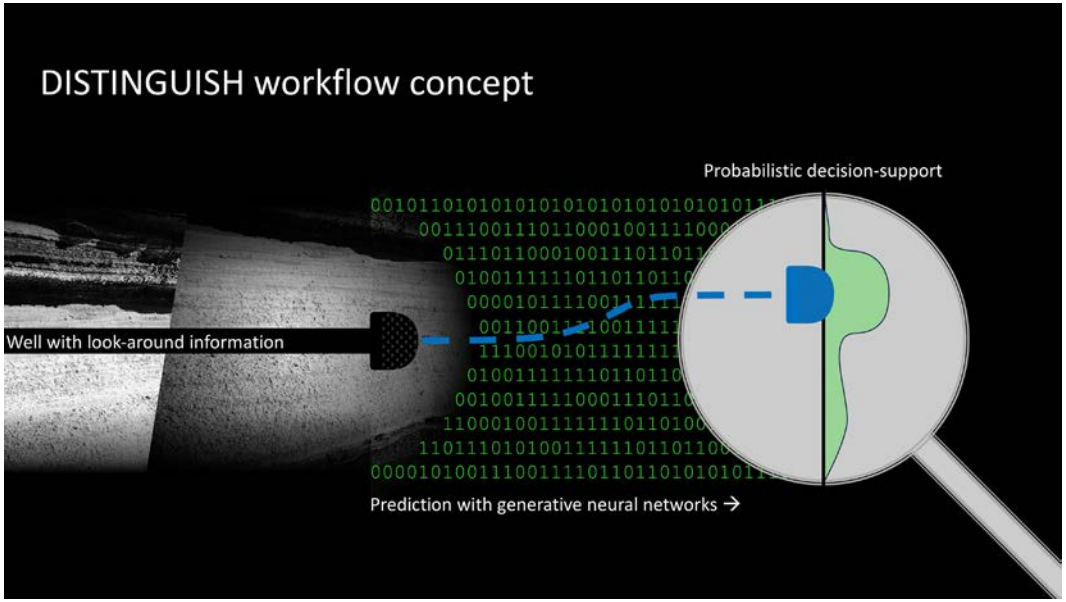


Figure: The conceptual representation of the DISTINGUISH workflow.

Flowrate Out Sensor

To improve the accuracy of the flow rate out measurements compared to the flow paddle, a new sensor is under development with the goal of achieving a measurement error as low as 1-2 %. The ongoing tests are promising, and if the project succeeds, this flow meter may provide a significant contribution to measure flow out of the well more accurately, supporting drilling automation technologies and increasing safety.

The Macondo blowout in 2010 was caused by a series of events, and a main critical factor was the lack of accurate flow rate measurement out of the well as pointed out in the investigation that followed. The commonly used measurement device, the flow paddle, used on Deepwater Horizon, has an accuracy of 10 %. This technology is still preferred due to the lack of good alternatives.

A new flowmeter concept using a horizontal rotating measuring wheel placed in the return flowline, is expected to give considerable improved accuracy. The sensor uses a rotating measuring wheel with four vanes, and the forces on the vanes result in a torque that can be measured. This torque is directly proportional to the mass flowrate of fluid passing through the measuring wheel.

To verify the principle and accuracy of the sensor, a medium-scale apparatus has been built. Experiments show very promising results. The results of the tests confirm that the rotating wheel mass flowmeter establishes a linear relationship between torque and mass flow rate, and that this linear relationship is valid both at low and high rotational speeds.

The prototype successfully handles flow rates up to 150 liters per minute and the experiments include various drilling fluids. A high precision vibrating tube Coriolis flowmeter is used for reference, and the results are promising for achieving the goal of 1-2% accuracy. The apparatus can include sensors for measuring cuttings rate, cutting size distribution, and gas content, making it a multi-measurement device. A patent has been granted for Norway in December 2021. An international patent application, PCT, is in process. The latest results of the experiments conducted in 2023 are promising and will be presented at the International Drilling Conference in March, in Galveston.

