

Research on wireless charging technology for in-flight drones

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Abstract. This article explores the development and application of wireless charging technology for unmanned aerial vehicles (UAVs), focusing on the principles and challenges of wireless charging via magnetic coupling. The paper reviews various wireless power transfer (WPT) methods such as electromagnetic induction, magnetic resonance and microwave transmission, discussing the advantages and limitations of each. The paper highlights the difficulties in improving charging efficiency, extending transmission distances and ensuring EMF safety. Using these principles, the thesis further explores the potential for future breakthroughs using new materials, intelligent control systems and advanced algorithms to improve the efficiency, safety and cost-effectiveness of wireless charging for UAVs. Insights gained from this research could provide significant support for the widespread use of drones in a variety of industries, including agriculture, logistics and military applications.

Keywords: wireless charging, UAVs, magnetic coupling, electromagnetic induction, charging efficiency, wireless power transfer

1. Introduction

The rapid advancement of unmanned aerial vehicle (UAV) technology has driven its applications beyond recreational and commercial logistics to critical domains such as precision agriculture, disaster response, surveillance, and national defense. However, the limited battery capacity of UAVs remains a significant bottleneck, curbing their operational range and endurance. Traditional wired charging methods are not only time-consuming but also introduce mechanical wear and dependency on human intervention, which can be impractical for UAVs requiring high mobility and continuous operation. To address these constraints, wireless charging has emerged as a transformative solution. By leveraging electromagnetic coupling technologies such as magnetic induction and resonance, wireless systems can transfer power without physical contact, enhancing operational flexibility and reliability. These systems eliminate the need for docking or manual connections, reducing wear on components and enabling UAVs to recharge in mid-air or while hovering. This paper explores the principles underpinning wireless charging technologies for UAVs, with a particular focus on magnetic coupling methods. It examines the latest advancements, evaluates current research efforts, and analyzes the technical and logistical challenges that must be overcome. Finally, it highlights emerging trends and innovations that could make wireless charging an indispensable component of UAV ecosystems in the near future.

2. Discussion

2.1. Concepts

Wireless charging technology, also known as Wireless Power Transfer (WPT), transfers electrical energy over distances through electromagnetic fields without the need for physical connections. As technologies such as smart devices and unmanned aerial vehicles (UAVs) continue to evolve, wireless charging demonstrates enormous potential, particularly in UAVs, where it significantly enhances endurance and convenience. Wang Qiang highlights that applying wireless charging to UAVs addresses multiple issues present in traditional wired methods, such as unstable connections and interface wear [1]. Wireless charging can be implemented via three primary methods: electromagnetic induction, electromagnetic resonance, and microwave transmission. Each method is suited for different applications depending on its efficiency and range.

In UAVs, wireless charging is especially critical. Conventional wired charging often suffers from issues such as cable interference, complex operation, and connector wear, limiting the efficiency and operational time of UAVs. By integrating wireless charging systems, UAVs can achieve automated docking and fast charging, boosting operational capabilities, especially in scenarios requiring minimal human intervention [2].

2.2. Fundamental principles

The core principle of wireless charging is electromagnetic coupling. The most common method is electromagnetic induction, based on Faraday's law of electromagnetic induction: a changing magnetic field generated by the transmitter's coil induces a current in the receiver's coil, enabling energy transfer. Liu Ming et al. state that while electromagnetic induction offers high efficiency, it requires close proximity and precise alignment between the transmitter and receiver, making it ideal for short-range, low-power devices [3].

Electromagnetic resonance is another technique that achieves energy transfer by tuning the resonance frequencies of the transmitter and receiver coils. Compared to electromagnetic induction, electromagnetic resonance is more tolerant of positional offsets, providing greater flexibility. Chen Xiaohua argues that in fields like robotics and automation, electromagnetic resonance significantly enhances charging efficiency and reduces dependency on precise alignment [4]. This flexibility makes it particularly suitable for UAV applications in dynamic environments.

Microwave transmission technology converts electrical energy into microwaves for long-distance transfer, which is then converted back to electricity by the receiver. Although microwave transmission enables longer distances, its low efficiency and safety concerns hinder widespread adoption. Li Bin suggests that while microwave transmission has theoretical potential—particularly for remote UAV charging—improving its efficiency and addressing radiation safety issues remains a technical challenge [5].

