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Discussion

Future role of artificial intelligence in advancing transportation electrification

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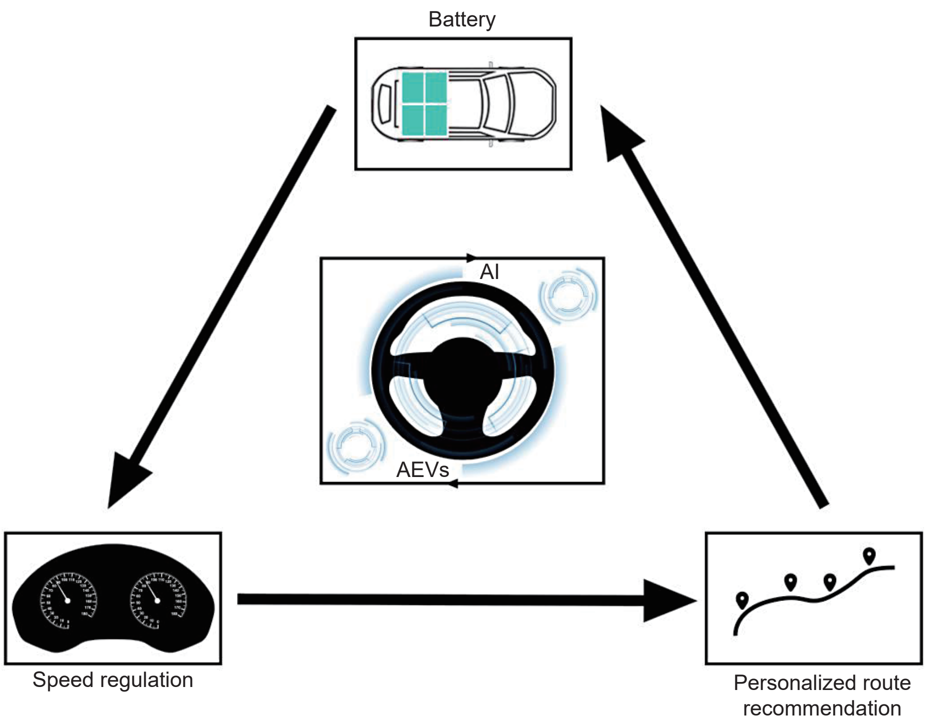
1 Introduction

Over the past decade, the rapid evolution of artificial intelligence (AI) has revolutionized various sectors, including transportation. This discussion explores the transformative potential of AI in enhancing transportation electrification, focusing on its role in battery management, vehicle speed regulation, and personalized route recommendations for Autonomous Electric Vehicles (AEVs).

AI's advancements have enabled breakthroughs in natural language processing, computer vision, and knowledge management, leading to innovations like AlphaGo, which proved AI's capability to surpass human expertise. In the transportation domain, the urgency to address environmental concerns and the need for sustainable solutions has spotlighted the significance of electric vehicles (EVs). As shown in Fig. 1, AI's integration promises to elevate EVs by optimizing battery health, ensuring energy-efficient speed controls using deep reinforcement learning, and providing personalized route recommendations that balance time efficiency with energy conservation.



Artificial Intelligence (AI) holds transformative potential in the field of transportation electrification, particularly in battery management, vehicle speed regulation, and personalized route recommendations for autonomous electric vehicles (AEVs). Utilizing deep reinforcement learning and big data analytics, AI aims to optimize battery health, enhance energy efficiency, and offer both energy-saving and personalized driving routes.

Fig. 1 Integration of AI in transportation electrification.

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At the battery level, AI-driven health-aware optimal control systems are being developed to predict and prevent premature battery degradation. By analyzing vast amounts of battery usage data, AI optimizes charging and discharging cycles, ensuring the battery's longevity and the vehicle's peak performance. In terms of speed regulation, deep reinforcement learning is employed to calibrate AEVs' speed settings, considering variables like traffic patterns, terrains, and battery health. This continuous learning ensures optimal energy utilization and passenger safety. Furthermore, AI's capability to analyze historical user patterns, current traffic dynamics, and road topographies allows for the recommendation of routes that are both personalized and energy-efficient.

Therefore, the fusion of AI with transportation electrification promises a future where transportation is not only environmentally friendly but also intelligently orchestrated. By harnessing AI's capabilities across battery management, vehicle speed regulation, and route recommendations, we are paving the way for a sustainable and tailored transportation experience.

2 Development of health-aware optimal control of battery system

Battery health is paramount in the realm of electric vehicles (EVs). A health-aware optimal control system, powered by AI, can predict and prevent premature battery degradation, ensuring the longevity and efficiency of batteries. Leveraging data-driven approaches, AI can analyze vast amounts of battery usage data to optimize charging and discharging cycles, ensuring the battery operates within optimal parameters (Vu et al., 2020). This not only extends the battery's life but also enhances the vehicle's overall performance. Hence, it is an emerging trend for electric vehicle development.

In health-aware optimal control of battery systems, AI plays a significant role in three aspects: predictive energy management, health-conscious strategy, and optimization of multiple objectives. Specifically, from the perspective of predictive energy management, AI (specifically model predictive control), is generally adopted to optimize the energy management of hybrid electric vehicles, which considers both the immediate energy needs and the long-term health of the battery and fuel cell system. By predicting future energy needs and adjusting energy distribution accordingly, the system can minimize energy waste and operating costs, and extend the lifespan of the battery and fuel cell (Kandidayeni et al., 2022). This makes electric vehicles more financially attractive to consumers and can accelerate their adoption (Hu et al., 2020).

Moreover, from the angle of health-conscious strategy, AI can be utilized to design a health-conscious battery system meaning that they are aware of the degradation of both fuel cell and battery. This awareness allows AI to make decisions that not only optimize immediate energy needs but also consider the long-term health and efficiency of the power sources.

