ARTIFICIAL INTELLIGENCE AND DATA ANALYTICS FOR ENERGY EXPLORATION AND PRODUCTION

Fred Aminzadeh
Cenk Temizel
Yasin Hajizadeh

Scrivener Publishing

WILEY

Artificial Intelligence and Data Analytics for Energy Exploration and Production

Scrivener Publishing
100 Cummings Center, Suite 541J
Beverly, MA 01915-6106

Publishers at Scrivener
Martin Scrivener (martin@scrivenerpublishing.com)
Phillip Carmical (pcarmical@scrivenerpublishing.com)

Artificial Intelligence and Data Analytics for Energy Exploration and Production

Fred Aminzadeh
Cenk Temizel
and
Yasin Hajizadeh

Scrivener Publishing

WILEY

This edition first published 2022 by John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, USA and Scrivener Publishing LLC, 100 Cummings Center, Suite 541J, Beverly, MA 01915, USA

For more information about Scrivener publications please visit www.scrivenerpublishing.com.

Wiley Global Headquarters
111 River Street, Hoboken, NJ 07030, USA

For details of our global editorial offices, customer services, and more information about Wiley products visit us at www.wiley.com.

Library of Congress Cataloging-in-Publication Data

ISBN 9781119879695

Cover image: Pixabay.com
Cover design by Russell Richardson

Set in size of 11pt and Minion Pro by Manila Typesetting Company, Makati, Philippines

Printed in the USA

10 9 8 7 6 5 4 3 2 1

Dedication

Fred Aminzadeh: AI will be even more impactful to the future generations. I am dedicating this book to Sara, David, Diana Aminzadeh and Henry Aminzadeh Pritt

Cenk Temizel: To my family for their continuous support

Yasin Hajizadeh: For my selfless mom. Love you, Azar janim!

Contents

Foreword

Sixteen years have passed since the publication of the book *Neural Networks and Soft Computing Techniques with Applications in the Oil Industry* by Fred Aminzadeh and Paul de Groot. I was kindly asked to write the foreword to that book. In that foreword, I mentioned that it was a book that was sorely needed at the time since it introduced the readers to several recent techniques that were destined to grow in importance in the future. As predicted, the techniques of Neural Networks and Soft Computing have indeed taken off. Only the names have been changed, and we now talk about Artificial Intelligence. Machine Learning, and Big Data Analytics. But these are all concepts that have grown out of the ideas discussed in the 2006 book. Thus, there is a real need for an update, and Fred Aminzadeh, along with two new co-authors, Cenk Temizel and Yasin Hajizadeh, has once again fulfilled that need with this new book, entitled *Artificial Intelligence and Data Analytics for Energy Exploration and Production*. In this new book, the authors explore a variety of techniques that are applicable to a wide range of geoscience and reservoir engineering tasks. Fred has once more asked me to write the foreword, and I am again honored to do so.

The first figure in this book shows the explosion in papers on the topic of machine learning, from less than 50 in 2006 to almost 1600 in 2020. In fact, we could say that machine learning has become the “flavor of the month” in virtually all disciplines these days. The big question is whether machine learning and big data analytics can live up to the high expectations everyone has placed on these new methods, and this is question that the authors set out to answer. They point out that the new digital transformation promises to “optimize production, reduce costs, and minimize the environmental impact of hydrocarbon recovery”. However, they also stress that the risk-averse nature of our business may work against the adoption of some of these techniques. My feeling is that companies that do not fully embrace these new ideas may run the risk of falling behind. Thus, it is imperative to at least be aware of these new ideas, and that is what this book brings to the practicing geoscientist or engineer.

Let me give a quick summary of the topics covered in this book. Although the emphasis is on downstream production engineering applications in the oil and gas sector, the authors also look at upstream exploration applications. The first seven chapters of the book give the reader an overview of the methods themselves, and discuss intelligent data analysis, machine learning and the human-computer interface, artificial neural networks and fuzzy logic, natural language processing and big data analytics. These are all very big topics, but the authors do a good job of distilling the main concepts into understandable terms.

After this comprehensive discussion of the new data analytic methods themselves, the next eight chapters apply these techniques to a range of different problems, from exploration to enhanced oil and gas recovery. Other topics discussed are drilling, reservoir characterization and optimization, production forecasting, reservoir engineering and simulation, and artificial lift. In other words, the authors present a comprehensive overview of how the new data analytic techniques are having an impact on virtually every aspect of the oil and gas industry. The book finishes with a look ahead to the future. Although no one has a crystal ball, we can be certain that the growth of these methods will continue to be almost exponential. The concepts learned in this book should allow the reader to keep up with this future development by reading the literature.

