OG4IR: 4th Industrial Revolution Applications in Oil & Gas Upstream Industry

Special track along with

ICSNC 2020, The Fifteenth International Conference on Systems and Networks Communications
October 18, 2020 to October 22, 2020 - Porto, Portugal
https://www.iaria.org/conferences2020/ICSNC20.html

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***Abstract*—The Fourth Industrial Revolution (4IR) can contribute to decision-making, enhance efficiency, and save capital and operational costs like never. It is the integration of multiple game-changers such as Internet of Things (IoT), remote sensing and big data. It has led to major transformations in the oil and gas industry, enabling to optimize recovery from oil and gas fields as well as enhancing the understanding of the subsurface formation. This special session will focus on topics related to the challenges encountered in the oil and gas industry with focus on overcoming the harsh environment conditions in the subsurface.**

Keywords*—4th industrial revolution; deep learning; wireless communication; Internet of Things; Edge Computing; Artificial Intelligence; Machine Learning; Deep Learning; Wireless Sensor Network.

I. INTRODUCTION

The Fourth Industrial Revolution (4IR) can contribute to decision-making, enhance efficiency, and save capital and operational costs like never. It is the integration of multiple game-changers such as Internet of Things (IoT), remote sensing and big data. It has led to major transformations in the oil and gas industry, enabling to optimize recovery from oil and gas fields as well as enhancing the understanding of the subsurface formation. 4IR technologies maximize the potential of data, automation, and integration and to establish an autonomous and intelligent advisory platform to enhance productivity through multidisciplinary integration and cyber-physical automation.

The challenges faced in the oil and gas industry distinguish themselves in terms of the harsh environment conditions that are encountered in the subsurface. They are:

- Artificial Intelligence (AI) in downhole sensor optimization.
- Wireless communication optimization in reservoir environments.
- Robotics for the optimization of fracturing.
- In-reservoir sensing technologies.

For this special session we focus on the following topics Related to 4th Industrial Revolution Applications in Oil & Gas Upstream Industry: FracBots: the next real reservoir IoT, real-time intelligent sensor selection for subsurface flow and fracture monitoring, an overview of natural language processing driven approaches towards assisted formation evaluation interpretation, edge computing-enabling new applications and insights in the drilling sector, machine learning and data mining for the early detection of stuck pipe incidents, feature-oriented joint time-lapse seismic and electromagnetic history matching using ensemble methods and finally modeling transient perturbations (waves in heterogeneous and time).

II. SUBMISSIONS

The first contribution is entitled "FracBots: the next real reservoir IoT". The author notes that FracBots (Fracture Robots) are tiny wireless sensors and network systems that can be used for real-time mapping of hydraulic fractures and monitoring key reservoir conditions [1]. They feature wireless inter-node communication, localization and sensing capabilities [2]. Eventually, they will be IoT inside the oil and gas reservoir since it will be needed to deploy massive amount of them. FracBots will establish the network connectivity among FracBot-to-FracBot to generate, exchange data inside the reservoirs without human intervention. The system architecture of the FracBots network has two layers: FracBot nodes layer and a base station layer. The FracBot nodes will be injected into the fracture during the hydraulic fracturing process, distributed inside the fracture and then they will sensing the data and communicate it to each other to deliver it to the base station in multi-hop fashion. The base station layer consists of a large antenna at the wellbore, connected to an aboveground gateway, to transmit the data collected from the FracBots network to the control room for further processing. Authors have developed the first generation of FracBots technology based on short range communication using near field communication (NFC) as a physical layer combined with an energy harvesting capability and ultra-low power requirements [3].

Authors selected NFC-based communication over (electromagnetic) EM-based communication since it exhibits highly reliable and constant channel conditions with sufficiently communication range in the oil reservoir environment. The reservoir environment consists of media such as rock, water, gas and crude oil which cause little variation in the attenuation rate of magnetic fields from that of air, since the magnetic permeability of each of these materials is similar. Accordingly, Authors design full integrated NFC-based FracBots that enable reliable and efficient wireless communications in oil and gas reservoirs to generate real-time mapping of hydraulic fractures and capture real-time reservoir conditions. When the FracBots are injected during hydraulic fracturing operations, autonomous localization algorithms can be used to create constellation maps of FracBots beds as placed. To explore this concept, authors develop a FracBot prototype platform and demonstrate three key functions. Authors begin by developing a novel cross-layer communication framework for NFC-based FracBot networks in dynamically changing underground environments. The framework combines the joint selection of modulation, channel coding, power control, and a geographic forwarding paradigm. Second, authors develop a novel NFC-based localization framework that exploits the unique properties of the NFC field to determine the locations of randomly deployed FracBot nodes. Third, authors develop an accurate energy model framework for the FracBot network that estimates FracBot data transmission rates while respecting harvested energy constraints. Forth, authors design, develop and fabricate NFC-based FracBot nodes. Finally, authors develop a physical NFC-based FracBots testbed to validate the performance of the FracBots [4].

