Planning and Control of Unmanned Transportation Systems Based on Monte Carlo Method

Abstract

With the development of mine intelligence, the efficiency and safety bottlenecks of the traditional transportation system in complex environments have become increasingly prominent. How to construct accurate and efficient vehicle and traffic flow models, realize the path planning and individual control of mine vehicles, and achieve the collaborative control and planning of mine vehicles are the three major difficulties in building mine intelligence. This plan intends to conduct research on three parts: unmanned mine vehicle and traffic flow modeling, vehicle planning and control, and the collaborative planning and control of mine vehicle clusters.

Background of the Project and Research Significance

Since the 21st century, due to the continuous growth of downstream consumption, the open-pit mining industry has gradually expanded. The challenges faced by traditional open-pit mining operations have become increasingly severe, with issues such as high transportation costs, frequent transportation accidents, and low vehicle dispatch efficiency being particularly prominent. Especially in the actual operation of open-pit mines, the costs of loading and transportation account for 16% and 37% of the total investment in the mines respectively, and the combined total exceeds 50% of the total cost[1]. Therefore, exploring automated transportation has become a key direction for reducing production costs and addressing labor shortages.

With the continuous improvement of hardware computing capabilities in recent years and the iterative progress of learning methods, intelligence has had a profound impact on the mining field[2]. Compared with traditional manual driving, unmanned driving technology has inherent advantages such as 24-hour uninterrupted operation, higher safety, and lower operating costs. In addition, through the comprehensive application of unmanned transportation systems, overall planning and real-time allocation of the optimal routes can improve the overall operational efficiency of the mines.

However, the development of mine unmanned driving systems still faces many challenges. In the actual working conditions of open-pit mines, mine vehicles often travel on unstructured roads, which have frequently changing slopes, large-angle turns, narrow and uneven pavements. These problems make traditional vehicle kinematics or dynamics models difficult to accurately and efficiently describe the movement characteristics of mining trucks[3]. At the same time, the complex dynamics system and frequent and intense changes in loads make the speed planning and tracking control of unmanned mining trucks more difficult. In addition, due to the changes in loading points and unloading points, as well as the collaboration of multiple equipment in the mines, the planning of the optimal path becomes extremely complex.

Therefore, how to ensure the accuracy and efficiency of the model, guarantee the robustness and reliability of the planning controller, and how to achieve the collaborative operation, intelligent path planning and real-time scheduling of different types of unmanned equipment remain key issues that the current mine unmanned driving control technology urgently needs to solve[4].

This study aims to explore the core issues of mine unmanned driving control, combined with the challenges in the actual mining environment, and design and optimize unmanned transportation systems that are adapted to complex environments. In particular, this study will focus on exploring how to construct precise and efficient mine vehicle and traffic flow models, and optimize existing technologies in path planning, trajectory tracking control, and multi-device collaboration by introducing Monte Carlo tree search(MCTS) and reinforcement learning methods.

A review of the current research status at home and abroad

In the field of vehicle mechanism models, they are typically divided into kinematic models and dynamic models. The kinematic models are simpler, but they have poor model matching accuracy in the case of high-speed vehicles. The dynamic models have more parameters and most of the parameters are difficult to accurately measure under different vehicle states[5]. Moreover, it is not realistic to consider all physical characteristics of the vehicle when modeling, and considering too many nonlinear factors may also lead to the collapse of the model. Using a combined model of data-driven models and physical models can solve many problems of pure physical models[3].

However, the vehicle model obtained using the data-driven method may be a nonlinear or black-box model. In the subsequent control module of the vehicle, the optimization solution of such models is usually quite complex. The introduction of MCTS brings convenience for the efficient solution of nonlinear models[6].

