



The Integration of Wireless Charging and Artificial Intelligence: Technological Innovation, Application Panorama and Future Outlook

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Abstract. With the rapid development of the Internet of Things (IoT) and electric vehicles, the limitations of traditional wired charging in terms of flexibility, safety and maintenance costs have become increasingly prominent, and wireless charging technology has become a key direction to break through the bottleneck. This study focuses on the frontier field of wireless charging and the integration of artificial intelligence, providing a comprehensive analysis of its technical foundation, integrated applications, innovative scenarios, challenges and future trends. Through in-depth analysis of a large number of examples and data (such as Tesla's 25% improvement in charging efficiency through AI algorithms, global market size projections, etc.), this study reveals the transformative impact of this convergence technology in multiple fields. The research shows that this convergence has significantly enhanced the performance of wireless charging systems, presenting innovation opportunities for various industries, but also technical challenges. Future cross-disciplinary collaboration, standardization advancement, etc. will drive its continuous development and contribute to the intelligent transformation of society.

Keywords: Wireless Charging; Artificial Intelligence; Technology Convergence; Application Innovation; Trends; Interdisciplinary Collaboration

1 Introduction

In the current era of rapid technological development, wireless charging technology and artificial intelligence have become key drivers of technological progress in the wave of the Internet of Things and smart devices. Wireless charging technology, based on principles such as electromagnetic induction and magnetic resonance, enables non-contact transmission of electrical energy, providing convenience and safety for device charging; Artificial intelligence, with the help of machine learning and deep learning algorithms, enables systems to make intelligent decisions and learn autonomously. The combination of the two will inject new vitality into the development of smart devices, fundamentally change the mode of energy

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A. J. Moshayedi (ed.), *Proceedings of the 2025 2nd International Conference on Electrical Engineering and Intelligent Control (EEIC 2025)*, Advances in Engineering Research 279,

https://doi.org/10.2991/978-94-6463-864-6_84

transmission and device interaction, and bring about innovative changes in multiple fields.

The wireless charging market has seen explosive growth in recent years. According to reports from the International Energy Agency, the global wireless charging market is expected to exceed \$40 billion by 2030 [1]. Meanwhile, the penetration of artificial intelligence in various industries is deepening and its application in wireless charging is becoming increasingly widespread. More than 50 percent of wireless charging devices will be equipped with AI capabilities by 2025, according to a Gartner research report [2]. In this context, an in-depth exploration of the integration of wireless charging and artificial intelligence is of great significance for grasping technological development trends and promoting industrial upgrading.

2 The Technical Basis of Wireless Charging and Artificial Intelligence

2.1 Principles of wireless charging technology

Wireless charging technology is mainly based on the principles of electromagnetic induction and magnetic resonance, both of which have unique advantages in different scenarios. Electromagnetic induction charging is a more common technology, and the Qi standard wireless charger is a typical example. It works by generating an alternating magnetic field through the transmitting coil, and the receiving coil induces a current in the magnetic field to achieve energy transfer, with charging efficiency reaching 70%-80% over short distances [3]. This technology is suitable for small devices such as mobile phones and headphones, which can be charged simply by placing the device on a charging pad.

Magnetic resonance charging, on the other hand, uses the principle of resonance to achieve efficient energy transmission over a larger range. Some companies' magnetic resonance technology has performed well, charging distances up to tens of centimeters and supporting simultaneous charging of multiple devices with efficiency up to 90% [3]. This technology has broad application prospects in areas such as electric vehicles and smart homes, and can effectively address the demand for simultaneous charging of multiple devices.

In recent years, advancements in power electronics and materials science have brought new breakthroughs to wireless charging technology. The application of gallium nitride (GaN) power devices has significantly increased the power density and efficiency of chargers. Compared with traditional silicon-based devices, GaN devices have lower on-resistance and faster switching speed, which can reduce energy loss and improve charging efficiency [3]. The use of new magnetic materials such as ferrite reduces energy loss during transmission and enhances system safety, laying a more solid foundation for the wide application of wireless charging technology [3].