The commercialization project continues until June 2024 with funding from the Research Council of Norway. With the promising results, the next step will be to find funding to build a full-scale flowmeter and aim to industrialize the new sensor.

Project leader: Jan Einar Gravdal

Publications

Paper SPE-217695 “Development and Validation of a Rotating Wheel Coriolis Mass Flowmeter for Accurate Measurement of Drilling Fluid with No Pressure Loss”, E. Cayeux, A. Holsaeter, A. Leulseged, S. Moi, J.E. Gravdal, NORCE, will be presented at the IADC/SPE International Drilling Conference and Exhibition, 5-7 March 2024, in Galveston, US

Photo: Lisa Ravna Rørmoen/Screen Story

Centre management

Erlend H. Vefring

SFI Director

WP7 - Project management

Helga Gjeraldstveit

SFI Assistant Director

WP6 - Studies and analysis

Sergey Alyaev

WP-leader

WP2 - Predictive modelling

Eric Cayeux

WP-leader

WP1 - Agile well construction work-flow

WP3 - Smart sensing

WP4 - Interopera-bility and user-sys-tem interaction

Rodica G. Mihai

WP-leader

WP5 - Drilling auto-mation and auton-omy

Mette Stokseth Myhre

Administrative coordinator

Board of Directors

As of 31.12.23

Tron Golder Kristiansen (Board Chair)
AkerBP ASA

Praveen Jain
Equinor Energy AS

Harald Nevøy
ConocoPhillips Skandinavia AS

Anar Ismayilov
TotalEnergies

Tron Helgesen
WintershallDEA Norge AS

Sergey Sakharov
Vår Energi ASA

Øystein Arild
University of Stavanger

Morten Jakobsen
University of Bergen

Ole Morten Aamo
Norwegian University of Science and Technology (NTNU)

Aina M. Berg
NORCE AS

Halil Qzarpa (Observer)
Research Council of Norway

PhD students

Ressi Bonti Muhammad

PhD topic: Sequential decision analysis in drilling and geosteering

Affiliation:	**University of Stavanger**
Supervisor:	**Reidar Brumer Bratvold**
Co-Supervisor:	**Sergey Alyaev**
Associated Epic:	**Real-time decision making in drilling and geosteering**
Period:	**2021-2024**

I come from Indonesia. My BSc is from Bandung Institute of Technology in Petroleum engineering. I recently graduated and earned my master's degree from NTNU, also in Petroleum engineering.

We have worked on proposing the use of Reinforcement Learning (RL) to optimize two published geosteering decision-making problems by building an RL-based decision support system. The results indicate that the RL approach outperforms the commonly used greedy optimization method and is comparable in performance to the approximate dynamic programming method while being more robust and computationally efficient. This work has the potential to improve the efficiency and accuracy of geosteering decision-making and reduce computational costs.

The current project involves collaborating with colleagues from Stanford University to develop the RL-based decision support system further. The aim is to extend the system's capabilities to support a more complex case than the previous two to provide even more accurate and efficient geosteering decision-making. Through this collaboration, the team hopes to push the boundaries of what is currently possible in geosteering and contribute to advancements in the field of decision support systems more broadly.

Felix James Cardano Pacis

PhD topic: Online / Offline Deep learning models

Affiliation:	**University of Stavanger**
Supervisor:	**Tomasz Wiktorski**
Co-Supervisor:	**Sergey Alyaev**
Associated Epic:	**Deep learning for drilling models**
Period:	**2021 – 2024**

Felix is a Ph.D. student in Deep Learning at UiS where he also finished his master's degree in drilling and well engineering. He also has a BSc degree in Petroleum Engineering from Palawan State University.

The main objective of their project is to leverage Artificial Intelligence (AI) to build adaptive data-driven models for drilling and positioning wells. Addressing the practical bottlenecks of data-driven models for field implementation is also part of their research.