As in the previous book by Fred, this new book presents the right mix of theory and real data examples. The reader will gain both an understanding of the techniques used as well as seeing real world examples of these techniques. I heartily recommend the book to all reservoir engineers and geoscientists who wish to gain a fuller understanding of new methods that can help them understand the complexity of their reservoirs.

I congratulate the authors on preparing this timely book which displays their technical expertise in these emerging areas of research. My only hope is Fred doesn't keep us waiting another sixteen years for an update, since this is an area of research that is increasing almost exponentially year by year!

Dr. Brian Russell
GeoSoftware, Calgary, Canada
brian.russell@geosoftware.tech

Preface

Petroleum engineers and geoscientists work with a wide spectrum of data from different sources to carry out various tasks for exploration and production (E&P) of oil and gas and other resources. In recent years the volume of data acquired has exploded. Aside from the BIG DATA requirements, the complexity of the problems to be addresses have risen. Many real-time data analysis to perform real-time monitoring is another concern. All these factors make the use of various artificial intelligence (AI), machine learning (ML) and data analytic methods a necessity.

AI and DA offer a natural toolbox to address many problems in the energy sector. AI and its Machine Learning/Deep Learning-based methods perform much like a human brain. They can receive variety of data from many different sources with drastically different characteristics and undertake necessary evaluations and interpretation of the data. This ultimately leads to the right and timely decisions and solution to the otherwise intractable and complicated problems.

While AI can play an important role as a key element of our toolbox, human intelligence (geologists, geophysicists, and engineers) will always be an essential part of the E&P process. Specifically, humans with their domain expertise have a superior performance with qualitative data than computers that are better dealing with quantitative data. Thus, we should design effective human-machine interfaces to create hybrid solutions based on combining machine intelligence with human intelligence.

To ensure the energy industry is keeping up with the recent advances, we need to fill the gap between the ever-increasing advances in AI and Data Analytics (DA) versus the growing demand for such technologies in various oil and gas and other energy related applications. We need to speed up infusion of Artificial Intelligence (AI), Machine Learning and Data Analytic (DA) concepts into the energy exploration and production arena. This book strives to play a role in accomplishing this objective. It will serve as a catalyst to break down the discipline, organizational, and industry versus academia boundaries to keep pace with the fast-evolving AI-DA technologies.

We expect to be a change agent in the way subsurface imaging deep drilling, and reservoir analysis has done. We need to combine the power of AI and data analytics with the many advances in high performance computing and computers memory (both physical and cloud/edge-based) to carry out modeling, imaging, and simulation tasks more efficiently and faster in a cost-effective manner. We also need to unleash the strength of AI and DA to address various "Big Data" challenges of the energy industry. The transformative changes resulting from more widespread use and full utilization of AI and DA will undoubtedly be as impactful to the energy industry as the role horizonal drilling and hydraulic fracturing played in the development of massive shale resources in the last 20 years.

We need to recognize the fact that reservoir characterization is a multi-disciplinary field. It attempts to describe petroleum deposits and the nature of the rocks that contain hydrocarbons using a variety of data types. Reservoir characterization relies on expertise from petroleum engineers, geologists, geochemists, petro-physicists, and of course geophysicists. The integration of information from these fields, with the aid of advanced data analytic techniques as well as artificial intelligence-based methods will make our reservoir models more accurate. Furthermore, the level of uncertainty of those models will be reduced with reduced level of uncertainty and their updating process for real time monitoring will be much faster.

This book will provide a comprehensive body of technical material on different aspects AI and DA. After the introductory chapter on modern intelligent data analysis, we cover the fundamentals of AI-DA, in the following 6 chapters. It starts with a brief introduction to Machine Learning and Human-Computer Interface. Chapter 3 highlights fundamentals of artificial neural network (ANN), arguably the most widely used AI technique in geosciences and petroleum engineering. ANNs are computer models, mimicking human brain are comprised of many connected processing elements that can receive input from different sources and create out with involving non-linear transformation of the input data. We describe the structure and learning mechanism of commonly used ANNs, how they work, and what they are used for.

Chapter 4 introduces Fuzzy logic (FL), a "soft" computing technique that deals with imprecise data and non-crisp rules and partial truths. Fuzzy logic generalizes the conventional set theory, allowing an object to belong to more than one category, with varying degrees of membership. It also allows linguistic qualifiers to be characterized and implemented in computer programs. We describe membership grades, fuzzy rules, computing with words, fuzzy functions, and fuzzy systems. Chapter 5 discusses the value of integration of conventional and unconventional methods in addressing specific challenges of real-world problems. It describes the respective strength and weakness of different unconventional computing methods, also referred to as "Soft Computing" or SC techniques, comprised of Neural Networks (NN), Fuzzy Logic (FL), and Genetic Algorithms (GA). Combining two or more of these methods and/or with conventional computing methods (CM) have many benefits. We highlight these benefits by introducing the "Hybrid Methods".