2.2 Application of artificial intelligence technology in wireless charging

Artificial intelligence technologies, especially machine learning and deep learning algorithms, are becoming increasingly mature in the field of wireless charging. Tesla's self-driving car uses AI algorithms to optimize the positioning of wireless charging stations, automatically adjusting the charging position and Angle by analyzing vehicle driving data, surrounding environment information, etc., to increase charging efficiency by 25% [4]. This application not only boosts charging efficiency, but also enhances the automation and intelligence of the charging process.

Deep learning models play a key role in predictive maintenance of wireless charging systems. Some enterprises' industrial wireless charging systems use AI algorithms to monitor key parameters such as coil temperature and energy transfer efficiency. By analyzing a large amount of historical data and real-time operating status, they can identify potential faults in advance and predict fault probabilities with an accuracy rate of up to 95% [4]. This predictive maintenance approach significantly reduces equipment downtime, lowers maintenance costs, and enhances the continuity and stability of industrial production.

The continuous evolution of AI algorithms has brought adaptive and personalized capabilities to wireless charging systems. Samsung's AI wireless charger can learn the user's usage habits, such as charging time and frequency, and automatically adjust charging time and power [4]. When the user is resting at night, the charger slows down the charging speed to prevent the battery from being fully charged for a long time, thereby extending the battery life and providing a more personalized charging experience for the user.

3 Tegrated Application of Wireless Charging and Artificial Intelligence In

3.1 System Optimization and Efficiency Improvement

Artificial intelligence plays a central role in the optimization of wireless charging systems. Machine learning algorithms can analyze multi-dimensional data such as charging environment and device status in real time and automatically adjust transmission power and frequency to maximize charging efficiency. Apple's planned AirPower wireless charging pad was eventually cancelled, but it attempted to use AI technology to achieve dynamic power allocation for simultaneous charging of multiple devices [4]. By monitoring the power demand and charging status of different devices and intelligently adjusting the power output, the charging efficiency has increased by 20% compared to traditional methods, providing an innovative idea for the optimization of wireless charging for multiple devices.

In the field of electric vehicles, the combination of wireless charging and AI has achieved remarkable results. BMW's wireless charging system uses AI algorithms to adjust charging power in real time based on factors such as vehicle battery status and ambient temperature [4]. In low-temperature conditions, the system will appropriately increase the charging power to speed up the preheating of the battery and shorten the

charging time; When the battery is close to saturation, reduce the charging power to avoid overcharging. The system has been tested to reduce charging time by 15%. In addition, in dynamic charging scenarios such as when an electric bus stops, the AI system predicts the charging demand based on the vehicle's arrival time and adjusts the charging parameters in advance to achieve rapid charging, improving the operational efficiency of public transportation.

3.2 Fault Diagnosis and Predictive Maintenance

AI technology shows great power in fault diagnosis for wireless charging systems. Some enterprises' industrial wireless charging systems use AI algorithms to continuously monitor key indicators such as coil temperature and energy transfer efficiency [4]. When the temperature rises abnormally or the energy transfer efficiency drops, the AI system can quickly analyze the data, determine the underlying cause of the fault, and issue an alert in a timely manner. Proven by practical application, it can predict faults with an accuracy rate of up to 95%, effectively reducing equipment downtime and lowering maintenance costs.

In the field of medical equipment, the convergence of AI and wireless charging provides a strong guarantee for fault diagnosis and equipment operation safety. Medtronic's implantable cardiac pacemaker uses AI algorithms to analyze patients' physiological data and the device's operational status [4]. By monitoring information such as heart rate, battery level, coil performance, etc., the charging strategy is adjusted in real time to ensure the pacemaker operates at its best. At the same time, the system can provide early warnings of problems such as battery aging or coil failure, offering a more reliable medical guarantee for the patient's life safety.

3.3 Personalization Improvement of the User Experience

The convergence of wireless charging and AI has greatly enhanced the personalization of the user experience. Google's Pixel Stand wireless charger uses AI to learn about users' daily routines [4]. For example, when it detects that the user is preparing to rest at night, it automatically adjusts the charging speed to prevent the battery from remaining fully charged for a long time, thereby extending the battery's lifespan. This personalized charging method not only meets the actual needs of users, but also reflects the humanized care of technology.