To achieve their objectives, they explored the application of transfer learning in ROP prediction. Simulated data using NORCE's OpenLab and real well data from the industry partners were used to pre-train models. Subsequently, these pre-trained models were fine-tuned with varying retraining data percentages from other wells. Initial results showed that transfer learning reduced computational costs and training time. In addition, the group observed that simulated data could be used in the absence of real data or in combination with real data to train a model without trading off the model's predictive capability.

The group is also working towards an adaptive ROP predictive model that provides expected ROP values in response to surface drilling parameters and formation properties. Since all factors affecting the drilling rate are not always known prior to drilling, the group is currently investigating the optimal fine-tuning configurations that would allow us to recalibrate the model as frequently as possible in real-time operations. This is a necessary step towards a data-driven ROP optimization that would directly translate to cost savings and emission reductions.

Luis Saavedra Jerez

PhD topic: Impact of the expected measurement quality and uncertainty while working on the engineering of a well

Affiliation:	**University of Stavanger**
Supervisor:	**Dan Sui**
Co-Supervisor:	**Eric Cayeux**
Associated Epic:	**Automated Drilling Engineering**
Period:	**2021 - 2024**

I got my bachelor's degree in Petroleum Engineering and Natural Gas in Bolivia (2018). I received my master's in drilling and well engineering at the University of Stavanger (UiS) in 2021. During my master's, I led the winning DrillBotics team for the Virtual Rig part. I was also awarded excellent academic performance at UiS.

My study focuses on analyzing the effects of uncertainty on parameters at the moment of making a drilling plan. Not knowing what will be found later carries some risks. Considering another alternative plan may lower the risk of finding further troubles.

Currently, I have developed and explored the application of a curve with constant curvature and constant toolface in the trajectory design to reduce the uncertainty linked with the difficulties of following the planned path.

Moreover, the next part of my study will focus on the statistical physics adapted to the forecast of the geo-pressure window in the drilling plan. The window is a fundamental part of establishing a safe range of the formation pressures that strongly influence the rest of the drilling plan.

Pauline Nüsse

PhD topic: Automatic control of sleeves for damping of drill-string vibrations

Affiliation:	**NTNU**
Supervisor:	**Ole Morten Aamo**
Co-Supervisor:	**Adrian Ambrus**
Associated Epic:	**Distributed Drilling Control**
Period:	**2021-2024**

The main objective of my thesis is to actively control the sleeves developed in this epic to allow a more efficient way of drilling.

The goal is to reduce vibrations and minimize energy consumption. Several sleeves can be placed along the drill string at the positions with the largest side forces, to maximize the reduction of mechanical friction along the wellbore. To show the positive effects of using active sleeves, subs with only local knowledge are used in the first place. To prevent the sleeves from slipping an On-Off based control scheme is implemented.

Stability maps allow a comparison of the stick-slip mitigation abilities of this controller and the passive sleeves for a broad range of top drive feed rates and RPM.

Marios Gkionis

PhD topic: Extremum seeking control using ideas from reinforcement learning

Affiliation:	**NTNU**
Supervisor:	**Ole Morten Aamo**
Co-Supervisors:	**Bjarne Andre Grimstad, John-Morten Godhavn, Ulf Jacob Flø Aarsnes**
Associated Epic:	**Distributed Drilling Control**
Period:	**2022 - 2025**

I am a Mechanical Engineer (received my Integrated Master's degree with honors from the Aristotle University of Thessaloniki, Greece in 2020) and hold extensive experience in dynamics simulations and Nonlinear Model Predictive Control. My interests lie in the development of intelligent control algorithms.

The goal of the PhD project is to develop Real-Time optimization control algorithms that improve the performance of traditional Extremum Seeking Control (ESC) by combining it with algorithms from the Machine Learning family. It is expected that this extension will result in the ability to identify optimal dither signals for high-dimensional systems so that faster convergence can be achieved with reduced excitation by leveraging stored data.

