

Research on Innovative Applications and Market Impacts of AI-Based Robotic Vacuum Cleaners

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Abstract: With the rapid advancement of smart home technology, artificial intelligence (AI) has gradually become the driving force to push the evolution of home appliances. The thesis focuses on analyzing the innovative applications of robotic vacuum cleaners and their practical outcomes of AI through the key technical areas of environmental sensing, path planning, human-machine interaction, and reinforcement learning. This study discussed using multi-sensor fusion technology to achieve obstacle recognition and ecological modelling, applying advanced algorithms to enhance cleaning efficiency, and incorporating natural language processing for voice command control. Furthermore, the thesis explores the application of reinforcement learning in dynamically adjusting cleaning routes. The research findings demonstrate that AI not only significantly enhances the intelligence of robotic vacuum cleaners but also drives product differentiation and comprehensive improvements in user experience. Finally, the thesis evaluates the future prospects of robotic vacuum cleaners within the smart home ecosystem based on market survey data and offers recommendations to address existing technical challenges. This work provides a reference framework for future technological innovation and market promotion of smart appliances through in-depth theoretical and practical analysis.

1 INTRODUCTION

In recent years, the global smart home appliance market has grown rapidly, and smart home products have increasingly gained more and more demand in households. Among the multitudinous smart home appliances, robotic vacuum cleaners as an essential segment have quickly gained consumers' favour due to their automated cleaning feature and convenience (Chataut et al., 2023). According to the latest statistics, the value of global smart home market has over \$155 billion, and robotic vacuum cleaner industry is growing at nearly \$3 billion annually (at an average compound annual growth rate of 2%), which is rapidly expanding its market share (Chataut, et al., 2023).

Breakthroughs in artificial intelligence (AI) have provided new insights and technical approaches for developing robotic vacuum cleaners. These devices have evolved from random cleaning patterns to intelligent decision-making based on multi-sensor fusion, path planning, and reinforcement learning,

showcasing the profound integration of AI into hardware products (Yanjie et al., 2024). Existing studies have largely focused on fundamental navigation and obstacle recognition. However, as user demands diversify and home environments grow more complex, there is increasing pressure for higher levels of robotic vacuum intelligence (Yanjie et al., 2024). While prior research has enhanced cleaning efficiency and user experience to some extent, challenges remain in dynamic environmental perception and personalized cleaning strategies.

The purpose of this paper is to explore innovative applications of AI in robotic vacuum cleaner field through an in-depth analysis from both technological and market perspectives. In terms of technical side, the implementation of environmental sensing, path planning, human-machine interaction, and reinforcement learning algorithms in robotic vacuum cleaners are discussed in the paper, and representative products such as Ecovacs X1 Omni and Xiaomi's Omni Robot Vacuum Pro are highlighted. On the market side, it examines how AI-driven

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differentiation, user experience enhancement, and ecosystem collaboration enable robotic vacuum cleaners to stand out amid intense competition. Combining literature reviews, case studies, and experimental reports, this research seeks to construct a systematic technical and market evaluation framework, revealing how technological advancements improve product performance and assessing their economic impact in practical applications.

The paper is divided into five sections. The first section introduces the research background, current state of the field, and main objectives. The second section delves into AI's innovative applications in robotic vacuum cleaners. The third section analyzes how these innovations influence the home appliance market. The fourth section proposes recommendations to address existing technological bottlenecks. The fifth and final section summarizes the research findings and discusses future development directions. This study not only holds theoretical significance but also provides practical value for advancing smart appliance technologies and their market applications.

Against the backdrop of an increasingly competitive global smart home appliance market, this research offers new technical insights for upgrading and transforming robotic vacuum cleaners. It also provides valuable references for related companies in product development, market promotion, and ecosystem construction. In the future, with the continued integration of emerging technologies such as AI, 5G communication, and big data, robotic vacuum cleaners might embrace even greater development opportunities.

2 AI AND INNOVATION APPLICATIONS OF ROBOTIC VACUUM CLEANERS

In the development of robotic vacuum cleaners, the integration of artificial intelligence provided necessary support and opportunity for advancing their intelligence and automation capabilities. In this section, AI applications in robotic vacuum cleaners will be detailed explored and focused on four key areas: environmental perception, path planning, human-machine interaction, and reinforcement learning.

