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Review

Swarm intelligence for atmospheric compensation in free space optical communication—Modified shuffled frog leaping algorithm

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ABSTRACT

A conventional adaptive optics (AO) system is widely used to compensate atmospheric turbulence in free space optical (FSO) communication systems, but wavefront measurements based on phase-conjugation principle are not desired under strong scintillation circumstances. In this study we propose a novel swarm intelligence optimization algorithm, which is called modified shuffled frog leaping algorithm (MSFL), to compensate the wavefront aberration. Simulation and experiments results show that MSFL algorithm performs well in the atmospheric compensation and it can increase the coupling efficiency in receiver terminal and significantly improve the performance of the FSO communication systems.

Contents

1. Introduction

A free space optical (FSO) communication system is widely used among the telecommunication community for both space and ground wireless link and last-mile applications [1] due to its unregulated spectrum, large bandwidth potential, relative low power requirement, low BER and ease of redeployment. However, atmospheric turbulence will bring phase disturbances along propagation paths that are manifested as intensity fluctuation (scintillation), beam wandering and beam broadening at the receiver, leading to significant decrease of coupling efficiency at the receiving terminal [2], which influences the stability and reliability of the FSO communication systems [3]. An adaptive optical (AO) system is an effective method to improve laser beam quality by correcting the wavefront aberration; it has already made great achievements [4–9]. In the conventional AO system, a deformable

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mirror (DM) is used to compensate the phase distortion. Generally, the Shack Hartmann wavefront sensor (S–H sensor) [10] measures the optical phase deviations of the incoming wavefront. DM generates a wavefront phase to compensate the phase aberration based on the phase conjugation theory [11,12].

Strong scintillation results in very difficult measurement for the wavefront aberration, and the conventional AO system based on wavefront measurement cannot work normally [13]; thus control of the wavefront correctors in the AO system can be conducted by using recently developed control algorithm based on optimization of a system performance metric, such as stochastic parallel gradient descent (SPGD) algorithm. Although the concept of wavefront control without wavefront measurement has been considered in the early stages of AO technology development [14–16], it has been largely disregarded because of the rather low control bandwidth that could be achieved even with a multi-dithering control technique [17,18]. But this situation has been largely different today because of the development of several novel technologies, for example, some efficient control algorithms whose implementation with parallel processing hard-ware, and the emergence of high-bandwidth wavefront correctors are based on microelectromechanical systems (MEMSs) [19].

Different from the traditional intelligent optimization algorithms, e.g. SPGD algorithm [13], swarm intelligence algorithms are novel optimized algorithms which imitate the natural biological group behaviors. Swarms are the systems that consist of many individuals which are organized and coordinated by principles of decentralized control, indirect communication, and self-organization. An interesting phenomenon of swarms is that collective swarm behavior can lead to a change on a global scale even one individual has only a restricted view. Examples for such collective behaviors are the nest building of ants or the coordinated movement of fish swarm [20]. The basic idea of swarm intelligence algorithms is using the solutions in the searching space as the individuals in nature. Take the "evolution and foraging process" as an analogy of the process of random search, the objective functions are equal to adaptive capability to natural environment. Consequently, based on the selection mechanism, replace a bad individual by a better one, make the individuals closer to the optimized solution, it can be considered as the iteration process of the random searching. It has been used in many fields such as artificial intelligence, robots and data analysis.

In this paper, we analyze the performance of the modified shuffled frog leaping (MSFL) algorithm in the FSO system. Particle swarm optimization (PSO) algorithm and SPGD algorithm are also simply introduced as comparisons. Related theoretical analysis and simulations indicate that MSFL algorithm increases the coupling efficiency at the receiving terminal, improve the performance of the FSO communication system, and some detailed differences between these algorithms due to their search strategies are worth researching. Because of the characters of MSFL algorithm, the effect of different individual-numbers and different group-numbers in MSFL is also important to the FSO system.

This paper is organized as follows: Section 2 provides the models of the FSO communication system, the sensorless AO system and DM. Section 3 analyses of MSFL algorithm related to the other two algorithms (PSO and SPGD) and their work principles in the FSO communication system is given. In Section 4, some simulations and experiments are carried out to show the comparisons of the improved performance of MSFL with other algorithms in the FSO communication system. In addition, the effect of different individual-numbers and group-numbers on the FSO system is analyzed. Finally, conclusions for this paper are given in Section 5.

2. System model

2.1. The FSO communication system model

The functional block diagram of the FSO communication system is shown in Fig. 1 [2].

The laser point source emits a Gaussian laser beam. The atmospheric disturbances reduce the fiber coupling efficiency at the receiver; the communication quality is seriously affected. The sensorless AO system is used here to compensate the wavefront aberrations. After compensation for the wavefront aberration, the laser beam is

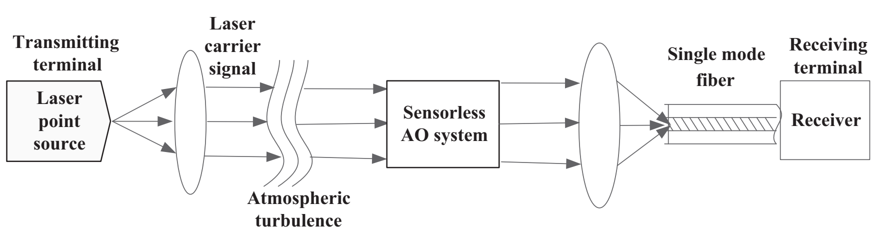

Fig. 1. Functional block diagram of the FSO system.

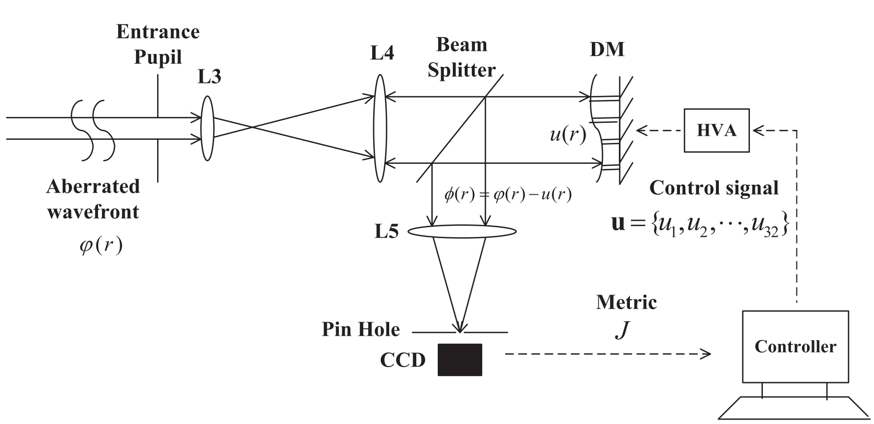

Fig. 2. Block diagram of simulation.