Using state-of-the-art implementations, the approach is to remedy known shortcomings of ESC with Reinforcement Learning and/or Deep Learning and formulate new implementations. The new algorithms will be tested and demonstrated on DigiWells applications, such as the control of drill string vibrations using multi-Agent Optimization with ESC and Reinforcement Learning, thus tackling the issue of the unknown damping when a multitude of damping subs along the drill string are deployed.

Durra Handri Saputera

PhD topic: Borehole electromagnetic modeling and inversion

Affiliation:	**University of Bergen**
Supervisor:	**Morten Jakobsen**
Co-Supervisors:	**Sergey Alyaev, Nazanin Jahani, Kjersti Solberg Eikrem**
Associated Epic:	**Real-time geophysical data imaging while drilling**
Period:	**2022-2025**

I have a keen interest in modeling geophysical data. I graduated from Idea League joint master program in Applied Geophysics, which is held at TU Delft, ETH Zurich and RWTH Aachen, and I worked on electromagnetic induction inversion in my master thesis.

In this project, I will be working on borehole electromagnetic induction tool data inversion to provide the subsurface image around the borehole during the drilling process. I have successfully implemented 3D forward modelling with integral equation method on GPU, which enables up to an order of magnitude speed up in computation time. Currently, I am working on investigating the domain decomposition method in integral equation method for further speeding up the computation time.

After finishing the development of forward modelling, I will explore different parameterization and algorithm that can be used for stochastic inversion to quantify uncertainty. In addition, I am going to study the effect of anisotropy in the inversion. Data-driven method such as physics-based machine learning is also considered as one possible alternative for fast computation.

Åsmund Aamodt Resell

PhD topic: Annular fluid flow coupled with drill string vibration

Affiliation: University of Stavanger
Supervisor: Hans Joakim Skadsem
Co-Supervisors: Rodica G. Mihai, Knut Erik Teigen Giljarhus
Associated Epic:
Period: 2023 - 2026

I received my master's degree in mechanical engineering from NTNU in Trondheim. My specialization is in structural mechanics and fluid dynamics, with a strong focus on numerical modeling and computational analysis.

This project aims to improve our understanding of fluid dynamics and particle transport within the annular space outside the drill string and to strengthen our knowledge of the coupling between drill string vibrations and fluid flow. The work will also investigate complex flow phenomena such as Taylor instabilities from drill string rotation, and gap instabilities caused by the eccentricity of the annulus.

The work of the thesis will also investigate how the coupled effects can be captured in real-time models. The research work will involve using numerical methods such as computational fluid dynamics, finite element analysis and may also involve the use of reduced models.

John Isak Fjellvang Villanger

PhD topic: Reinforcement Learning for Optimization Within Drilling

Affiliation: University of Stavanger
Supervisor: Dan Sui
Co-Supervisors: Rodica G. Mihai, Troels Arnfred Bojesen
Associated Epic: Drilling Optimization
Period: 2023-2026

I studied Cognitive Science at UiB for my bachelor and then moved on to Machine Learning for my master's, there I specialized in Reinforcement learning.

The general objective of my thesis is to apply Reinforcement Learning within drilling, this could for example include set point optimization for Weight on Bit and Rounds per Minute in order to increase Rate of Penetration and decrease drill string vibrations. Several approaches could be tried here including Multi Agent Reinforcement Learning.

Post Doc.

Nils Christian Aars Wilhelmsen

Post Doc.: Modeling and detection of slip in damping subs

Affiliation: NTNU
Supervisor: Ole Morten Aamo
Associated Epic: Distributed Drilling Control
Period: 2023 - 2024

Nils Christian A. Wilhelmsen received the M.Sc. degree in Engineering Cybernetics from NTNU in Trondheim, Norway in 2018 and the Ph.D. degree in Mathematics and Control from MINES ParisTech in 2021.

In my research project I intend (1) to develop a simplified mathematical model to describe the rolling motion of damping subs in the wellbore together with their slipping and (2) to derive a method for detecting when the damping subs slip using IMU signals. The idea is then that this algorithm can be used together with active control algorithms for the damping subs which require knowledge of whether the damping sub is slipping or not. I intend to achieve this using tools from mathematical modeling, control theory and computer simulations.