Microseismic and tiltmeter surveys are ones of many technologies available nowadays to characterize hydraulic fractures but they are expensive, approximate, and time consuming. Moreover, they are conceptual approaches that don't unfortunately provide useful information about the inner working of hydraulic fractures. The FracBots technology will provide mapping of hydraulic fractures and in-stiu information that eventually aims at optimizing fracturing jobs. In addition, FracBots will contribute in maximizing well productivity, improving oil recovery and monitor real-time downhole rock properties such as in-situ stress, fracture pressure and temperature.

The second contribution is entitled “real-time intelligent sensor selection for subsurface flow and fracture monitoring”. It presents that 4th Industrial Revolution (4IR) technologies have assumed critical importance in the oil and gas industry, enabling data analysis and automation at unprecedented levels [5]. Formation evaluation and reservoir monitoring are crucial areas for optimizing reservoir production, maximizing sweep efficiency and characterizing the reservoirs. Automation, Robotics, and Artificial Intelligence (AI) have led to tremendous transformations in these areas, in particular in subsurface sensing. Authors present a novel 4IR inspired framework for the real-time sensor selection for subsurface pressure and temperature monitoring, as well as reservoir evaluation. The framework encompasses a deep learning technique for sensor data uncertainty estimation, which is then integrated into an integer programming framework for the optimal selection of sensors to monitor the reservoir formation. The results are rather promising, showing that a relatively small number of sensors can be utilized to properly monitor the fractured reservoir structure [6].

The third contribution is entitled “an overview of natural language processing driven approaches towards assisted formation evaluation interpretation”. It presents that formation evaluation literature and reports in the oil and gas industry are crucial in decision making and understanding of optimizing recovery. The literature provides a comprehensive summary of tools and interpretations, as well as use cases for individuals to learn and utilize the information for enhancing their formation evaluation interpretations, and decision-making. A major challenge in practice is the abundance and separateness of information available that leads to individuals facing enormous obstacles to retrieve the right information within an adequate timeframe [7].

Authors present an overview of several approaches in natural language processing for creating an ontology framework of formation evaluation data and literature, as well as conversational AI tools to extract requested information from the users. The review outlines the challenges that are faced when categorizing data related to formation evaluation, as well as establishing correlations and connections between various information sources [8]. Finally, the review will provide a summary of different conversational AI approaches and systems for assisting well log and formation evaluation interpretation, as well as the opportunities and challenges faced. Authors will dedicate the way forward for NLP driven approaches for assisting formation evaluation interpretation in real-time, and the business impact it has in the oil and gas industry, and relationship to other initiatives both in the oil and gas industry as well as beyond.

The fourth contribution is entitled “edge computing-enabling new applications and insights in the drilling sector”. Artificial intelligence (AI) algorithms, and their subcategories machine learning (ML) and deep-learning (DL), have been successfully deployed to address challenging problems across different domains, such as genomics [9], chemistry, medicine, and manufacturing, among others. Similarly, and inspired by the Fourth Industrial Revolution (4IR), AI, ML, and DL has become valuable tools to utilize in the oil and gas industry [10]. The current practice in the oil and gas industry is to train the ML/DL models from historical data sent from the rig and stored in the headquarters. The resulting trained models are stored in the headquarters and are used for real-time applications for the rig crew. The process of sending data requires tight security measures/protocols and implies delays for real-time applications, and data down sampling, as it is simply unfeasible to transmit all the extracted data. The down sampling of the data is a critical factor as it directly affects the accuracy of AI, ML, and DL as trends in the data are lost, thereby limiting the applicability of these models to more challenging problems.

Edge computing or computing on site reduces both the privacy risks and bandwidth required to transfer the data, while allowing advanced data-based models to use the high-frequency data to detect hidden patterns at an improved response time [11]. Therefore, edge computing is an efficient methodology where the sensitive data can be analyzed locally and the identified or highlighted critical/specific events, patterns, trends, or hazards resulting from the models may be sent through the network to the headquarters [10]. In this presentation, authors introduce AI and Internet of Things as building blocks for edge computing and discuss the benefits, deficiencies, challenges, and novel technologies that may be use to cope with the challenges associated for developing robust models for the rig complex and dynamic environment. Finally, authors present a pilot project combines on edge computing and image recognition for the auto-well space out, a critical process for well control.

The fifth contribution is entitled “machine learning and data mining for the early detection of stuck pipe incidents. It presents that Oil and gas drilling operations involve several activities based on well parameters and safety assurance. Unwanted events can delay operations and generate nonproductive time (NPT) [12]. Among these critical events, stuck pipe is a condition that interrupts the drilling operation and puts the wellbore at risk, which results in both delays and unexpected additional expenses [13]. The risk assessment and the setting of drilling parameters during the operations depend on rig supervisor expertise, which makes the identification of drilling hazards both subjective and susceptible to failure. Accurate computational models able to predict the early signs of stuck pipe incidents are of great value to assist the rig crew, providing a larger time-window for reacting and ultimately to avoid getting stuck [13].

In this work, authors provide a thorough review of the existing data and physics based models for the identification of stuck pipe incidents, describing their advantages and limitations. Authors performed large-scale analysis of historical data and derived novel machine learning and deep learning models for the prediction of stuck pipe incidents from surface drilling parameters and compared their performance.