The multi-vehicle coordinated passage decision technology, as an important part of the multi-vehicle cooperative system, can be divided into centralized methods and distributed methods. The centralized method calculates the behavior of all vehicles by the central controller and can find the global optimal solution, but when the number of controlled vehicles increases, the computational cost significantly increases[7]. The distributed method includes methods based on reinforcement learning and game theory, etc.[8]. However, in general, these methods treat all vehicles as independent decision-makers with selfish nature and cannot converge to the global optimal solution[7]. Currently, research on unmanned vehicle multi-vehicle coordinated passage decision is mainly concentrated on structured road scenarios such as urban intersections and highway merging areas, while research on non-structured road scenarios such as open-pit mines is relatively scarce.

Research Objectives and Main Contents

During the study period, the main research contents are as follows: Firstly， for the driving system of unmanned mining trucks in open-pit mines, an efficient and precise mathematical model was established. This model strives to accurately reflect the complex terrain of the mine, dynamic traffic flow and environmental changes, and can achieve efficient real-time simulation and decision support while saving computing resources. Secondly, combined with the MCTS method, a control system meeting the actual working conditions of the mine was designed. The system will adapt to the dynamic changes and uncertainties in the mine environment, provide efficient real-time decision support in path planning and task scheduling, and ensure the robustness and adaptive ability of the unmanned mining trucks. Thirdly, A distributed multi-truck collaborative control system was designed and implemented to optimize the operational efficiency of multiple unmanned mining trucks in the mine. Through intelligent methods such as reinforcement learning, the collaborative operation ability between mines was enhanced, ensuring the optimization of task scheduling, resource allocation and traffic flow, and thereby improving the overall operational efficiency of the mine transportation system.

Research plan and technical approach

For the driving system of unmanned mining trucks in open-pit mines, a mathematical model combining machine learning and traditional dynamic models is designed. This model will accurately reflect the complex terrain of the mine, dynamic traffic flow and environmental changes, especially providing rapid decision support in the dynamic environment of the mine. Machine learning algorithms will be used to perform real-time optimization and adjustment of the traditional dynamic models, enhancing the system's ability to cope with complex environmental changes in the mine, while saving computing resources and improving the efficiency of real-time simulation and decision-making.

Combining the MCTS method, a control system for unmanned mining trucks that meets the requirements of complex mining conditions is designed. This system can respond to dynamic changes and uncertainties in the mine environment in real time, provide efficient real-time decision support in path planning and task scheduling, and ensure the robustness and adaptability of the mining truck. By simulating multiple decision paths, MCTS will provide the global optimal solution for the mining truck, especially suitable for the variable conditions in the mine environment.

Using reinforcement learning algorithms to optimize the collaborative operations between mining vehicles. By designing a reward mechanism adapted to the mine environment, the reinforcement learning model will continuously optimize task scheduling and resource allocation strategies through interaction with the environment, achieving efficient collaborative operations of multiple mining trucks and thereby improving the overall transportation efficiency.

Progress schedule and plan

January - June 2026: Literature review and problem analysis
July - December 2026: Data collection and simulation platform setup
January - June 2027: Research on mine car mathematical model and traffic flow model
July - December 2027: Design of mine car control system

January - June 2028: Construction and research of multi-vehicle collaborative mathematical model
July - December 2028: Research on multi-vehicle collaborative planning and strategies
January - June 2029: System integration and simulation testing
July - December 2029: Summary and thesis writing

Expected Outcomes and Innovation Points

A hybrid modeling method combining machine learning and traditional dynamic models is proposed for simulating the behavior of unmanned mining trucks in mines. By integrating machine learning with classical dynamic modeling, the computational efficiency is optimized while ensuring the accuracy of the model.

A real-time trajectory planning and optimization control system based on MCTS is designed, which can enable real-time decision-making and efficient operation of unmanned mining vehicles in complex mine environments.

A multi-vehicle collaborative operation optimization method based on reinforcement learning is proposed, which is used for task scheduling and resource allocation among unmanned mining vehicles, improving the overall operational efficiency of multiple unmanned mining vehicles in mines.

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Signature of the supervisor:

Date: