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Research Paper

Application of Reinforcement Machine Learning Models in Predicting Penetration Rate of Rotary Blast Holes

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Abstract: Drilling with the help of a rotary drilling machine is an important tool for exploration and extraction in mines. On the other hand, estimating the costs and efficiency of the rotary drilling machine is a fundamental step in the design of mining and construction projects. Drilling Penetration Rate (PR) is a suitable indicator for estimating the costs and efficiency of rotary drilling rigs. Therefore, achieving the optimal amount of PR in the rotary drilling machine will reduce costs and increase the efficiency of the rotary drilling machine. For this purpose, in this article, one of the enhanced Machine Learning (ML) methods that combines Light Gradient Boosting (LGB) and Random Forest (RF) with Meta-Heuristic algorithms (MH), including Grey Wolf Optimizer (GWO) and Harris hawk (HHO), has been done to estimate PR. In order to validate the developed models, the models were implemented on the collected data sets. The dataset, including 7 independent input variables, was used. The independent input variables are drilling Diameter in inches (D), rotational speed in Revolutions Per Minute (RPM), Weight On Bit (WOB), Uniaxial Compressive Strength (UCS) of rock in megapascals, Tensile (T) strength of rock in terms of megapascals, the Joints Spacing (JS) in the ground in centimeters, and the relative accuracy of the Joints in Degrees (JD). The obtained results show that the RF-GWO method (R2 = 0.987 and RMSE = 3.059) is more accurate than LGB-GWO (0.912 and 8.045), LGB-HHO (0.917 and 7.831), and RF-HHO (0.912 and 8.044) in training data. Also, sensitivity analysis studies indicate that RPM and JD parameters have the most and least effect on the PR of the rotary drilling machine, respectively.

Keywords: Penetration rate drilling, Light Gradient Boosting (LGB), Random Forest (RF), Grey Wolf Optimizer (GWO), Harris Hawk Optimization (HHO).

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INTRODUCTION

Predicting drilling machine efficiency in mining is crucial for optimizing costs and operations, with rate of penetration being a key factor influenced by various variables. Machine learning techniques, including Artificial Neural Networks and others, can enhance penetration rate management, improving drilling performance and reducing costs [1,2]. Darbor et al. assessed rotary drilling machine penetration rates using Non-Linear Multiple Regression and Multi-Layer Perceptron models, finding that the MLP-ANN model outperforms NLMR in accuracy [3]. Additionally, Zhou et al. introduced a new optimization method for geological drilling, utilizing fuzzy C-means clustering and support vector regression to enhance operational efficiency [4].

Numerous studies have aimed to create a unified model for accurately estimating the rate of penetration (PR) in drilling, utilizing both analytical and data-driven techniques, but often lacking generalizability. Sharifinasab et al. introduced a deep learning approach using Generative Adversarial Networks (GANs) to improve PR predictions, while other researchers implemented data mining and optimization algorithms to enhance prediction accuracy further [5,6].

The research aims to enhance Tunnel Boring Machine (TBM) performance predictions by developing six hybrid models utilizing various optimization algorithms, with a focus on improving accuracy and minimizing risks in tunneling projects. The LSTM-GWO model demonstrated superior results in predicting TBM penetration rates, highlighting the importance of input parameters in influencing performance outcomes [7,8].

METHODS

Two machine learning methods, LGB and RF, were enhanced by GWO and HHO algorithms to create four models for estimating the rotary drilling machine's penetration rate, while Astarita et al. demonstrated the effectiveness of a GWO-ML model over a baseline model in a case study in Calabria, Italy [9].

According to what has been said regarding optimization algorithms, Figure 1 illustrates the flowchart of the model.

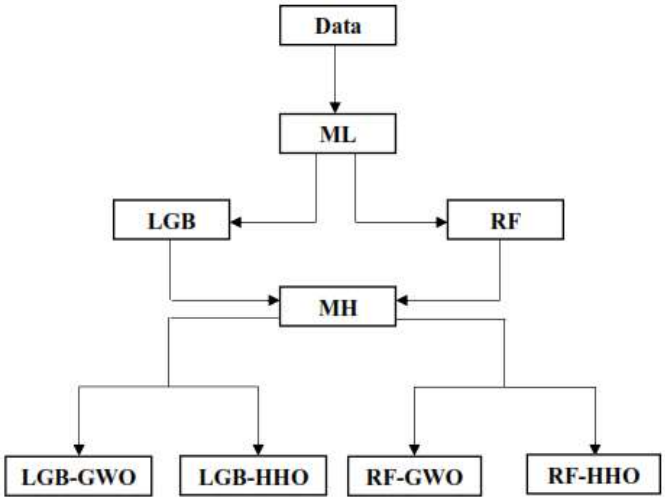

Figure 1. Flowchart of the model

FINDINGS AND ARGUMENT

To enhance the estimation of PR, the dataset was categorized into two groups: training and testing. The previously mentioned models were executed using Python software to ascertain the most effective model. Ultimately, R^2 and RMSE metrics were utilized to determine the leading model. Following this, the estimation results of each model were analyzed and compared. Additionally, a sensitivity analysis method was applied to identify which parameter had the most significant influence on PR.

Given that the optimization relied on two machine learning algorithms, LGB and RF, each was further

refined using two metaheuristic algorithms, GWO and HHO. The optimization results revealed that the correlation between the measured and estimated values of RF-GWO was significantly stronger than that of the other algorithms. Consequently, the recommended approach for optimizing the prediction of the penetration rate in rotary drilling of explosive boreholes is the RF-GWO model. More information regarding the machine learning algorithms is provided below.