PhD. group. Photo: Rune Rolvsjord, NORCE

Publications

Alyaev, Sergey. DISTINGUISH from the depth of detection to the probabilistic distance of prediction. DigiWells Seminar; 2023-11-28 - 2023-11-29

Alyaev, Sergey; Elsheikh, Ahmed H.; Ambrus, Adrian; Jahani, Nazanin. Direct Multi-Modal Inversion of Geophysical Logs Using Deep Learning. SIAM Conference on Mathematical & Computational Issues in the Geosciences (GS23); 2023-06-19 - 2023-06-22

Annaiyappa, Pradeep; Macpherson, John D.; Cayeux, Eric. Clock Synchronization and Timestamping of Data on Acquisition at the Wellsite: Guidelines and Recommendations. SPE Drilling & Completion 2023 s. 1-16

Cayeux, Eric. A General Framework to Describe Drilling Process States. SPE/IADC Drilling Conference; 2023-03-07 - 2023-03-09

Cayeux, Eric. Automated Well Engineering. DigiWells Seminar 2023; 2023-11-28 - 2023-11-29

Cayeux, Eric. Automatic Well Planning: A New Paradigm For Automatic Well Path Generation Using Multidisciplinary Constraints. DigiWells Seminar 2023; 2023-11-28 - 2023-11-29

Cayeux, Eric. Drilling Systems Automation: Fault Detection, Isolation and Recovery Functions for Situational Awareness. SPE/IADC Drilling Conference; 2023-03-07 - 2023-03-09

Cayeux, Eric. Interoperability of Real-Time Drilling Signals at the Rig Site: An Example Based on Mechanical Specific Energy. SPE/IADC Drilling Conference; 2023-03-07 - 2023-03-09

Cayeux, Eric. SPE-DSATS DWIS: Drilling and Wells Interoperability Standards. Directional Drilling Digital Transformation Forum; 2023-05-25 - 2023-05-25

Cayeux, Eric. Taxonomy for Autonomous Drilling. DigiWells Seminar 2023; 2023-11-28 - 2023-11-29

Cayeux, Eric. 6n Degrees of Freedom Transient Torque and Drag. DigiWells Seminar 2023; 2023-11-28 - 2023-11-29

Cayeux, Eric; Ambrus, Adrian. Self-Attenuation of Drillstring Torsional Vibrations Using Distributed Dampers. SPE Journal 2023 ;Volum 1.(22)

Cayeux, Eric; Daireaux, Benoit. Drilling & Wells Interoperability. DigiWells Seminar 2023; 2023-11-28 - 2023-11-29

Cayeux, Eric; Daireaux, Benoit. DWIS ROP Optimization Demonstration and Presentation. SPE DSATS DWIS; 2023-09-19 - 2023-09-19

Cayeux, Eric; Daireaux, Benoit; Macpherson, John D.; Bolt, Harald; Harbidge, Philip; Annaiyappa, Pradeep; Carney, Jonathan; Ziadat, Wael; Edwards, Michael G.
Analysis of the Sources of Uncertainty in Geopressure Estimation While Drilling. I: SPE Annual Technical Conference and Exhibition, October 16–18, 2023. Society of Petroleum Engineers 2023 ISBN 978-1-61399-992-9.

Cayeux, Eric; Daireaux, Benoit; Macpherson, John D.; Florence, Fred; Solbu, Espen. Interoperability of Real-Time Drilling Signals at the Rig Site: An Example Based on Mechanical Specific Energy. I: SPE/IADC Drilling Conference and Exhibition March 7-9, 2023. Society of Petroleum Engineers 2023 ISBN 978-1-61399-875-5.

