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Interpretable modeling of cutterhead torque in Earth Pressure Balance machines via Kolmogorov-Arnold networks

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ABSTRACT: Earth pressure balance (EPB) shield machines are preferred in tunnel excavation due to their adaptability and efficiency. Given dynamic geological conditions during tunnelling often cause fluctuations in the cutterhead torque, challenging numerical models. This study proposes a Kolmogorov-Arnold network (KAN) model to estimate cutterhead torque using operational EPB parameters. Moreover, KANs showed superiority compared to state-of-the-art methods while providing interpretability. Mutual information analysis is utilized for feature selection and the jellyfish search optimization algorithm is used to fine-tune KAN hyperparameters. This integration offers a robust and interpretable framework for real-time torque estimation, supporting a more adaptive tunnel excavation under geological conditions.

1 INTRODUCTION

Earth pressure balance (EPB) shield machines are prevalent in tunnel construction due to their strong adaptability, advance speed, and short interferences (Wan et al., 2024). Given a complex geological environment and sudden changes during excavation, the machine parameters should be adjusted to match driving and soil conditions (Kim et al., 2022). Among these, the operational parameters, the cutter torque is likely to exceed the rated value in changing geological driving conditions, and limit the values of cutter speed and thrust.

Several physical models and numerical simulations have demonstrated acceptable results on modelling operational EPB parameters; however, these fail in estimating these parameters under dynamic geological conditions during the tunnel excavation (Gao et al., 2025). Recent advances have considered artificial intelligence (AI) techniques that analyse the relationship among the operating variables to enable strong generalization capabilities. These features are suitable for uncertain conditions and fuzzy environments during tunnel excavation (Loy-Benitez et al., 2024).

Shielding machine parameters are influenced by rock mass conditions, machinery specifications, and working process (Erharter et al., 2025). These influences can be leveraged by soft-computing methods to estimate relevant parameters. Over the past decade, multilayer perceptron (MLP) models have been extensively utilized for integrated management systems, considering modelling, monitoring, and control in shielding machines. However, novel techniques have been recently introduced, adding interpretability to the models, allowing operators to understand the impact and influence of machine parameters over the cutterhead torque.

Recently, the Kolmogorov-Arnold networks (KAN) have been introduced as a novel neural approach in which the activation functions need to be learned, evidencing superior performances compared to the MLP in terms of model accuracy and interpretability (Liu et al., 2024). This study aims to introduce a KAN-based cutterhead torque model considering EPB operational parameters while adding interpretability in terms of the impact of each variable on the target. In addition, mutual information (MI) analysis is utilized to select the most relevant features to

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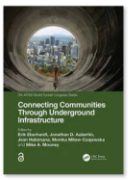

Chapter

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