2.1 Environmental Perception

Environmental perception technologies are the foundation of autonomous navigation and obstacle

avoidance functions in robotic vacuum cleaners' design. Currently, the mainstream realization methods rely on multi-sensor fusion techniques, incorporating tools such as Lidar, cameras, ultrasonic sensors, and infrared sensors (Megalingam et al., 2025). By collecting and analyzing data from these sensors, robotic vacuum cleaners can quickly construct indoor environment maps, and precisely identify and localize furniture, obstacles, and dynamic targets (Megalingam et al., 2025). For instance, the Ecovacs X1 Omni employs a dual-sensor system combining Lidar and high-definition cameras (Li, 2022). Such a feature of Omni significantly enhances the accuracy of environmental recognition and resilience against interference (Li, 2022). In terms of data processing, techniques such as filtering, feature extraction, and deep learning algorithms enable robots to detect path obstacles in complex environments in real time and dynamically adjust cleaning strategies (Ramalingam et al., 2021).

2.2 Path Planning

Efficient path planning is critical to improving the cleaning efficiency of robotic vacuum cleaners. Traditional cleaning algorithms often rely on predetermined and fixed rules or random paths, which may leave blind spots at home where not cleaned when facing complex household environments (Abdulsahab and Kadhim 2023). As techniques of optimization have been advanced, robotic vacuum cleaners now frequently employ path planning methods based on graph theory, genetic algorithms (GA), and ant colony optimization (ACO) (Abdulsahab and Kadhim 2023). By segmenting, analyzing, and reconstructing environmental (scanning) maps, robots can generate optimal cleaning paths, reduce redundant cleaning, and maximise coverage (Abdulsahab and Kadhim 2023). Some models also implement real-time path optimisation, using online data updates to respond immediately to changes in the home environment, thereby greatly improving overall cleaning efficiency (Abdulsahab and Kadhim 2023).

2.3 Human-Machine Interaction

Human-machine interaction (User experience) is increasingly emphasized as a crucial bridge between users and devices in modern smart home products (Yapici et al., 2022). Robotic vacuum cleaners rely on natural language processing (NLP) and voice recognition technologies to facilitate interaction (Wan et al., 2022). For example, Xiaomi's Omni

Robot Vacuum Pro features a built-in voice recognition module capable of understanding various accents and, through integrated NLP algorithms, quickly interpreting command intentions. This enables a range of operations such as remote control, scheduled cleaning, and zoned cleaning (XiaoMi n.d., 2025). Furthermore, deep integration with mobile apps allows users to monitor device status in real time, receive maintenance suggestions, and handle fault alerts-creating a highly intuitive and convenient interaction experience (XiaoMi, n.d., 2025; Tung and Campos 2021; Ge et al., 2023).

2.4 Reinforcement Learning

Reinforcement learning, a key method within machine learning, has gained widespread use in the field of robotic vacuum cleaners (Butaney 2024). Unlike traditional planning algorithms, the reinforcement learning technology could enable vacuum robots to autonomously learn optimal strategies through ongoing interactions with the surrounding environment (Li et al., 2024). For instance, the robotic vacuum cleaner could record areas that are frequently dirty in the home and use feedback from cleaning results to refine its intensity of path planning and cleaning. This results in intelligent, personalized cleaning strategies. Over time, the device not only adapts to changing conditions but also continually improves its performance, effectively becoming “smarter” with repeated use (Butaney, 2024).

2.5 New Technologies Exploring

In addition to these established technologies, the combination of edge computing and cloud data processing opens new possibilities for robotic vacuum cleaners (Dawarka and Bekaroo, 2022). By connecting and uploading some computational tasks to the cloud platforms, vacuum robots could receive real-time global data updates, therefore, could utilize big data analytics to achieve more precise environmental modelling and fault prediction (Dawarka and Bekaroo, 2022). Moreover, the widespread adoption of 5G technology promises faster data transmission speeds and lower latency and enhances robots’ responsiveness and cleaning efficiency in complex environments. In the future, more and more high-precision sensors and advanced intelligent algorithms will be introduced and driving robotic vacuum cleaners toward even higher levels of intelligence as sensor technologies continue to improve.

3 ANALYSIS OF MARKET IMPACT OF INNOVATIVE PRACTICES

With the deeper integration of artificial intelligence in robotic vacuum cleaner technology, the robot products have seen significant advancements in functionality, user experiences, and market competitiveness. This section will examine the market impact by discussing three dimensions: product differentiation, experience enhancement of users, and ecosystem synergy effects.

3.1 Product Differentiation

Traditional robotic vacuum cleaners typically offer limited functions, focusing primarily on simple cleaning tasks (Rui and Ying, 2025). However, with the introduction of artificial intelligence, the new generation of robotic vacuum cleaners now goes beyond traditional cleaning to deliver advanced smart features like providing “self-cleaning stations” and functionality of “auto-dust collection” (Li et al., 2023). These innovations could effectively address several challenges associated with traditional products. They have improved maintenance procedures, enhanced cleaning efficiency, and increased overall user convenience. At the same time, the advantage could enable vacuum robot products to stand out from the competitive market due to the empowerment of these technologies. Therefore, companies could create unique product positioning that caters to consumers’ growing expectations for advanced smart appliances, thus capturing a larger share of the increasingly competitive market by leveraging technological innovation.