Cayeux, Eric; Macpherson, John D.; Damski, Carlos.
Drilling Data Quality and Uncertainty: Pathways to Value. SPE Webinar; 2023-05-22 - 2023-05-22

Cayeux, Eric; Macpherson, John D.; Laing, Moray; Pirovolou, D.; Florence, Fred. Drilling Systems Automation: Fault Detection, Isolation and Recovery Functions for Situational Awareness. I: SPE/IADC Drilling Conference and Exhibition March 7-9, 2023. Society of Petroleum Engineers 2023 ISBN 978-1-61399-875-5.

Cayeux, Eric; Macpherson, John D.; Pirovolou, D.; Laing, Moray; Florence, Fred. A General Framework to Describe Drilling Process States. I: SPE/IADC Drilling Conference and Exhibition March 7-9, 2023. Society of Petroleum Engineers 2023 ISBN 978-1-61399-875-5.

Cayeux, Eric; Pelfrene, Gilles; Mihai, Rodica Georgeta; Dvergsnes, Erik Wolden; Tjøstheim, Bjørn Peter; Baume, Antonin; Khosravanian, Rasool; Kristiansen, Tron Golder.
A New Paradigm for Automatic Well Path Generation Using Multidisciplinary Constraints. I: SPE Annual Technical Conference and Exhibition, October 16–18, 2023. Society of Petroleum Engineers 2023 ISBN 978-1-61399-992-9.

Holsaeter, Andrew Martin. Experimental Verification of Vibration Mitigation Through a Viscous Damping System Along the Drill String. SPE/IADC Drilling Conference; 2023-03-07 - 2023-03-09

Holsaeter, Andrew Martin. Flowrate Out Sensor. DigiWells Seminar 2023; 2023-11-28 - 2023-11-29

Holsaeter, Andrew Martin; Ambrus, Adrian; Cayeux, Eric; Mihai, Rodica G.; Moi, Sonja. Experimental Verification of Vibration Mitigation Through a Viscous Damping System Along the Drill String. I: SPE/IADC Drilling Conference and Exhibition March 7-9, 2023. Society of Petroleum Engineers 2023 ISBN 978-1-61399-875-5.

Jahani, Nazanin. 3D geological interpretation for geosteering of wells. DigiWells Seminar 2023; 2023-11-27 - 2023-11-29

Jahani, Nazanin; Alyaev, Sergey; Ambia, Joaquin; Fossum, Kristian; Suter, Erich Christian; Torres-Verdin, Carlos.
Enhancing the Detectability of Deep-Sensing Borehole Electromagnetic Instruments by Joint Inversion of Multiple Logs Within a Probabilistic Geosteering Workflow. Petrophysics 2023 ;Volum 64.(1) s. 80-91

Jahani, Nazanin; Torres-Verdin, Carlos; Hou, Junsheng.
Limits of 3D target detectability of logging while drilling deep-sensing electromagnetic measurements from numerical modeling. Geophysical Prospecting 2023 s. -

Jahani, Nazanin; Torres-Verdin, Carlos; Hou, Junsheng; Tveranger, Jan. Limits of 3D Detectability and Resolution of LWD Deep-Sensing Borehole Electromagnetic Measurements Acquired in the Norwegian Continental Shelf. I: SPWLA 64th Annual Logging Symposium. USA: SPWLA 2023 ISBN 978-0-7918-8595-6.

Muhammad, Ressi Bonti; Srivastava, Apoorv; Alyaev, Sergey; Bratvold, Reidar Brumer; Tartakovsky, Daniel M..
Integrating Reinforcement Learning and Particle Filter for Enhanced Geosteering Decision-Making. DigiWells Seminar; 2023-11-28 - 2023-11-29

Nüsse, Pauline Marie; Ambrus, Adrian; Aarsnes, Ulf Jakob Fløe; Aamo, Ole Morten. Evaluation of distributed damping subs with active control for stick–slip reduction in drilling. Geoenergy Science and Engineering 2023 ;Volum 231.(Part A)

