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Current status and future prospects of artificial intelligence (AI) application in pavement engineering

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ABSTRACT

In the field of pavement engineering, the introduction of artificial intelligence (AI) has replaced manual inspection as the main technology for highway disease detection and preventive maintenance in China. While AI has made significant progress, there are still challenges and limitations at this stage in terms of technical issues, such as pavement condition data collection and processing, as well as ethical issues. Meanwhile, AI technology is still developing and may be applied to more aspects of the pavement engineering field in the future, and these applications will provide more efficient and intelligent management methods for the pavement engineering field. The application of artificial intelligence (AI) in the field of pavement engineering has achieved some remarkable results with the continuous development of science and technology, and technical development has a wide range of prospects and potential. At the same time, we also need to note the related challenges, which require further technical development and practical verification.

KEYWORDS

Pavement engineering; Artificial intelligence; Machine learning algorithms; Decision-making autonomy; Data privacy leakage; Algorithmic decision-making

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Current AI Applications and Challenges

At the present stage, AI is mainly applied to the monitoring and maintenance aspects of highways in the field of pavement engineering [1]. Its applications include data acquisition, model building, and result analysis. The image, temperature, humidity, and other data about the pavement are collected through high-precision sensors and equipment such as drones and auto-detection vehicles. Machine learning and deep learning algorithms are utilized for the model building to assess the condition of the pavement [2]. Based on the condition assessment of the pavement, vehicle detection and tracking, pavement material analysis, and other information, AI technology can develop a reasonable maintenance program. AI can predict the life of the pavement and the trend of breakage and carry out maintenance in advance to avoid the expansion of breakage by mining and analyzing historical maintenance data [3].

AI has made significant progress in pavement monitoring and maintenance, but there are still some problems in the collection and processing of pavement condition data. At present, there is a lack of open and uniformly formatted road inspection databases to be used as the training set for deep learning algorithms; image data collected by equipment such as road maintenance vehicles is susceptible to light and other influences; there are noisy and low-quality images; the number of road monitoring data and images is often limited; there is a lack of deep learning algorithms for small data sets suitable for road maintenance data analysis [4]; current technology is still not mature enough in terms of data accuracy and precision; and the cost of pavement condition data collection is high [5]. In the future, it is necessary to build an open large database with a uniform format, improve the quality of road inspection data, develop machine learning algorithms for small data sets of road maintenance suitable for the characteristics of the industry, and develop general-purpose fast intelligent learning algorithms and platforms suitable for on-site maintenance, etc. It is also necessary to further study the cost-effectiveness of AI in pavement engineering, improve and optimize image processing, and promote the sustained development of automated pavement data collection technology to better support and serve road intelligent maintenance in the new era [4]. In addition to this, only a few studies have been conducted to further quantify the extent and severity of pavement distress through the results of pavement inspection and classification. Since quantitative research relies on the accuracy of the detection results, in order to further improve the accuracy of quantitative research, more and more research may be conducted in the future on fully automated pavement condition data acquisition, which utilizes algorithms to automatically detect, classify, and quantify pavement defects [6].

Since the emergence of AI, the debate on ethical issues has never ceased. In the field of pavement engineering, the ethical issues brought about by AI are mainly in the form of data privacy leakage as well as liability and safety confusion. Algorithmic decision-making is a very important technique for AI application in pavement engineering, which can perform tasks based on autonomous procedures with little need for human decision-making. Therefore, the decision-making autonomy, the complexity of algorithms, and the incompleteness of data can bring about product safety issues. Moreover, the algorithms and data of AI systems require specialized analytical skills and technical expertise, and poorly interpreted algorithms can lead to complex systems making incorrect decisions. As the complexity of the system increases, so does the risk. The attribution of responsibility for autonomous systems is unclear, and data users and administrators have not taken responsibility for privacy protection [7]. However, pavement engineering

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involves a large amount of sensitive data, such as topographic maps and traffic flow, and it is a challenge to protect privacy while utilizing the data. In view of these problems, in the future, it will be necessary to formulate appropriate regulations, use encryption to protect sensitive data, strengthen data security protection, and develop interpretable algorithms to increase the transparency of the decision-making process so that AI can be maximized in the field of pavement engineering.

Future AI Applications and Developments

In the future, the application of AI in pavement engineering will be more extensive and in-depth, especially in the fields of intelligent sensors and detection systems, automated construction and maintenance, intelligent traffic management systems, and environmental sustainability.

Intelligent sensors are an important tool for the combination of AI and pavement engineering. Intelligent sensors can monitor the pavement condition in real-time, including information on the condition of pavement materials, such as pavement breakage, cracks, and deformation; information on the operation status of the road, such as temperature, rainfall, and snow; and information on the status of the traffic flow, such as traffic flow and traveling loads. In the future, AI can be used to further improve the transmission efficiency of sensory information and the accuracy of data processing, to achieve data sharing between sensors and intelligent decision-making, and to provide data support for pavement inspection, maintenance, and traffic management.

The traffic flow status information provided by intelligent sensors can not only optimize traffic signal control but also achieve the optimal configuration of traffic flow, cope with the complex road traffic environment, and effectively avoid management loss of control and traffic congestion [8]. It can also help the automatic driving system perceive the surrounding environment and make road planning and decision-making easier. AI promotes the development of automatic driving technology through vehicle-road collaboration. In order to better promote the construction of automatic driving lanes, there is an urgent need to establish a road information management and analysis platform based on the Internet, cloud computing, and various AI algorithms in the future. In addition, with the development of autonomous driving technology, AI may further influence the design and construction of road engineering, for example, through high-precision measurements and non-destructive testing through self-driving vehicles [4].

At present, the detection automation of pavement construction has been realized, and the AI intelligent control terminal is embedded in the construction tools to complete the intelligent supervision of the whole process of mixing, transporting, spreading, and rolling in the asphalt construction, so as to realize the whole-area control of asphalt pavement construction, the real-time process of decision-making, the construction lifecycle on-line, the supervision and early warning, and the pavement quality of the traceability [9]. In the future, it is necessary to further optimize the intelligent operation and adaptive control of construction equipment automation detection and combine it with drones, self-driving cars, and other technologies for pavement construction services.

In the future, during real-time monitoring of pavement construction, AI can be used to detect the impact of the construction process on the environment in real-time, such as air quality, noise, etc., so as to facilitate the assessment and optimization of environmental quality. In addition, AI algorithms can be used to optimize pavement construction technology, pavement material selection, and the construction quality of pavement to enhance pavement performance (durability and reliability), thereby reducing the frequency of pavement construction, reducing the pollution in the environment, and achieving sustainable development of pavement construction and the environment.

These applications will bring more efficient and intelligent management methods to the pavement engineering field, improve inspection accuracy and efficiency, optimize traffic management, reduce accident rates, lower operating costs, and promote the transformation and upgrading of the pavement engineering field.

Disclosure statement

No potential conflict of interest was reported by the authors.

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