2.3. Advantages and disadvantages

Wireless charging technology has made significant advancements in recent years, especially in short-range and medium-range scenarios using electromagnetic induction and resonance.

Its main advantages include:

- 1) Convenience: Wireless charging eliminates the need for physical connections, avoiding repetitive plugging and unplugging. This is particularly advantageous for mobile devices like UAVs, which require high mobility [1,2].
- 2) Reduced Wear and Tear: Traditional wired charging can cause interface wear, especially in devices like UAVs that undergo frequent use.

Wireless charging, by transmitting power through the air, avoids this issue, thereby extending the lifespan of devices [3].

- 3) Enhanced Safety: Non-contact power transfer reduces risks such as poor connections or loose plugs, which could lead to electrical faults or fires [4].

However, wireless charging faces several challenges:

- 1) Efficiency: Despite its promise, current wireless charging technologies exhibit relatively low energy transfer efficiency, particularly over greater distances. This poses challenges for UAVs requiring efficient long-range charging [5,6].
- 2) Alignment Precision: Electromagnetic induction, in particular, demands precise alignment between the transmitter and receiver to maintain efficient power transfer. Even slight misalignments can cause a significant drop in efficiency, which is especially problematic in dynamic UAV charging environments [3].
- 3) Range Limitations: Most current technologies achieve high efficiency only over short or medium distances. Although microwave transmission enables long-range transfer, its efficiency and safety remain bottlenecks [5].

2.4. Future directions

The future of wireless charging in UAVs holds immense potential, but further optimization is needed. Wang Wei (2023) identifies three key areas for development: improving efficiency, extending transmission range, and enhancing system intelligence [1,6].

- 1) Boosting Efficiency: One of the most critical bottlenecks in wireless charging is its efficiency. To improve this, researchers can optimize the design of transmitters and receivers to enhance magnetic coupling. Additionally, utilizing advanced materials such as superconductors could reduce energy losses and further increase efficiency [2,7].
- 2) Extending Transmission Range: To enable long-range charging, researchers can focus on optimizing electromagnetic resonance and microwave transmission. Yang Chen argues that advancements in resonance frequency control could expand the effective range of electromagnetic resonance [8]. For microwave transmission, Li Xiaodong (2024) suggests that innovations in antenna design and frequency modulation could greatly enhance its applicability in UAV scenarios [5].
- 3) System Intelligence: Future wireless charging systems will become more intelligent, with real-time UAV monitoring and dynamic adjustment of charging strategies to maximize efficiency. Li Bin emphasizes that integrating smart control algorithms and automated calibration could enable systems to adapt to diverse UAV types and charging conditions [5,9].

- 4) Safety and Reliability: With the growing prevalence of wireless charging, safety concerns such as electromagnetic field exposure are increasingly prominent. Future systems could incorporate measures like electromagnetic shielding and better field intensity control to mitigate potential health risks [7].
- 5) Cost Reduction: The high cost of wireless charging systems remains a barrier to adoption. Standardization and large-scale production could lower manufacturing costs, making the technology more accessible [6].

3. Conclusion

Wireless charging technology offers a promising solution to enhance the efficiency and autonomy of unmanned aerial vehicles (UAVs), particularly in hovering applications. Unlike traditional wired methods, wireless charging eliminates the need for physical connections, reducing wear and improving mobility. Techniques such as electromagnetic induction, electromagnetic resonance, and microwave transmission each have their own advantages and limitations. Electromagnetic induction is efficient but requires precise alignment, while electromagnetic resonance offers more flexibility, though its range is limited. Microwave transmission can cover longer distances but suffers from low efficiency and safety concerns. Despite these challenges, wireless charging promises increased operational time, safety, and convenience for UAVs. It reduces downtime, mitigates connector wear, and supports continuous operations in dynamic environments like surveillance and search-and-rescue missions.

The future of wireless charging for UAVs lies in improving efficiency, extending range, and adapting to dynamic environments. Advances in materials and power transmission techniques will enhance energy transfer, while smarter control algorithms will optimize charging in real-time. With ongoing research into safety and cost reduction, wireless charging could soon become integral to UAV operations, offering greater autonomy and operational flexibility.

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