Pacis, Felix James Cardano; Alyaev, Sergey; Wiktorski, Tomasz. Demo: Chatbot for oil and gas data. DigiWells Seminar; 2023-11-28 - 2023-11-29

Pacis, Felix James Cardano; Ambrus, Adrian; Alyaev, Sergey; Khosravanian, Rasool; Kristiansen, Tron Golder; Wiktorski, Tomasz. Improving predictive models for rate of penetration in real drilling operations through transfer learning. Journal of Computational Science 2023 ;Volum 72.(102100)

Pacis, Felix James Cardano; Wiktorski, Tomasz; Ambrus, Adrian; Alyaev, Sergey. Exploration of Strategies to Improve Continual Learning From Irregular Sequential Drilling Data. OMAE 42nd International Conference on Ocean, Offshore & Arctic Engineering; 2023-06-11 - 2023-06-16

Pacis, Felix James Cardano; Wiktorski, Tomasz; Ambrus, Adrian; Alyaev, Sergey. Exploration of strategies to improve continual learning from irregular sequential drilling data. I: ASME 2023 42nd International Conference on Ocean, Offshore and Arctic Engineering: Volume 9: Offshore Geotechnics; Petroleum Technology. The American Society of Mechanical Engineers (ASME) 2023 ISBN 978-0-7918-8691-5.

Pelfrene, Gilles. The microservice architecture for scientific applications. Open Source Drilling Community Technical Seminar Series; 2023-04-24 - 2023-04-24

Saputera, Durra Handri; Jakobsen, Morten; Alyaev, Sergey; Jahani, Nazanin; Eikrem, Kjersti Solberg; van Dongen, Koen W. A. 3D Modeling and Inversion of Induction Logs. 2023 Highlights. DigiWells Seminar; 2023-11-28 - 2023-11-29

Saputera, Durra Handri; Jakobsen, Morten; Jahani, Nazanin; Alyaev, Sergey; Eikrem, Kjersti Solberg; van Dongen, Koen W. A.. Towards Real-Time 3D Modeling of Induction Logs Using an Integral Equation Method. 84th EAGE Annual Conference & Exhibition; 2023-06-05 - 2023-06-08

Saputera, Durra Handri; Jakobsen, Morten; Jahani, Nazanin; Alyaev, Sergey; Eikrem, Kjersti Solberg; van Dongen, Koen W. A. Towards Real-Time 3D Modeling of Induction Logs Using an Integral Equation Method. I: 84th EAGE Conference & Exhibition 2023. European Association of Geoscientists and Engineers (EAGE) 2023 ISBN 000-0-00-000000-0. s. 1-5

Saputera, Durra Handri; Jakobsen, Morten; van Dongen, Koen W. A.; Jahani, Nazanin; Eikrem, Kjersti Solberg; Alyaev, Sergey. 3-D induction log modelling with integral equation method and domain decomposition pre-conditioning. Geophysical Journal International 2023 ;Volum 236.(2) s. 834-848

Strecker, Timm; Aarsnes, Ulf Jakob Fløe. Boundary Control and Estimation for Under-Balanced Drilling with Uncertain Reservoir Parameters. IEEE Transactions on Control Systems Technology 2023 ;Volum 31.(1) s. 281-294

Volpi, Lucas. 6n DOF Transient Torque and Drag; Detailed Hydraulic Simulations. DigiWells Seminar 2023; 2023-11-28 - 2023-11-29

