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Title(English)	A Study on Optical Wireless Power Transmission System and Its Photovoltaic Target Tracking Based on Differential Absorption Imaging
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論 文 要 旨

THESIS SUMMARY

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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

Among the wireless power transmission technologies, Optical Wireless Power Transmission (OWPT) has the strength of its directivity due to short-wavelength electromagnetic waves. Besides that, the opportunity is that the recent development of long-distance optical communication technologies will significantly impact the future OWPT. In this thesis, to maximize the value of OWPT, such strength and opportunity are focused on, OWPT intended for long-range and high-power is investigated.

There are many demonstration studies in OWPT. In one study, the range between the transmitter and the receiver is fixed, and the beam shape is predetermined. In another, the transmitter is fixed, and the receiver moves under control from the transmitter. However, in the real operation of OWPT, the transmitter must align its beam dynamically depending on the position and attitude of the receiver. To address this issue, a proposal of requirements for beam alignment and shaping based on a performance model of the general OWPT system is necessary. This thesis proposes a methodology to consolidate system-level requirements for beam alignment and shaping for general configurations of non-cooperative and cooperative OWPT systems. In the former configuration, the receiver is fixed, and the transmitter aligns its beam with the receiver. In the latter one, the transmitter and the receiver mutually align. The derived requirements for the non-cooperative model were generally much stronger than for the cooperative system, and the longer the distance to the receiver, the stronger these requirements were. Further relaxation of the system-level requirement of a cooperative OWPT system was realized with a module utilizing the fly-eye lens surrounded by reflective walls.

In traditional OWPT research, a photovoltaic device (PV) contained in the receiver was recognized by detecting its figure, outline, and specific marker through image processing. Trials have been reported as successful in certain conditions. However, recognition is reported to become unstable, especially when outdoor background illumination varies by weather or diurnally. This study proposes differential absorption imaging to recognize PV and estimate its position and attitude. Generally, PVs are semiconductors, such as Si or GaAs, and their light absorption changes rapidly within a narrow wavelength range, including their band gaps. On the other hand, compared with PV, the background illumination of the environment surrounding the PV is expected to be sufficiently flat in the above narrow wavelength range. By utilizing this inherent feature of PV, a more robust detection would be realizable than other methods using much more general features such as shapes or colors. Images are captured in both wavelengths which are strongly absorbed by the PV , and the one which is not. Then the unnecessary common background in these images is canceled in the differential image of these two, and the PV image is extracted from it. A concept-proof experiment was conducted, and the "detectability criteria" were defined as the accuracy requirements for the X and Y center coordinates and the area size derived from the system-level requirements study. The experiment was followed by exploiting a GaAs substrate exhibiting a diffuse reflection characteristic and a real thin-film GaAs PV with a non-diffuse one. Two infrared wavelengths 850nm and 940nm were utilized in the experiments. The "threshold equation" which holds at the threshold was derived and verified by experiments. Combined with the SNR discussions, the "detectable range" was defined as the performance limit of this image sensor.

Position estimation for both a stationary and a moving target was studied by utilizing stereo imagery, which is a scalable technology widely used in from small equipment to much larger systems. This method can directly generate the coordinates of the targets on the 2D plane. The results were not strongly affected by the target's attitude angle in the GaAs substrate experiments, whereas the results were quite different in the GaAs PV case. It is noted that direction estimation is not so affected as position estimation by the target's attitude angle. A condition, the "integrity measure", was defined to avoid inconsistencies between the center coordinates estimations by the left/right optical sensors. It

was suggested experimentally that the integrity measure is closely related to the detectability. The "integrity measure" rapidly converges when the exposure time of the image sensor exceeds a certain threshold, and this minimum exposure time depends on the target's attitude angle. When the target is non-diffuse, the reflection characteristic becomes sharp. Using this characteristic of the minimum exposure time, the target's attitude angles for the non-diffuse target were estimated with 10 degrees error within a range of approximately 60 degrees, including its normal. Three algorithms were evaluated to investigate tracking moving non-diffuse GaAs PV targets, and a score function based on the mean position estimation error over tracking was defined to compare the performances of the three algorithms.

A concept of operation for a cooperative OWPT system was proposed, and it was shown to be consistent with the requirements developed previously. Example of OWPT system disigns of various transmission rages are presented.

The models in the thesis depend on parameters in the simulations and experiments, and the values used in the analysis depend on the conditions and apparatus in the experiment study. Moreover, there would be an OWPT system that utilizes other PV materials. However, the methodologies in this thesis are general, and they easily derive new models and values accommodating a new experiment and its apparatus. The author hopes that the results in this thesis exhibit an advancement toward the practical implementation of the operational OWPT system.