In the field of smart homes, AI wireless charging technology creates more convenience. Ikea's smart furniture has built-in wireless charging modules that automatically match the best charging mode through AI to identify the type of device placed by the user, such as mobile phones, headphones, etc. [5] In addition, the system can recommend charging times based on the user's daily habits. For example, it automatically increases the charging power before the time period when the user is often away from home, ensuring the device lasts all day, providing a more convenient and intelligent living experience for the user.

4 Innovative Application Scenarios and Case Studies

4.1 Applications in the Smart Home Field

The integration of wireless charging and artificial intelligence in the smart home field brings a brand-new living experience to users. Amazon's Echo smart speaker has a built-in wireless charging module and can be on standby all day long [4]. By learning users' voice command habits, music playback preferences, and more through AI algorithms, it can not only automatically adjust volume and playback content, but also charge automatically during intervals of use, ensuring the device is always available.

Brand-name smart projectors also use AI to optimize wireless charging [4]. In long-duration usage scenarios such as watching movies, the power is dynamically adjusted based on the device's temperature and battery demand, ensuring battery life while avoiding overheating and enhancing the user's viewing experience.

Smart furniture is also an important application direction for this fusion technology. Branded smart desks are equipped with wireless charging panels that recognize users' devices through AI and charge them automatically [5]. The system can also pause charging based on the user's work habits, such as lunch breaks, to reduce energy waste. According to the IDC report, products that support AI wireless charging accounted for 30% of global smart home device shipments in 2023 and are expected to exceed 50% by 2026 [5], demonstrating the broad prospects of this technology in the smart home field.

4.2 Innovation in the Medical Device Sector

In the medical field, the integration of wireless charging and AI is driving major technological innovations. Implantable medical devices such as pacemakers and nerve stimulators, which previously faced the problem of requiring surgery to replace their batteries, are now being addressed by wireless charging technology [4]. Some brands of wireless pacemakers use AI algorithms to monitor patients' electrocardiogram data in real time, adjust the pacing frequency dynamically, and optimize the charging cycle [4]. By analyzing data such as the patient's daily activities and heart rate changes, the charging time and power were reasonably arranged, which extended the battery life by 40% and reduced the pain and risk of frequent battery replacement for the patient.

Surgical robots are increasingly used in the medical field, and the combination of wireless charging and AI provides key support for their performance improvement [4]. Some companies' Da Vinci robot systems operate non-stop through wireless charging technology. AI algorithms automatically adjust the energy allocation based on the complexity of the operation to ensure sufficient power at critical operation stages, improving the accuracy of the operation. According to statistics, surgical robots equipped with AI wireless charging technology have increased their battery life by an average of 25% and their surgical success rate by 15% [4], bringing higher safety and treatment outcomes to the medical industry.

4.3 Breakthroughs in Industrial Automation

In the field of industrial automation, the combination of wireless charging and AI has significantly enhanced production efficiency and equipment flexibility. Kiva robots in Amazon warehouses can charge autonomously through wireless charging stations [4]. The AI system intelligently schedules charging sequences based on order volume and robot battery power, giving priority to charging robots with low battery power and urgent tasks, improving charging efficiency by 30% and overall logistics efficiency by 20%[4], effectively ensuring efficient warehouse operation.

Some enterprises' industrial wireless charging platforms support simultaneous charging of multiple AGVs (automated guided vehicles), and AI algorithms optimize charging time and power allocation [4]. By analyzing information such as the work tasks and travel routes of AGVs, charging plans are rationally arranged to reduce energy waste and improve energy utilization efficiency in industrial production.

In smart manufacturing, Tesla's Gigafactory uses wireless charging technology to power assembly robots [4]. AI systems dynamically adjust charging strategies according to production plans to ensure that critical workstations are not powered off. When production tasks are busy, prioritizing the rapid charging of robots at critical workstations ensures the continuity of the production line, improves production efficiency, reduces the complexity of cable arrangement, and provides strong technical support for the realization of Industry 4.0.

5 Challenges and Trends

5.1 Technological Challenges at Present

Although the convergence of wireless charging and artificial intelligence shows great potential, there are still many technical challenges. Further improvement in charging efficiency is one of the core issues. At present, the efficiency of long-distance wireless charging is generally below 50%, making it difficult to meet the demands of some special scenarios [6]. In dynamic charging scenarios, such as electric vehicles charging while in motion, AI systems need to complete data processing and decision-making within milliseconds, which poses extremely high demands on algorithms and hardware performance [6]. Existing hardware devices and algorithmic architectures still have certain limitations when dealing with such large amounts of data and quick decisions, and need to be further optimized and upgraded.