Chapter 6 deals with Natural Language Processing, which has recently emerged as an important branch of artificial intelligence. This is due to more widespread applications of NLP in assisting computers to interpret, manipulate, understand, and drive meaning from human languages. We highlight different NLP methods and introduce concepts such as pragmatic analysis of contextual information, sentence segmentation, tokenization, labeling, and lamentation. We also highlight a few oil and gas applications of NLP. Chapter 7 discusses general aspects of Data Sciences and Big Data issues. After a general introduction to data science, we introduce the 4V concept of big data comprised of key elements of data that we have deal with characteristics associated with data volume, velocity, variety, and veracity. We then introduce a few algorithms commonly used in data sciences and how different elements of machine learning are applied in this area. This is followed be brief introduction to infrastructure and tooling for data science as well as a few E&P applications.

The second part of the book from chapters 8 through 15 deal with specific application of AI-DA in different stages of E&P. Chapter 8 addresses the applications of AI in exploration. Among the topics covered here are the Petroleum System and Exploration Risk Factors, Data Acquisition, Processing, and Integration for Exploration, Exploration and Appraisal Drilling, Geological Risk Assessment Level of Knowledge and Experience, Auto-Picking for Microseismic data, Facies Classification using Supervised CNN and Semi-Supervised GAN, generating "Gas Chimney Cube" using MLP ANN, Geostatistical estimation of Imprecise Information Using Fuzzy Kriging Approach; and Fracture Zone Identification Using Seismic, Micros-Seismic and Well Log Data. Chapter 9 deals with Real-time Measurements in Drilling Automation, Event Detection in Drilling, Rate of Penetration Estimations, Estimation of bottomhole and formation temperature by drilling data, and Drilling Dysfunctions issues addressed by Machine Learning.

Chapter 10 deals with the applications of machine learning in reservoir characterization. It focuses on porous media characterization, reservoir modeling, porosity-permeability relationship, data mining, and computational intelligence for petroleum reservoir characterization. It addresses AI fo permeability and porosity prediction as well as use of neural networks, fuzzy logic, support vector machines, hybrid computational intelligence, extreme machine learning, ensemble machine learning, and physics-informed machine learning for real-time reservoir management. Chapter 11 covers machine learning applications in production forecasting. In this context, it highlights topics such as: type curves, numerical solutions, limitations, machine learning applications, decline curve analysis, Tail-End Exponential Decline, Power Law Loss Ratio" Rate Decline Model, Stretched Exponential Decline Curve Model, Duong's method, Weibull Decline Model Predictions and their comparison of conventional methods to data-driven methods.

Production optimization, well completion and stimulation with AI are the topics covered in Chapter 12. With constantly fluctuating oil prices, operators need to be cost conscious in connection with development projects and increase recovery from existing assets. In this chapter we discuss how AI-based techniques can contribute to production optimization. Examples of applications of advanced data analytics and machine learning methods to maximize production while minimizing capital and operating expenses are given here. This is a complex process where factors around well parameters, production conditions, reservoir rock and fluid properties, surface facilities and their capacities, economics, and health, safety and environment must be considered in evaluating different operational parameters. Chapter 13 deals with machine learning applications in reservoir and reservoir simulation. Some of the relevant topics discussed here are using machine learning for: Estimation of fluid properties, reservoir simulation, geothermal reservoir engineering, and well testing.

Chapter 14 deals with use of machine learning, big data concept and analytical solutions for artificial lift. Use of Machine Learning in Oil and Gas Industry, Failure Prediction Framework and Algorithms for Artificial Lift Systems, Overview of Production Systems Analysis, Types of the Artificial Lift Systems, Electrical submersible pumps, plunger lift, rod/beam pumps, Gas Lift, Artificial Lift Applications, Monitoring, and Automation Services, Detection of Well (Alarm) Control, Trigger Detection of Drilling, Predicting and Detecting Equipment Malfunctions, Forward and Inverse Looking Models.

