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Review

Breaking new ground: Opportunities and challenges in tunnel boring machine operations with integrated management systems and artificial intelligence

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ABSTRACT

Advances in tunnel boring machines (TBM) have leveraged applied artificial intelligence to promote sustainable and automatic tunneling construction. This paper highlights the significance of AI-based management subsystems for automatic TBM operations and presents recent key contributions in the field by identifying three key parallel subsystems: modeling, monitoring, and control. Moreover, each subsystem is evaluated from the standpoint of practical implications. In this context, specific challenges are identified, suggesting research paths that include integrated management systems, and encouraging further investigations into TBM automation by integrating the existing management subsystems from an operational perspective.

1. Introduction

Over the past century, a shift in the industrial revolution, combined with precipitous population growth, has intensified urbanization. Efforts are required to satisfy and ensure the demand for different urban services, including usable and potable water, safe public spaces, health services, efficient energy supply, food production, and effective means of transportation [1–3]. Moreover, with the growth of cities, road, and underground transportation development have become crucial to access while saving time. As a result, the field has positively impacted economic growth and social development [4].

Road infrastructures generally consist of bridges, highways, interchanges, roads, roundabouts, and tunnels. Tunneling has played a crucial role in transport development as it reduces cost, distance, and negative environmental consequences [5]. For instance, underground transportation has rapidly developed. It is preferred over other transportation means because it can reduce traffic congestion and alleviate vehicle exhaust pollution [6]. Accordingly, approximately 2.86 million people commute daily via subway in megacities such as Seoul. Meanwhile, the annual number of passengers averages between 2 and 11 million commuters per station, with 344 train stations and an underground coverage of >49% [7,8].

Moreover, tunneling has been utilized for various purposes, including water conveyance megaprojects for municipal water supply, industrial processes, irrigation, and even hydroelectric plant operation, thus allowing clean energy production [9]. Other tunnel services include sewage, pedestrian and bike access, and mining operations. In this context, the tunnel boring machine (TBM) has been preeminent in large-scale tunneling development as it is considered safe, efficient, environmentally friendly, and cost-effective; it can also maintain the stability of the surrounding rock mass [10]. Nevertheless, the effectiveness of the TBM operation is strongly sensitive to degradation by external factors, including uncertain geological conditions, groundwater flows, rock bursts, and high-stress ground [11].

Generally, overcoming problems during TBM-guided operation involves generating an immediate response by adjusting parameters under the guidance of the operator's experience. However, this may lead to excessive wear and abrasion of the cutters, degradation of tunneling efficiency, and machine blockage, negatively impacting additional project costs and delays [12]. In addition, significant parts of the TBM, such as the disc cutters, are particularly affected by poor tunneling performance and depend heavily on parameters such as cutter head (CHD) torque and thrust force. Similarly, TBM monitoring involves other issues, including detecting abnormal events, such as mud cake formation, and predicting cutter wear [13–15]. Therefore, proper and real-time management of TBM operations is required, which gives room

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