Authors performed feature selection by keeping the top-ranked drilling parameters from the analysis of variance, which measures the capability of the drilling and rheology parameters to discriminate between stuck pipe incidents and normal drilling conditions, such as, weight on bit and revolutions per minute, among others. The selected parameters were then used to derive a machine learning model that achieved 79% and 60% for precision and recall, respectively. The derived analysis of variance for feature selection and prediction model, is designed to be implemented in the real-time drilling portal as an aid to the drilling engineers and the rig crew to minimize or avoid the NTP due to a stuck pipe.

The sixth contribution is entitled “feature-oriented joint time-lapse seismic and electromagnetic history matching using ensemble methods”. This study aims at enhancing reservoir characterization through simultaneous history matching of time-lapse seismic and electromagnetic (EM) data [14]. By exploiting the complementary nature of these data types, an efficient ensemble-based history-matching approach is proposed.

Instead of directly history matching original seismic and EM data, which are of high dimensions, authors follow an image-oriented approach by utilizing the front information of identified water flooded zones. The proposed workflow consists of three main steps. Firstly, water saturation is estimated by joint inversion of seismic and EM data, in which prescribed rock physics models are used to quantify the corresponding relationship of rock properties to elastic attributes and formation resistivity. Secondly, front positions are identified from the inverted saturation field and used as the observed data for history matching. Finally, model parameters are conditioned to the observed fronts using an iterative ensemble smoother with distance parameterization [15]. The novelty of the proposed approach consists in combining the feature-based history matching with ensemble-based inversion methods to achieve an efficient joint integration of time-lapse seismic and EM data [16].

The performance of the proposed history-matching workflow is examined using a 2D channelized reservoir model with a crosswell configuration for seismic and EM surveys. It is demonstrated that the developed workflow provides an effective way to calibrate reservoir models with multiple sources of geophysical data. The experimental results show a positive synergy effect on the characterization of model variables by jointly assimilating seismic and EM data.

The final contribution is entitled “modeling transient perturbations (waves in heterogeneous and time)”. It presents that Wave phenomena in non-linear, heterogeneous and time-varying media is the key behind multiple photonic devices and electromagnetic effects that have applications in many industries and fundamental research [17,18]. For example, Brillouin Scattering in optical fibers can be understood as the interaction of an electromagnetic wave with a traveling Bragg mirror, this in turn is the basis for fiber-based Distributed Temperature Sensing (DTS) used in the Oil and Gas Industry for well monitoring. In another example, light confinement and amplification has been posited to occur in superluminal refractive index perturbation in optical fibers leading to the creation of optical black-holes, spontaneous trapping, and selective-ultra-fast and directional coupling [17, 18, 19].

Over the past several decades novel characterization and fabrication techniques has allowed us to create materials with space heterogeneities and time-dependent properties that can vary in scales comparable to electromagnetic wave oscillation [19]. These results present an exciting field for discovery and development of novel applications of interest to many industries, ranging from Oil and Gas to Computing and Telecommunications. Previously only one numerical scheme had been advanced to model linear time-varying materials using finite differences. Recently, EMClaw has provided the means to model a generalized approach to Maxwell’s equations for non-linear, heterogeneous and time-varying media using a finite volume approach [20].

Wave phenomena in space-time-varying media can be modeled by the equation: $\bar{\kappa}(\boldsymbol{q},\boldsymbol{r},t)\cdot\boldsymbol{q}_t+\boldsymbol{f}^i(\boldsymbol{q})_{x^i}=\boldsymbol{\psi}(\boldsymbol{q},\boldsymbol{r},t)$. In this work, authors summarized the numerical scheme to solve this problem departing from the wave propagation algorithms incorporated in SharpClaw [21]. Linear and non-linear spatial and time heterogeneities in the material are assimilated into the convective terms of the hyperbolic wave equation. This led to a semi-discrete and multi-dimensional scheme: EMClaw [20], which can be used to model Maxwell’s electromagnetic equations and can be extended to other wave phenomena where similar material properties occur. Authors use this scheme to describe wave phenomena in a new range of technologies for downhole photonics, namely: travelling Bragg mirrors in single mode and hollow fibers and explore their use for DTS and DAS analysis, spontaneous ring resonators for energy harvesting, and to study an electromagnetic pulse propagating in a multiphase flow. The results of this last investigation posit new methods for multiphase sensing and flow characterization.

III. CONCLUSION

The OG4IR special track includes a broad range of topics related to The Fourth Industrial Revolution (4IR) applications in oil & gas upstream industry. It includes both academic research as well as studies from industry providing interesting ideas to solve outstanding problems in oil & gas upstream industry.

ACKNOWLEDMENT

We would like to thank the organizers of ICSNC 2020 for their tireless efforts and for accepting OG4IR as a special track. I also thank the members of the program committee for their hard work with the reviews and feedback. Also, I’m so grateful to EXPEC ARC, Saudi Aramco for most of the research presented in this special track. Last, but not least, I am very thankful to the authors for their very interesting contributions.

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