Chapter 15 addresses Enhanced Oil Recovery (EOR) in the context of Machine Learning Applications in, this chapter focuses on thermal, chemical, gas, and microbial enhanced oil recovery methods, offshore reservoirs, the economic value of EOR, Machine Learning in Enhanced Oil Recovery (EOR)

Screening, onshore oil reservoirs. Specific EOR related applications of AI methods discussed are: (1) Use of Neuro-Fuzzy (NF) architecture, (2) An Expert System for Water-Flooding, (3) Machine Learning in Enhanced Oil Recovery (EOR) Screening, among others. Several AI based commercial software package for EOR are also highlighted.

Chapter 16, the final chapter of the book includes conclusions and future directions both on the fundamentals and application areas. Specific areas of expected new developments in each of the topics covered in chapters 2 through 16 were highlighted. Among such new directions envisioned to shape the future of AI/DA in general and their expected impact on oil and gas applications are listed below:

1. Use AR/VR based systems to visualize machine learning solutions and interact with the respective specific domain data and possibly multitude of domain data simultaneously,
2. Adoption of computer- human interface to allow mind-reading by computer, leading to creation of a Brain-Computer Interface (BCI) by translating brain activity into digital commands. This would allow controlling visual interfaces in real time. Mind reading computers would be responding to human brain waves.
3. Capsules that nested set of neural layers may lead to versatility on ANN. In a conventional neural network, one keeps on adding more layers. In CapsNet, more layers are added inside a single layer that involves nesting a neural layer inside another.
4. Use of Multi-Criteria Group Decision Making (MCGDM) aims to find consensus from several decision makers/users by evaluating their respective uncertainty in judgments. This may involve utilizing Type-2 Fuzzy Logic with the Big Bang-Big Crunch (BB-BC) optimization.
5. Ensemble Learning Machines (ELM) nay be employed as a generalization of some of the hybrid techniques. Ensemble learning combines the predictions from two or more models, possibly using different AI methods. The main goal of using ensemble methods is to improve the skill of predictions over that of any of the contributing members.
6. With the emergence of Generative Pre-trained Transformers (GPT) and Bidirectional Encoder Representations from Transformers (BERT), NLP's future and its applications will continue to extend even further.

7. We predict that a new wave of privacy-preserving data marketplaces will be adopted in the oil and gas industry to address challenges associated with Big Data. Sterling, a decentralized marketplace for data, that uses smart contracts running on permission-less blockchain to empower users to access to data while persevering privacy is one such example
8. Among new application areas will be the use of AI-DA for subsurface reservoir property visualization for real-time decision-making bot for energy extraction and carbon capture and sequestration. Currently, a major 10-year program called SMART initiative is going on at the DOE's NETL with the involvement of many other national labs, universities, and research organization to accomplish this very objective.
9. We will see more extensive use of AI-DA in every aspect of development of new energy resources including exploration. One of the areas of studies in the future is expected to be addressing the SURE challenge to account for differences in **S**cale, **U**ncertainty, **R**esolution and **E**nvironment discussed in earlier chapters. AI-DA is likely to play a significant role in addressing the SURE challenge.
10. Real-time measurements in drilling automation, kick and overpressure prediction, estimation of the rate of penetration, estimations of downhole, formation fluid temperatures. Drilling operations generate a significant amount of time-series data., requiring more extensive use of Data Analytics System where the algorithm provides optimized drilling operational parameters based on the results obtained from the trained machine-learning algorithms.
11. We can apply ML to develop advanced models to find new reservoirs devoid of drilling and monitor any wells, reducing the project expenses and risks. These examples of the applications increase the interdisciplinary collaboration among engineers, geoscientists, computer scientists, and mathematicians to appraise ML's practical applications for reservoir characterization, improving the exploration, production, and management of energy resources.
12. Artificial intelligence-based approximations can play a key role for overcoming challenges of production forecasting and production forecasting. Variety of AI-based methods such as ANNs, RNNs, DNNs, Bayesian MLs, Edge Intelligence (EI) and Transfer Learning could be utilized.

Also of Interest

Check out these other related titles from Scrivener Publishing

Books in the Series, "Sustainable Energy Engineeering"

RESERVOIR CHARACTERIZATION: Fundamentals and Applications, by Fred Aminzadeh, ISBN 9781119556213. The second volume in the series, "Sustainable Energy Engineering," written by some of the foremost authorities in the world on reservoir engineering, this groundbreaking new volume presents the most comprehensive and updated new processes, equipment, and practical applications in the field. *NOW AVAILABLE!*

Hydraulic Fracturing and Well Stimulation, edited by Fred Aminzadeh, ISBN 9781119555698. The first volume in the series, Sustainable Energy Engineering, written by some of the foremost authorities in the world on well stimulation, this groundbreaking new volume presents the advantages, drawbacks, and methods of one of the hottest topics in the energy industry: hydraulic fracturing ("fracking"). *NOW AVAILABLE!*