The sensitivity analysis results of the model, illustrated as a bar chart in ascending to descending order in Figure 2, show that the angular velocity of the rotary drilling machine has the greatest impact on PR-DM, while the relative orientation of the fractures has the least. The minimal significance of the relative orientation of fractures allows us to disregard its influence on PR-DM.

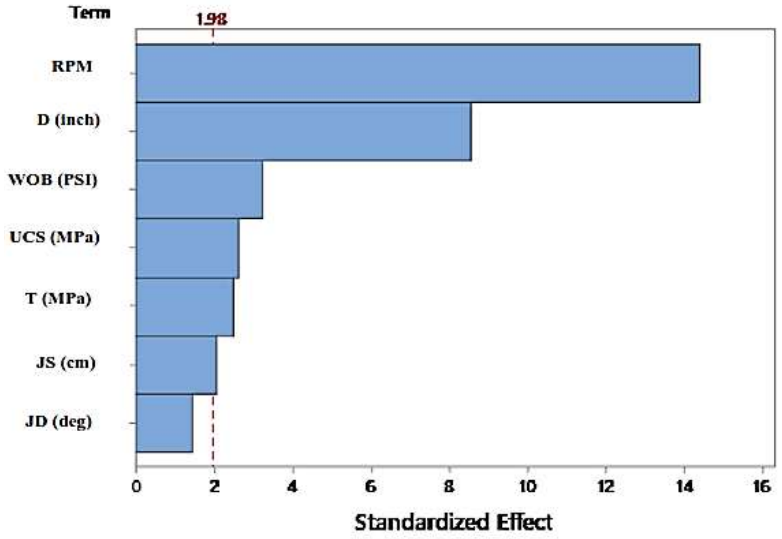

Figure 2. Results of PR sensitivity analysis

CONCLUSIONS

Rotary drilling rigs play a vital role in the mining sector, making the efficiency of these machines a key factor in the planning of mining projects. Research indicates that the Performance Ratio (PR) is an effective measure for assessing the efficiency of rotary drilling equipment, and optimizing this ratio is essential for achieving desired outcomes. To estimate PR, advanced machine learning techniques such as LightGBM (LGB) and Random Forest (RF), combined with metaheuristic algorithms like Grey Wolf Optimization (GWO) and Harris Hawks Optimization (HHO), were utilized. The models developed were tested on a dataset that was previously gathered to ensure their reliability. Results revealed that the RF-GWO method yielded the highest accuracy (R^2 = 0.987 and RMSE = 3.059) compared to LGB-GWO (0.912 and 8.045), LGB-HHO (0.917 and 7.831), and RF-HHO (0.912 and 8.044) methods when evaluated with test data. Furthermore, sensitivity analysis indicated that the parameters Revolutions Per Minute (RPM) and Jack Depth (JD) significantly influence the PR of the rotary drilling machine, with RPM having the greatest effect and JD the least.

REFERENCES

[1] Mirzehi-Kalate-Kazemi, M., Nabavi, Z., and Armaghani, D. J. (2024). *"A novel hybrid XGBoost methodology in predicting Penetration rate of rotary based on rock-mass and material pPRerties"*. Arabian Journal for Science and Engineering, 49: 5225-5241. DOI: https://doi.org/10.1007/s13369-023-08360-0.

[2] Najjarpour, M., Jalalifar, H., and Norouzi-Apourvari, S. (2022). *"Half a century experience in rate of penetration management: Application of machine learning methods and optimization algorithms - A review"*. Journal of Petroleum Science and Engineering, 208: 109575. DOI: https://doi.org/10.1016/j.petrol.2021.109575.

[3] Darbor, M., Faramarzi, L., and Sharifzadeh, M. (2019). *"Performance assessment of rotary drilling using non-linear multiple regression analysis and multilayer perceptron neural network"*. Bull Eng Geol Environ, 78: 1501-1513. DOI:

https://doi.org/10.1007/s10064-017-11923.

[4] Zhou, Y., Chen, X., Wu, M., and Cao, W. (2023). *"A novel optimization method for geological drilling vertical well"*. Journal of Information Sciences, 634: 550-563. DOI: https://doi.org/10.1016/j.ins.2023.03.082.

[5] Sharifinasab, M. H., Emami-Niri, M., and Masroor, M. (2023). *"Developing GAN-boosted Artificial Neural Networks to model the rate of drilling bit penetration"*. Journal of Applied Soft Computing, 136: 110067. DOI: https://doi.org/10.1016/j.asoc.2023.110067.

[6] Shaygan, K., and Jamshidi, S. (2023) *"Prediction of rate of penetration in directional drilling using data mining techniques"*. Journal of Geoenergy Science and Engineering, 221: 111293. DOI: https://doi.org/10.1016/j.petrol.2022.111293.

[7] Mirjalili, S. A., Mirjalili, S. M., and Lewis, A. (2014). *"Grey Wolf Optimizer"*. Journal of Advances in Engineering Software, 69: 46-61. DOI: http://dx.doi.org/10.1016/j.advengsoft.2013.12.007.

[8] Mahmoodzadeh, A., Nejati, H. R., Mohammadi, M., Ibrahim, H. H., Rashidi, S., and Rashid, T. A. (2022). *"Forecasting tunnel boring machine penetration rate using LSTM deep neural network optimized by grey wolf optimization algorithm"*. Journal of Expert Systems with Applications, 209: 118303. DOI: https://doi.org/10.1016/j.eswa.2022.118303.

[9] Astarita, V., Haghshenas, S. S., Guido, G., and Vitale, A. (2023). *"Developing new hybrid grey wolf optimization-based artificial neural network for predicting road crash severity"*. Transportation Engineering, 12: 100164. DOI: https://doi.org/10.1016/j.treng.2023.100164.