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Model-free correction algorithm for wireless power transmission with adaptive optics system

Haijun Gu*, Jiaji Gu, Wei Liu, Xiaohui Zhao

Nanhu Road 5372, Changhun, Jilin Province 130012, China

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ABSTRACT

Adaptive optics (AO) is the most promising technique to compensate for wave-front distortions caused by atmospheric turbulence or other factors, and is widely used in astronomy observation, microscopy and other fields. The AO system is applied for the wireless power transmission (WPT) system to design a distortion correction solution in this paper. A laboratory-simulated optical link under many kinds of turbulence is implemented to propose and experimentally demonstrate the use of model-free correction algorithm as an elementary and efficient way to improve optical energy transfer efficiency in WPT system. The experimental results under different conditions show that the proposed PSO algorithm and SPGD have significantly improved the charging efficiency of the WPT system, which can increase about 37%.

1. Introduction

Wireless technologies have developed rapidly in recent years and have influenced societies in various fields. The reason for the rapid development of wireless technology is mainly due to the achievements of James Clerk Maxwell in the field of mathematics in 1864: Electromagnetic wave is a kind of energy carrier that can spread in space. Based on the research results obtained by James clerk Maxwell, we can apply this theory to energy transfer. In 1904, the establishment of the Wardenclyffe Tower symbolized the concept of wireless energy transfer from theory to reality. It also marked that Nikola Tesla became the originator of this field and had a representative work ”The transmission of electric energy without wires”, which introduced the new technology to people [1–3]. Thanks to Tesla's theory, we can use lasers to transmit electrical energy, ranging from a few centimeters to several kilometers, without the need for wires as a transmission medium [4].

When the laser is used as the energy source of a WPT system, the system has a limitation. Atmospheric turbulence exists in the atmosphere, and atmospheric turbulence is an important form of movement in the atmosphere. It significantly enhances the vertical and horizontal exchange of heat, moisture, and pollutants in the atmosphere, far more than the exchange strength of molecular motion. The existence of atmospheric turbulence has a certain interference on the transmission of energy in the atmosphere [5]. In order to improve the transmission efficiency of the WPT system, we need to suppress the impact of the environment. We try to add the adaptive optics (AO) system to the WPT system. The principle of AO is to improve the quality of the beam by correcting the wave front of the atmospheric turbulence, and then improve the efficiency of the energy transmission [6]. The system effectively reduces or even eliminates the effects of atmospheric turbulence, and shows the practicability and stability of the system in many applications [7,8]. In the AO system, a deformable mirror (DM) is generally used to compensate the aberration of the beam affected by atmospheric turbulence. Generally, Charge-coupled device (CCD) is used to measure the energy distribution and beam convergence at the

* Corresponding author.
E-mail addresses: ghyciom@163.com (H. Gu), gujj16@mails.jlu.edu.cn (J. Gu), liuvivi512@163.com (W. Liu), xhzhao@jlu.edu.cn (X. Zhao).

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receiving end of the WPT system. Based on the energy distribution gray image detected by CCD sensor, DM optimizes the energy distribution and the degree of beam convergence through model-free algorithm, and finally achieves the goal of improving WPT transmission efficiency [9,10]. In the traditional WPT system, when the atmospheric turbulence is large or the distance is long, the strong scintillation will have a great impact on the receiving end of the energy. Then, the WPT system based on the normal mode is often inefficient or even unable to work properly [11].

In order to reduce or counteract the effect of strong scintillation and atmospheric turbulence on CCD energy detection, we introduced the AO system to control the DM and used the control algorithm based on system performance indicators (such as SPGD algorithm) to offset the effect of environmental interference on energy transmission [12]. After introducing an sensor-less AO system into the WPT system, one of the key problems is to find a fast and effective optimization algorithm to optimize the energy distribution and convergence of the receiving end. SPGD algorithm is a kind of adaptive optics control system more application prospects of stochastic parallel optimization algorithm, it is at the same time perturbation stochastic approximation control algorithm based on adaptive optics correction technology, has the characteristics of easy implementation, all control circuit parallel computing [13].