Personnel

Key researchers	Institution	Research area
Eric Cayeux	NORCE	Drilling
Sergey Alyaev	NORCE	Geostreering
Rodica Mihai	NORCE	Drilling
Adrian Ambrus	NORCE	Drilling
Erik Wolden Dvergsnes	NORCE	Drilling
Gilles Pelfrene	NORCE	Drilling
Knut Steinar Bjørkevoll	NORCE	Drilling
Benoit Daireaux	NORCE	Drilling
Steen Agerlin Petersen	NORCE	Drilling
Sonja Moi	NORCE	Drilling
Nazanin Jahani	NORCE	Geosteering
Ulf Jakob Aarsnes	NORCE	Drilling
Andrew Holsaeter	NORCE	Drilling
Amare Leulseged	NORCE	Drilling
Lucas Volpi	NORCE	Drilling
Jan Tveranger	NORCE	Geology
Kristian Fossum	NORCE	Reservoir Engineering
Kjersti Eikrem	NORCE	Reservoar
Bjarte Lønøy	NORCE	Geology
Morten Jacobsen	UiB	Formation physics
Reidar Bratvold	UiS	Decision Analysis
Dan Sui	UiS	Control System
Hans Joakim Skadsem	UIS	Fluid Mechanics
Tomasz Wiktorski	UiS	Computer science and Data science
Ole Morten Aamo	NTNU	Cybernetics

Post Doc. working on projects in the centre with financial support form other sources

Name	*Sex M/F*	*Period*	*Topic*
Nils Christian Aars Wilhelmsen	M	2023-2024	Modeling and detection of slip in damping subs

PhD students with financial support form the Centre budget

Name	*Nationality*	*Period*	*Sex M/F*	*Topic*
Ressi Bonti Muhammad	Indonesian	2021-2024	M	Sequential decision analysis in drilling and geosteering
Luis Alberto Saavedra Jerez	Bolivian	2021-2024	M	Impact of the expected measurement quality and uncertainty while working on the engineering of a well
Felix James Pacis	Filipino	2021-2024	M	Online / Offline Deep learning models
Pauline Nüsse	German	2021-2024	F	Automatic control of vibration-damping sleeves for drill strings
Durra Handri Saputera	Indonesian	2022-2025	M	Efficient integral equation methods. For modelling and inversion of electromagnetic induction data: Focus on the use of different scattering approximations

PhD students working on projects in the centre with financial support form other sources

Name	*Funding*	*Nationality*	*Period*	*Sex M/F*	*Topic*
Marios Gkionis	NTNU	Greek	2022-2025	M	Extremum seeking control using ideas from reinforcement learning
John Isak Fjellvang Villanger	UIS	Norwegian	2023-2026	M	Modeling and optimization of the drilling process using tools within machine learning. Physics informed machine learning in drilling
Åsmund Aamodt Resell	UIS	Norwegian	2023-2026	M	Computational fluid dynamics and drill string mechanics

Master degrees

Name	*Sex M/F*	*Period*	*Topic*
Uchenna Blesseth Ochije	M	Feb-July 2023	Automated real-time rate of penetration optimization using trend dynamic analysis in drilling operations
Alisher Khodajev	M	Aug 2022-Jeny 2024	Modelling of borehole electromagnetic induction logging data in anisotropic rock formations

Statement of accounts

(All figures in 1000 NOK)

Funding			
	Amount	**In-kind**	**Sum**
The Research Council	11,383		11,383
The Host Institution (NORCE Energy)		1,000	1,000
Research Partners			
Universitetet i Bergen, UiB		-	-
Universitetet i Stavanger, UiS		1,557	1,557
Norges Teknisk-Naturvitenskapelige uni.		1,456	1,456
Enterprise partners			
Operators	10,000	2,044	12,044
Vendors		37	37
Public Partners			
Sum	**21,383**	**6,094**	**27,477**
Costs			-
The Host Institution (NORCE Energy)	15,043		15,043
Research Partners	7,340	3,013	10,353
Enterprise partners		2,081	2,081
Sum			**27,477**

DigiWells
Postboks 22 Nygårdstangen,
5838 Bergen

E-mail: mette.stokseth-myhre@norceresearch.no
Phone: + 47 56 10 70 00
www.DigiWells.no

Host institution: NORCE Norwegian Research Centre AS
www.norceresearch.no

sfi Senter for forskningsdrevet innovasjon

NORCE

Universitetet i Stavanger

UNIVERSITETET I BERGEN

NTNU
Norwegian University of Science and Technology

Photo: Lisa Ravna Rørmoen/Screen Story