Furthermore, from the point of optimizing multiple objectives, AI technology can be used to balance multiple objectives such as minimizing hydrogen consumption, reducing costs associated with fuel cell and battery degradation, and ensuring optimal vehicular performance (Gao et al., 2020). Due to the complex nature of multi-objective optimization, a sophisticated algorithm, such as AI, is essential to achieve ultimate optimization.

3 Advanced speed regulation in AEV leveraging deep reinforcement learning

Another pivotal advancement in the realm of transportation electrification, powered by AI, is the formulation of sophisticated speed control systems tailored for AEVs. Google Maps, a dominant force in the navigation service sector, boasts a staggering user base exceeding 1 billion active users every month. While mainstream users heavily rely on features such as the Estimated Time of Arrival (ETA) and intricate route planning, there is a discernible void when it comes to specialized services catering to AEV enthusiasts. A prime example of this shortfall is the absence of tools that offer energy consumption estimates for planned routes before embarking on a journey.

AEVs are not merely vehicles; they symbolize the next evolutionary leap in transportation. Deep Reinforcement Learning (DRL), an advanced branch of AI, is perfectly poised to calibrate the ideal speed settings for AEVs. This calibration takes into account a myriad of variables, from fluctuating traffic patterns and diverse terrains to the intricate nuances of battery health (Mohammadi et al., 2023). The inherent strength of DRL lies in its ability to perpetually assimilate knowledge from its surroundings. This continuous learning paradigm ensures that AEVs maintain an optimal speed, optimizing energy utilization while prioritizing passenger safety.

At the heart of this innovation is the meticulous design of estimators and controllers (Hang et al., 2022). These are anchored in the creation of battery models that are oriented towards control. By employing a structured approach, a harmonious equilibrium is struck between the precision of the models and the intricacies of electrochemical systems (Mohammadi et al., 2022). This leads to the inception of a multi-tiered estimation framework, underpinned by a set of assumptions that are fine-tuned for prevalent use cases. A significant emphasis during this phase is placed on analyzing error dynamics and ensuring impeccable tracking without deviations.

Incorporating data-driven predictive models for battery behavior, and factoring in elements like the topographical nuances of roads and surrounding traffic conditions, a DRL-centric vehicle speed control strategy emerges. This strategy is laser-focused on curtailing energy expenditure and mitigating battery wear and tear. The culmination of these efforts is the realization of outcomes that align with the Pareto optimality principle, ensuring the best possible results with given resources.

4 Personalized AEV destination prediction and route recommendation model

Navigating the intricate landscape of individual travel behaviors necessitates a profound understanding and meticulous modeling. Drawing upon advanced recommender system methodologies and the insights gleaned from recent research in location-based services, our approach bifurcates the process into three distinct yet interrelated phases: precise destination prediction, meticulous evaluation of route energy expenditure, and informed route suggestion. The overarching objective is to equip AEV users with routes that are meticulously tailored to align with both energy efficiency and individualized preferences.

Conventional navigation paradigms predominantly focus on delivering the Estimated Time of Arrival (ETA). However, the infusion of AI into this domain paves the way for a more nuanced metric: the Estimated Energy Consumption of Arrival (Raja et al., 2023). This avant-garde metric furnishes AEV users with routes that strike a harmonious balance between time efficiency and energy conservation. By harnessing the power of AI to dissect historical user patterns, current traffic dynamics, and intricate road topographies, we can proffer route suggestions that are not only personalized but also underscore energy optimization (Mohammadi et al., 2022, 2023; Raja et al., 2023). The integration of the 'Estimated Energy Consumption of Arrival' adds an essential dimension to this personalization. Incorporating the 'Estimated Energy Consumption of Arrival' into the AI-driven AEV experience unlocks several key advantages. Firstly, it facilitates energy efficiency optimization, reducing operating costs for users while promoting environmental sustainability by curbing unnecessary energy consumption. Secondly, it assures users of their AEV's range capabilities, eliminating range anxiety and enhancing the overall travel experience. Finally, by suggesting energy-efficient routes, it contributes to environmental impact reduction, aligning with sustainability objectives and promoting responsible transportation.

In the current rapidly evolving transportation landscape, users are no longer content with mere conveyance; they are in pursuit of a holistic experience. The predictive prowess and analytical depth of AI offer a unique opportunity to customize services for individual AEV users (Ibrahim and Jiang, 2021). Whether it is forecasting favored destinations rooted in historical patterns or suggesting ideal departure windows to maximize energy conservation, AI metamorphoses the AEV from a mere transportation medium to an astute personal travel concierge.

5 Conclusions

The convergence of AI and transportation electrification heralds a future where journeys are not only eco-friendly but also smartly orchestrated. This discussion delves into the exciting prospects of embedding AI into electrified transportation across three dimensions: the battery, the vehicle, and the route. At the battery level, pioneering projects are underway to develop advanced Battery Management Systems (BMSs) using data-driven methodologies. The goal is to harness AI's predictive capabilities to avert premature battery wear, thereby enhancing its lifespan and efficiency. By merging data-driven electrochemical battery models with deep reinforcement learning, we can craft energy-efficient speed profiles for AEVs. This ensures that vehicles operate within optimal safety parameters. On the route front, there is potential in leveraging AI to offer personalized destination predictions and route suggestions for AEV users. This not only enhances user experience but also ensures efficient energy consumption. AI's transformative potential in transportation is further amplified when insights from diverse domains like automatic control, electrochemistry, and deep reinforcement learning are amalgamated. Such a multidisciplinary approach promises a future where transportation is not merely electrified but is also smart and tailored to individual needs.

Declaration of competing interest

The authors have no competing interests to declare that are relevant to the content of this article.

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