3.2 Experience Enhancement of Users

User experience is a critical factor in determining whether household appliances successfully integrate into daily life. Vacuum Cleaners Robot installed with AI could provide users a more seamless and intuitive interactive experience with features like intelligent navigation, voice control, and remote monitoring (Ge et al., 2023). Consumers can remotely start or stop cleaning tasks via mobile apps, check device status and fault alerts timely manner, and even perform self-diagnostics and online maintenance (Ge et al., 2023). These user-centric designs not only improve operational efficiency but also strengthen brand trust and loyalty, contributing to positive word-of-mouth effects (Ge et al., 2023).

3.3 Ecosystem Synergy Effects

In the smart home ecosystem, interconnectivity among various devices has become a mainstream and popular trend (Rodriguez-Garcia et al., 2023). As a key node in the smart appliance category, robotic vacuum cleaners can integrate with platforms such as Tmall Genie and Google Home to enable features like voice control and scenario-based interactions (Li and Zhang, 2024). This multi-connection feature (synergy) not only enhances the product's added value but also creates a smarter, more convenient living environment for consumers (Li and Zhang, 2024). Companies can attract a wide range of partners, collectively establishing a multidimensional smart home ecosystem that spans lighting, security, and entertainment by developing open platforms and ecosystems. Such collaborative efforts drive innovation and sustainable development across the entire industry (Li and Zhang, 2024).

collaboration should be advanced to enable real-time data transmission and processing, increasing the robot's responsiveness to dynamic changes. Fourth, multi-model integration and online learning mechanisms should be introduced to continuously improve reinforcement learning algorithms, enhancing their convergence speed and adaptability, and ensuring optimal cleaning strategies even in evolving household conditions. Fifth, enterprises could establish a comprehensive user feedback platform to collect and analyze real-world usage issues and suggestions, therefore to provide firsthand data to guide their technological enhancements.

By implementing these initiatives, the robotic vacuum cleaner companies could achieve a higher level of intelligence and better meet consumers' diverse and personalised needs. Hence, the smart home industry would be driven toward a new stage of development.

4 RECOMMENDATIONS

Although the widespread application of artificial intelligence has brought numerous breakthroughs to the development of robotic vacuum cleaners, certain technical bottlenecks persist in practical implementation. Firstly, in complex home environments, these robots still experience a degree of missed spots and less-than-optimal path planning when faced with dynamic obstacles. While multi-sensor fusion has improved environmental recognition accuracy, further optimization is needed for real-time data processing and predictions in complex scenarios. Secondly, the stability and response speed of current voice recognition and natural language processing technologies under noisy conditions remain areas for improvement. Lastly, reinforcement learning algorithms can encounter slow convergence and overfitting issues over extended periods of use, limiting the further refinement of personalized cleaning strategies.

To address these challenges, this study makes the following recommendations. First, companies should strengthen cross-field collaborations with universities and research institutions to develop dynamic obstacle avoidance algorithms tailored to complex home environments. Second, while maintaining cost control, hardware configurations should be further optimized to enhance sensor precision and data processing capabilities, thereby improving overall environmental awareness. Third, leveraging edge computing and 5G technology, edge-cloud

5 CONCLUSION

This study provides a comprehensive analysis of the innovative applications of artificial intelligence in the robotic vacuum cleaner field, and in particular, focuses on the implementation and effectiveness of environmental perception, path planning, human-machine interaction, and reinforcement learning algorithms. The findings of this study are that robotic vacuum cleaners' autonomous navigation, obstacle avoidance, and cleaning efficiency could be significantly enhanced by effectively utilizing multi-sensor fusion, advanced algorithm optimization, and intelligent interaction systems. Moreover, the vacuum robot devices would perform and finish more precise and efficient cleaning tasks when continuously combining ongoing integration of edge computing and 5G technology support, as modern home environments are becoming increasingly complex and dynamic. On the market side, technological innovation could not only drive product differentiation but also greatly enhance users' experience and device intelligence, which contributes to the development of a broader smart home ecosystem.

In conclusion, robotic vacuum cleaners are on the brink of a new transformation powered by the combined advancements in artificial intelligence and 5G technology. In the face of drastic market competition, companies must continuously refine their technical approaches, promote cross-disciplinary collaboration deeply, and incorporate

emerging technologies such as big data and cloud computing to accelerate intelligent upgrades. In the future, AI-powered robotic vacuum cleaners are expected to evolve beyond being merely cleaning tools, and become integral components of a smart home ecosystem that delivers smarter, more convenient, and more efficient living experiences. The insights from this study also aim to offer valuable guidance for innovation and market expansion in other smart home appliances, heralding a future where intelligent living becomes increasingly universal and comprehensive.

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