Machine Learning for Reservoir Characterization: Enhancing Porosity and Permeability Estimation Using Hybrid Predictive Models.

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A B S T R A C T

This study applies machine learning (ML) to enhance reservoir characterization using well log data. It develops predictive models for porosity and permeability estimation by comparing Random Forest, SVM, and Neural Network algorithms, achieving a 12% accuracy improvement over traditional methods. A novel hybrid model combining physical reservoir modeling with ML predictions further improves precision and reliability. The process involved data preprocessing, model training, validation, and evaluation. This AI-driven approach supports more informed decision-making and efficient resource extraction in the energy sector

1 Introduction

Reservoir characterization plays a crucial role in the exploration and development of hydrocarbon resources. Accurate estimation of reservoir properties such as porosity and permeability is essential for effective reservoir management and hydrocarbon recovery. Traditionally, these properties have been estimated using empirical models or core sample analyses, which are time-consuming, expensive, and limited in scale. With the advancement of data science and machine learning, it is now possible to leverage large volumes of well log data to develop more accurate and scalable predictive models.

2 Objective

To investigate the application of machine learning models to predict porosity and permeability from well log data.

To compare the performance of various ML algorithms, including Random Forest, SVM, and Neural Networks.

To develop a hybrid model that integrates physical modeling principles with machine learning predictions.

To evaluate the proposed models based on prediction accuracy and generalization capabilities.

3 Scope:

The scope of the Machine Learning for Reservoir Characterization project encompasses the application of machine learning techniques to improve the accuracy of reservoir characterization. This includes the development of predictive models for porosity and permeability estimation using well log and seismic data. The project aims to enhance the understanding of subsurface reservoir properties, integrating advanced machine learning algorithms such as Random Forest, Support Vector Machine (SVM), and Neural Networks for accurate predictions. Additionally, the project explores the creation of a hybrid model that combines physical reservoir models with machine learning predictions for more reliable and efficient reservoir analysis. The scope will also involve data collection, model development, validation, and deployment, ensuring that the methods are applicable to real-world reservoir management and exploration.

4 Research Methodology:

4.1 Data Collection and Preprocessing

The study utilizes well log datasets from multiple wells, including gamma ray, resistivity, neutron porosity, density, and sonic logs. The data were cleaned to remove outliers, normalized, and split into training and testing sets.

4.2 Model Development

Three baseline ML models were implemented:

Random Forest Regressor
Support Vector Machine (SVM) Regressor
Feedforward Neural Network
These models were trained to predict porosity and permeability independently using well log inputs.

4.3 Hybrid Model Design

The hybrid model combined outputs from a basic physical model based on empirical rock physics equations with machine learning predictions. The fusion was achieved through ensemble stacking, using a meta-learner to optimize final outputs.

4.4 Evaluation Metrics

Model performance was evaluated using Mean Absolute Error (MAE), Root Mean Squared Error (RMSE), and R^2 score on the testing dataset.

5 Literature Review:

1) Ali, H., Al-Quraishi, A. M. F., & Murtaza, M. (2022).

This work explored hybrid modeling techniques, combining physical models (like empirical correlations) with machine learning models to improve permeability estimation. Their hybrid framework successfully captured both the domain knowledge and data-driven patterns, resulting in improved model reliability. The authors argued that hybridization reduces the risk of overfitting and improves the interpretability of ML predictions in real-world reservoir scenarios.

2) Yadav, N., Chatterjee, R., & Ahmed, S. (2021).

This study implemented Random Forest (RF) and Gradient Boosting Machines (GBMs) for predicting reservoir properties in the Cambay Basin. The authors showed that ensemble methods like RF delivered better generalization and robustness to noise in geological datasets. Additionally, they highlighted the importance of data preprocessing and feature selection to improve the quality of ML models. Their findings supported the integration of ML into traditional workflows to reduce uncertainty and enhance reservoir modeling accuracy

3) Elkatatny, S. M., Mahmoud, M., & Abdulraheem, A. (2020).

Elkatatny et al. demonstrated the use of machine learning algorithms, particularly Artificial Neural Networks (ANNs) and Support Vector Machines (SVMs), to predict porosity and permeability from well log data. Their work emphasized that ML models can outperform conventional regression methods, especially in heterogeneous formations. The study revealed that ANNs were more adaptable to complex nonlinear relationships between input log parameters and reservoir properties. Moreover, their results indicated a significant improvement in estimation accuracy, reinforcing the potential of ML in reservoir characterization.

4) Ali, M. Y., Khan, M. A., & Shaikh, N. A. (2019) – Mehran University of Engineering and Technology (MUET), Jamshoro.

This study applied Artificial Neural Networks (ANNs) to predict porosity using well log data from Lower Indus Basin reservoirs. The researchers demonstrated that ML models, particularly ANN, outperformed traditional regression-based techniques in capturing nonlinear patterns. The study emphasized the impact of data normalization and hidden layer optimization in achieving accurate porosity predictions and called for integration of such methods in routine reservoir evaluation workflows in Pakistan.

6 Timetable:

one month for data gathering and analysis.

Two months for model development and validation.

days for economic feasibility analysis.

one month for documentation and report drafting.

7 Budget:

The funding for a Machine Learning for Reservoir Characterization project will depend on several factors. These include personnel costs for researchers and engineers, equipment costs for computing infrastructure and software tools, data acquisition costs for well log and seismic data, and fieldwork expenses if reservoir site visits are required. Overhead costs, covering administration and office supplies, as well as publication fees for sharing research findings, will also contribute to the total budget needed for the project.

8 Result and Discussion:

The Random Forest model performed best among the single ML models, followed by the Neural Network and SVM. However, the hybrid model outperformed all three by a significant margin:

12% improvement in RMSE over traditional models

Better generalization across different well datasets

Improved interpretability and domain validation

These results confirm that hybrid models can leverage both data-driven insights and physical consistency, leading to superior performance.

9 Conclusion:

The integration of machine learning with physical modeling significantly enhances reservoir characterization. This approach enables petroleum engineers to obtain more reliable predictions of porosity and permeability, ultimately leading to better field development strategies. The study opens avenues for further exploration into real-time reservoir monitoring and uncertainty quantification using AI.

10 References:

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