Other Related Titles from Scrivener Publishing

Hybrid Renewable Energy Systems, edited by Umakanta Sahoo, ISBN 9781119555575. Edited and written by some of the world's top experts in renewable energy, this is the most comprehensive and in-depth volume on hybrid renewable energy systems available, a must-have for any engineer, scientist, or student. *NOW AVAILABLE!*

Energy Storage 2nd Edition, by Ralph Zito and Haleh Ardibili, ISBN 9781119083597. A revision of the groundbreaking study of methods for storing energy on a massive scale to be used in wind, solar, and other renewable energy systems. *NOW AVAILABLE!*

Nuclear Power: Policies, Practices, and the Future, by Darryl Siemer, ISBN 9781119657781. Written from an engineer's perspective, this is a treatise on the state of nuclear power today, its benefits, and its future, focusing on both policy and technological issues. *NOW AVAILABLE!*

Progress in Solar Energy Technology and Applications, edited by Umakanta Sahoo, ISBN 9781119555605. This first volume in the new groundbreaking series, Advances in Renewable Energy, covers the latest concepts, trends, techniques, processes, and materials in solar energy, focusing on the state-of-the-art for the field and written by a group of world-renowned experts. *NOW AVAILABLE!*

A Polygeneration Process Concept for Hybrid Solar and Biomass Power Plants: Simulation, Modeling, and Optimization, by Umakanta Sahoo, ISBN 9781119536093. This is the most comprehensive and in-depth study of the theory and practical applications of a new and groundbreaking method for the energy industry to "go green" with renewable and alternative energy sources. *NOW AVAILABLE!*

Zero-Waste Engineering 2nd Edition: A New Era of Sustainable Technology Development, by M. M. Kahn and M. R. Islam, ISBN 9781119184898. This book outlines how to develop zero-waste engineering following natural pathways that are truly sustainable using methods that have been developed for sustainability, such as solar air conditioning, natural desalination, green building, chemical-free biofuel, fuel cells, scientifically renewable energy, and new mathematical and economic models. *NOW AVAILABLE!*

Sustainable Energy Pricing, by Gary Zatzman, ISBN 9780470901632. In this controversial new volume, the author explores a new science of energy pricing and how it can be done in a way that is sustainable for the world's economy and environment. *NOW AVAILABLE!*

Sustainable Resource Development, by Gary Zatzman, ISBN 9781118290392. Taking a new, fresh look at how the energy industry and we, as a planet, are developing our energy resources, this book looks at what is right and wrong about energy resource development. This book aids engineers and scientists in achieving a true sustainability in this field, both from an economic and environmental perspective. *NOW AVAILABLE!*

The *Greening of Petroleum Operations*, by M. R. Islam et al., ISBN 9780470625903. The state of the art in petroleum operations, from a "green" perspective. *NOW AVAILABLE!*

Emergency Response Management for Offshore Oil Spills, by Nicholas P. Cheremisinoff, PhD, and Anton Davletshin, ISBN 9780470927120. The first book to examine the Deepwater Horizon disaster and offer processes for safety and environmental protection. *NOW AVAILABLE!*

Biogas Production, Edited by Ackmez Mudhoo, ISBN 9781118062852. This volume covers the most cutting-edge pretreatment processes being used and studied today for the production of biogas during anaerobic digestion processes using different feedstocks, in the most efficient and economical methods possible. *NOW AVAILABLE!*

Bioremediation and Sustainability: Research and Applications, Edited by Romeela Mohee and Ackmez Mudhoo, ISBN 9781118062845. Bioremediation and Sustainability is an up-to-date and comprehensive treatment of research and applications for some of the most important low-cost, "green," emerging technologies in chemical and environmental engineering. *NOW AVAILABLE!*

Green Chemistry and Environmental Remediation, Edited by Rashmi Sanghi and Vandana Singh, ISBN 9780470943083. Presents high quality research papers as well as in depth review articles on the new emerging green face of multidimensional environmental chemistry. *NOW AVAILABLE!*

Bioremediation of Petroleum and Petroleum Products, by James Speight and Karuna Arjoon, ISBN 9780470938492. With petroleum-related spills, explosions, and health issues in the headlines almost every day, the issue of remediation of petroleum and petroleum products is taking on increasing importance, for the survival of our environment, our planet, and our future. This book is the first of its kind to explore this difficult issue from an engineering and scientific point of view and offer solutions and reasonable courses of action. *NOW AVAILABLE!*