As a model-free algorithm, SPGD algorithm is widely used in the field of adaptive optics. In this paper, we simulated a simulation environment and used the SPGD algorithm to correct the static atmospheric turbulence so as to improve the transmission efficiency of the WPT system. In addition, we have also compared the PSO algorithm with the SPGD algorithm. As an evolutionary algorithm, the PSO algorithm has the characteristics of rapid convergence. In addition, we have also compared the PSO algorithm with the SPGD algorithm. As an evolutionary algorithm, the PSO algorithm has the characteristics of rapid convergence [14]. In addition, different algorithms have different search strategies. The same algorithm has different time and success rate to achieve the target value under different parameters. Due to the characteristics of the SPGD algorithm, different parameters in the SPGD algorithm, such as the difference between the disturbance amplitude δ and the gain factor γ, have a great influence on the correction result of the final WPT system.

The following is an overview of this article: In Section 2, we introduced the components of the WPT system: laser sources, collimated laser beam expander, the sensor-less adaptive optic system and the solar panel. In Section 3, we introduced the principles of the SPGD algorithm and the PSO algorithm. In Section 4, we conducted several sets of simulation experiments to prove the effectiveness of the algorithm in improving WPT system performance, and analyzed the impact of different parameters on the WPT system. In Section 5, the conclusions of this paper are given.

2. System model

Fig. 1 presents a conceptual framework illustrating the WPT system which is low power requirement and ease of redeployment.

In WPT system model, the laser source is taken as part of energy supply emits a laser beam with a wavelength of 808 nm. However, the existence of the atmospheric turbulence generally affects the laser focus quality at the solar panel, and the charging efficiency is seriously affected. Therefore, to increase charging efficiency, we then utilize the Sensor-less AO system which has no wave-front sensor to compensate the phase aberrations [15]. After doing so, the degree of convergence has been improved. Charging efficiency is the most important metric for WPT system in which better charging efficiency means lower energy consumption. The second most important metric for WPT system is maximum output power P_m. On the basis of theoretical analysis and simulations, the charging efficiency of the above system is improved significantly, and the P_m can also be improved. Finally, the laser signal is received by solar panel.

2.1. Laser source

As an energy converter, lasers have many types of media, such as solids, gases, semiconductors, optical fibers, and dyes. In order to obtain a high peak power, the laser often uses a pulsed output and consumes a relatively large amount of power. Selecting a method at this time is very significant in keeping the input power constant. For WPT system, the choice of laser shall comply with the following principles: (1) high power conversion efficiency; (2) small beam divergence angle; (3) high transmitting power; (4) small size; (5) low price. Semiconductor lasers are inexpensive, with high power conversion efficiency (up to 70%), much higher than gas lasers and solid lasers (about 30%). Because of the stacked array structure composed of laser diode array, the semiconductor lasers can realize the laser output of each power level according to the need. Therefore, a semiconductor laser with a laser wavelength of 808 nm was used in this experiment.

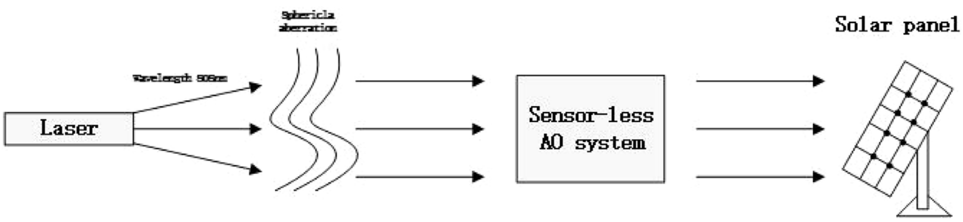

Fig. 1. Block diagram of the WPT system.