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RESEARCH ARTICLE-CIVIL ENGINEERING

Real-Time Prediction of Disc Cutter Wear in Low-Abrasive Rocks: Integrating Physico-Mechanical Properties and Signal Processing Features Through Machine Learning Methods

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Abstract
Tunnel boring machine (TBM) is a popular choice for mechanical excavation due to its efficient, safe, and cost-effective tunnelling capabilities compared to traditional methods. One of the factors that can impact TBM performance is the wear of disc cutters. The wear of the cutting discs can lead to a reduction in their cutting ability, resulting in slower excavation rates, increased power consumption, and increased wear on other TBM components. In this research, sound and vibration signals, along with physical and mechanical characteristics, were used as a real-time method to determine disc wear during the cutting of low-abrasive rocks. For this purpose, the features extracted from the sound and vibration signals recorded during the cutting process were compared with the amount of disc wear. It was observed that with the progress of disc wear, the sound signal decreases, and the vibration increases. Finally, three machine learning methods, including decision tree (DT), random forest (RF), and extreme gradient boosting (XGBoost), were employed to analyse disc wear. The fivefold cross-validation approach was utilized to assess the predictive accuracy of the models. The XGBoost model achieved an R^2 value of 0.9424, making it the most accurate model for predicting the wear of the disc cutter. The DT and RF models attained an accuracy of $R^2 = 0.8379$ and $R^2 = 0.8941$, respectively. The method presented in this study can estimate the wear of the disc in real-time and suggest the right time to replace the disc.

Keywords TBM disc cutter · Signal Processing · Physio-mechanical Properties · Machine Learning · Real-time detection

1 Introduction

Land resources are becoming scarce in developed countries, and environmental protection requirements are increasing. It is necessary to avoid huge demolitions, reduce the impact of buildings and operations on inhabitants, and ensure high-quality urban development [1]. Tunnelling has become more advantageous due to urban transportation and underground space development requirements. Tunnel boring machines (TBMs) are popular for efficiently excavating long tunnels in various geological conditions. However, complex and varied geological conditions can affect their efficiency [2, 3]. TBMs are efficient and safe for excavation in many types of strata, such as soft, hard, and mixed strata [4]. TBMs are more accurate and safer than standard drilling and blasting methods. They also speed up the tunnel-building process [5, 6]. TBMs are commonly used in hydropower, mining, highway, and railway projects. Still, the construction time and cost of hard rock TBM tunnels are influenced by various factors such as rock parameters, machine specifications and operation, and TBM design [7, 8].

A disc cutter is a tool to break hard rocks in tunnel boring machines (TBMs). During the TBM cutting process, the disc cutter comes in contact with the hard rock and rolls and grinds it with the help of thrust and torque. Poor working conditions cause disc cutters to wear out easily, which is the primary cause of cutter failure. This leads to an increase in the energy consumption of TBM excavation and alterations to the fundamental laws and parameters of the tunnelling projects [9]. If worn-out cutters are not replaced promptly, it can reduce TBM utilization and advance rate, leading to increased project cost and downtime [10]. It is estimated that the usage and replacement of disc cutters account for over 33% of the project expenses and time spent on tunnelling

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