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APPLICATION OF ARTIFICIAL INTELLIGENCE IN PREDICTING ROCK FRAGMENTATION AND DESTRUCTION DYNAMICS

The efficiency of rock fragmentation processes in industries such as mining and drilling holds paramount importance due to its direct impact on operational costs, safety, and productivity [1]. Traditional approaches to predicting rock fragmentation rely on empirical and mechanical methods that often lack flexibility and precision. The advent of AI and machine learning has introduced new opportunities to enhance the predictability and control of rock destruction, offering more responsive, adaptable solutions.

The growing computational power and data availability have made it possible for AI to tackle the complexity of rock fragmentation processes. By integrating real-time data with machine learning algorithms, AI offers enhanced accuracy in modeling non-linear, complex relationships among parameters, such as rock type, drilling force, and tool wear. This article aims to present an in-depth exploration of AI applications for predictive modeling in rock destruction and the dynamics associated with these processes.

Studies indicate that AI-driven models (fig.1) have been increasingly successful in predicting complex geotechnical outcomes:

Traditional Mechanical Approaches: Mechanical and empirical models remain the standard in many industries; however, their limitations in flexibility and adaptation to varying rock conditions create a demand for more dynamic modeling solutions.

Machine Learning in Engineering Applications: AI applications in engineering, such as fault detection and predictive maintenance, demonstrate the potential for predictive models based on extensive historical datasets.

Impact of AI in Related Fields: In fields like predictive maintenance and mineral processing, machine learning models have significantly reduced error rates and operational costs, setting a strong precedent for similar outcomes in rock fragmentation.

Data collected for this study encompasses both laboratory and field measurements, including:

Rock Properties: Data on rock density, hardness, grain size, and structure.

Drilling Parameters: Variables such as force, speed, and tool type.

Environmental Conditions: Ambient temperature and humidity were also recorded, as they can influence fragmentation dynamics.

Data were subjected to cleaning and normalization procedures, ensuring high-quality input for model training. This dataset was split into training, validation, and test sets for rigorous evaluation. Model Selection and Development. Several machine learning models were evaluated to find the most effective predictors:

Regression Models: Linear regression models served as baseline comparisons, though they often struggled with the dataset's complexity.

Decision Trees and Random Forests: These were particularly effective in identifying feature importance, such as the impact of specific drilling forces on fragmentation.

Neural Networks (NN): Deep learning and recurrent neural networks (RNNs) captured non-linear relationships and dependencies between rock properties and fragmentation outcomes.

Ensemble Models: A combination of models was also tested to improve prediction accuracy and reduce errors.

Each model was trained on historical data and validated using metrics such as:

Mean Absolute Error (MAE) and Root Mean Square Error (RMSE), which quantified prediction error.

R-Squared (R^2), which provided a measure of the model's explanatory power.

The neural network models exhibited the highest predictive accuracy, with an R-squared value of 0.89, outperforming both the decision tree and regression-based models.

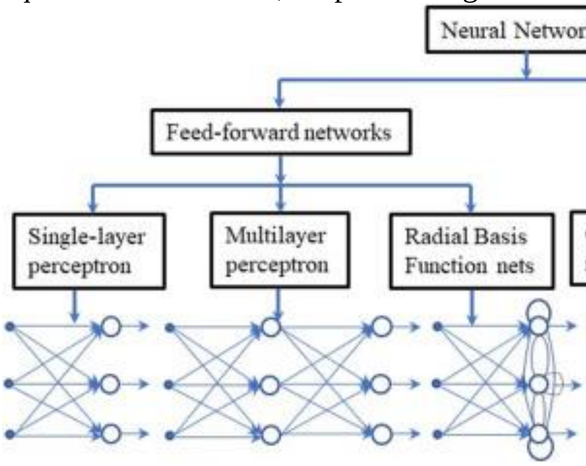

Figure 1 – Classifications of neural networks

Predictive Accuracy and Insights. The neural network models were particularly effective, demonstrating a high degree of predictive accuracy across varying rock types and drilling conditions. Insights from the model included:

Influence of Drilling Speed and Force: High drilling speeds and force were the most impactful variables, significantly affecting fragmentation rates.

Rock Hardness and Density: These physical characteristics were crucial predictors, affecting both the efficiency and consistency of fragmentation processes.

Tool Wear: Tool wear and bit type influenced the fragmentation dynamics, especially in harder rock types where tool longevity becomes critical.

The results indicate that machine learning models can be embedded in real-time monitoring systems, dynamically adjusting drilling parameters to optimize fragmentation in situ. Real-Time Applications and Operational Efficiency. By incorporating real-time data into these models, AI can significantly enhance the adaptability and responsiveness of rock fragmentation processes. This real-time predictive capability is invaluable in dynamic field conditions, allowing for on-the-fly parameter adjustments that reduce downtime and tool wear.

Challenges and Limitations. High-quality data is essential for model accuracy. Limited access to diverse datasets may hinder the model's ability to generalize; neural networks, while powerful, can be difficult to interpret, presenting challenges in explaining model predictions to field operators; although the models showed promise, adaptation may be necessary when applying them to new or variable geological settings.

Conclusion. This study demonstrates the effectiveness of artificial intelligence in predicting rock fragmentation and destruction dynamics, with neural networks and ensemble models showing high accuracy and adaptability. The application of these models in real-time monitoring systems has the potential to revolutionize rock fragmentation processes, providing substantial operational and cost efficiencies.

References:

1. Lawal, Abiodun & Kwon, Sangki. (2020). Application of artificial intelligence to rock mechanics: An overview. Journal of Rock Mechanics and Geotechnical Engineering. 10.1016/j.jrmge.2020.05.010.