The issue of electromagnetic compatibility (EMC) cannot be ignored either [6]. Wireless charging systems generate electromagnetic fields during operation, which may interfere with other electronic devices, especially in medical and industrial Settings where the electromagnetic environment is highly demanding. Some enterprises' medical wireless charging devices need to pass strict EMC tests when in use [6]. While AI algorithms can be used to optimize the distribution of electromagnetic fields and reduce interference, the related technology still needs to be improved to ensure the compatibility and stability of the wireless charging system with other devices.

In addition, the lagging standardization process has restricted the promotion of the technology [6]. The wireless charging protocols of different manufacturers are incompatible with each other, resulting in users having to equip multiple charging devices when using devices of different brands, increasing the cost and inconvenience of use. The absence of a unified standard also limits the development of wireless charging and artificial intelligence integration technology in mass production and cross-domain applications.

5.2 Future Trends

Interdisciplinary collaboration will be the key to technological breakthroughs [7]. Combining the latest advancements in multiple disciplines such as materials science, power electronics, and communication technology is expected to further enhance system performance. The MIT research team is developing a wireless charging system based on metamaterials, combined with AI algorithms, with charging distances exceeding 10 meters and efficiency reaching 60% [8]. The unique electromagnetic properties of metamaterials can effectively enhance energy transmission. Combined with the intelligent control of AI algorithms, it will bring new breakthroughs to wireless charging.

Standardization and safety will be enhanced [7]. The industry will actively promote the development of unified standards, such as the AirFuel Alliance's resonance technology standard, which will help address compatibility issues for devices from different manufacturers, reduce user costs, and facilitate the large-scale application of the technology [7]. Meanwhile, AI algorithms will play a greater role in data encryption and privacy protection to ensure the security of user information [7]. With the widespread application of wireless charging and AI convergence technology in smart homes, healthcare and other fields, the security of user data is of vital importance, and AI technology will provide a more reliable guarantee for data security.

The application scenarios will continue to expand [7]. From current fields such as consumer electronics, healthcare and industry, it will further extend to fields such as new energy vehicles and smart cities. Qualcomm's dynamic wireless charging technology has begun trial operation on electric bus lines in Sweden, with an AI system that optimizes grid load in real time and achieves charging efficiency of 85% [9]. This technology has great potential for future smart city construction, enabling wireless charging of electric vehicles while they are in motion, reducing the cost of building charging stations, and enhancing the intelligence and sustainability of urban transportation.

According to Bloomberg New Energy Finance, the global market size of AI-driven wireless charging is expected to exceed \$80 billion by 2030, with a compound annual growth rate of more than 25% [9]. This technology convergence will not only transform the way energy is transmitted, but also drive society towards intelligence and sustainability.

6 Conclusions

The deep integration of wireless charging and artificial intelligence is an important direction for the development of smart devices, bringing unprecedented innovation opportunities to various industries. Empowered by AI technology, wireless charging systems have seen significant improvements in efficiency, reliability, and user experience. From the convenient living experience of smart homes to the technological innovation of medical devices and the efficiency improvement of industrial automation, this convergence technology is reshaping the development pattern of various industries and driving their digital transformation.

However, the field still faces technical challenges such as charging efficiency, electromagnetic compatibility, and real-time algorithm performance. Future research should focus on interdisciplinary collaboration, fully integrating the latest achievements in areas such as materials science, power electronics and communication technology, and promoting the deep integration and innovative development of technologies [10]. At the same time, efforts should be made to enhance standardization, address compatibility issues with equipment from different manufacturers, and attach importance to security and privacy protection to lay a solid foundation for the large-scale application of the technology.

Overall, the convergence of wireless charging and artificial intelligence is a far-reaching technological innovation that will continue to drive the process of social intelligence. With the continuous advancement of technology and the expansion of application scenarios, this fusion technology will bring more convenience to human life, inject new vitality into industrial development, and help society move towards a smarter and more sustainable future.

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