論文 / 著書情報
Article / Book Information

題目(和文)	IoT向けLEDベースの高性能・自動化光無線給電の開発
Title(English)	LED based high-performance and automatic optical wireless power transmission for IoT
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出典(和文)	学位:博士(工学), 学位授与機関:東京科学大学, 報告番号:甲第282号, 授与年月日:2025年3月26日, 学位の種別:課程博士, 審査員:宮本 智之,中村 健太郎,植之原 裕行,德田 崇,宮島 晋介,丸山 武男
Citation(English)	Degree:Doctor (Engineering), Conferring organization: Institute of Science Tokyo, Report number:甲第282号, Conferred date:2025/3/26, Degree Type:Course doctor, Examiner:,,,,,
学位種別(和文)	博士論文
Category(English)	Doctoral Thesis
種別(和文)	要約
Type(English)	Outline

論　文　要　約

LED based high-performance and automatic optical wireless power transmission for IoT

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With the rapid expansion of the Internet of Things (IoT), the demand for reliable, efficient, and maintenance-free power supply solutions has become increasingly critical. Traditional power delivery methods, such as wired connections and battery-based solutions, present significant challenges in terms of installation constraints, frequent maintenance, and environmental impact. Wireless power transmission (WPT) technologies offer a promising alternative, eliminating the need for direct physical connections and enabling flexible deployment of IoT devices. Among WPT techniques, optical wireless power transmission (OWPT) has emerged as a viable solution, offering high directivity, long-range power delivery, and no electromagnetic interference (EMI). However, conventional OWPT systems relying on laser-based power sources face stringent concerns, requiring complex regulatory compliance and additional safety mechanisms. In contrast, LED-based OWPT presents a safer and scalable alternative for IoT applications, leveraging the inherent advantages of LEDs in terms of safety, low cost , and ease of integration.

Despite its potential, current LED-OWPT systems suffer from key limitations that hinder their practical adoption in real-world applications. These challenges include (1) low power conversion efficiency, which restricts the total power delivered to IoT devices; (2) limited transmission distance due to beam divergence and optical losses; (3) the inability to autonomously track and power mobile devices in dynamic environments; and (4) the absence of a robust mechanism for powering multiple IoT devices in varied lighting conditions. Addressing these challenges is essential to unlocking the full potential of LED-OWPT for scalable and autonomous wireless power solutions. This dissertation proposes a series of innovations aimed at enhancing the efficiency, transmission range, and adaptability of LED-OWPT systems. The research is structured around four major advancements:

1. **Development of a high-efficiency LED-OWPT system**

A novel LED-array collimation scheme is introduced to maximize power output while maintaining a compact system footprint. The optical design optimizes lens selection and beam-shaping techniques to enhance irradiance at the receiver. The system's power output saturation phenomenon is analyzed, leading to an optimized 4-LED array configuration that achieves both high efficiency and high power output. Through simulation and experimental validation, it is demonstrated that the proposed system significantly improves energy conversion efficiency compared to conventional LED-OWPT setups.

2. **Enhancing transmission distance with an adaptive optical system**

To overcome the inherent transmission limitations of LED-OWPT, a multi-layer lens system with an adaptive auto-focus mechanism is designed. The proposed approach mitigates beam divergence and ensures a concentrated power delivery at distances beyond 3 m. By dynamically adjusting focal parameters in real time, the system maintains a stable energy flux at the receiver, effectively extending the operational range of LED-OWPT for practical IoT applications.

3. **Automatic tracking and power supply for mobile IoT device**

To facilitate seamless power transfer to moving IoT devices, an automatic beam aiming and tracking system is developed. The system integrates computer vision techniques, including OpenCV-based detection and convolutional neural network (CNN) models, to identify and track the photovoltaic receiver. Additionally, a dual-axis motorized reflector system is implemented to dynamically adjust the beam direction in response to target movements. To enhance tracking accuracy, a prediction algorithm incorporating Kalman filtering is employed, enabling real-time trajectory estimation and ensuring uninterrupted power supply to mobile objects. Experimental validation using a drone-based mobile IoT platform confirms the system's ability to sustain stable power delivery under dynamic conditions.

4. **Multi-device adaptive OWPT for varied environmental conditions**

The final research focus addresses the challenge of powering multiple IoT devices in diverse lighting environments. A hybrid detection mechanism incorporating retroreflector-based PV identification and optimized spot detection is introduced. Additionally, an adaptive power allocation strategy is implemented to ensure efficient energy distribution across multiple receivers. The system is designed to operate effectively under both illuminated and unilluminated conditions, enabling seamless day-night power delivery for large-scale IoT deployments. The experimental results demonstrate that the proposed LED-OWPT system can adaptively regulate power distribution, ensuring reliable operation of multiple devices in dynamic environments. Comprehensive experimental evaluations validate the effectiveness of the proposed advancements. The results indicate substantial improvements in power transfer efficiency, extended transmission distances, and enhanced tracking capabilities. The developed LED-OWPT system successfully addresses the core challenges of existing solutions, positioning it as a viable technology for future IoT applications requiring flexible, autonomous, and scalable wireless power delivery.

This research contributes to the advancement of LED-OWPT by providing a systematic framework for optimizing power efficiency, extending transmission distances, and enabling intelligent autonomous power management. The findings pave the way for the practical implementation of LED-OWPT in real-world IoT ecosystems, offering a sustainable and maintenance-free alternative to conventional power supply methods. Future work will explore further improvements in system miniaturization, efficiency, and integration with intelligent power management frameworks to enhance the scalability and adoption of LED-OWPT for next-generation IoT applications.