

Research on Wavefront Sensorless Correction Technique Based on Differential Evolution

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Abstract: Wavefront sensor-less adaptive optics is an alternative way for correcting the wavefront aberration distorted by atmospheric turbulence. Differential evolution (DE) is used to search the optimum mirror surface for the deformable mirror. An adaptive optics system with a 37-element DM based on DE algorithm is established. Numerical simulation results show that the algorithm can achieve good correction effect.

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Keywords: Adaptive optics, Differential evolution, Deformable mirror.

1. Introduction

Adaptive optics can be used for compensating aberration distorted by atmospheric turbulence. The conventional adaptive optical system [1] is composed of the wavefront sensor, the wavefront constructor and the wavefront corrector. In these systems, the wavefront sensor is used for measuring wavefront information [2-4], and the distorted wavefront is reconstructed by the wavefront constructor. Wavefront sensor-less techniques [5-6] provides an alternative way for compensating aberration. The operation of these systems is based on image sharpening. The image sharpening is used for evaluating the degree of correction of the wavefront aberration [7-8]. These systems use optimization algorithms to improve correction effect.

In this case, an appropriate optimization control algorithm is the key to correcting distorted wavefront successfully for this technique. DE is an evolutionary algorithm first proposed by Storn and Price [9]. It is very useful for global optimization problems [10-11].

Based on DE algorithm, the correction capability of the AO system is analyzed.

2. Description of AO system

Based on DE algorithm and fitness function, an adaptive optics system with a 37-element DM is established, shown in Fig. 1. The system includes a CCD that measures the light intensity, a control system including DE algorithm that searches the optimum mirror surface for driving a 37-element DM [12-13]. The correction course is controlled by DE algorithm and fitness function.

The actuators location distribution of a 37-element DM is introduced in Fig. 2 [13]. The layout of all actuators in DM is hexagonal.

We use the following equation as the fitness function [5]. The equation is examined in our system.

$$S_8 = \iint |I(x, y) - I_0(x, y)|^2 dx dy, \quad (1)$$

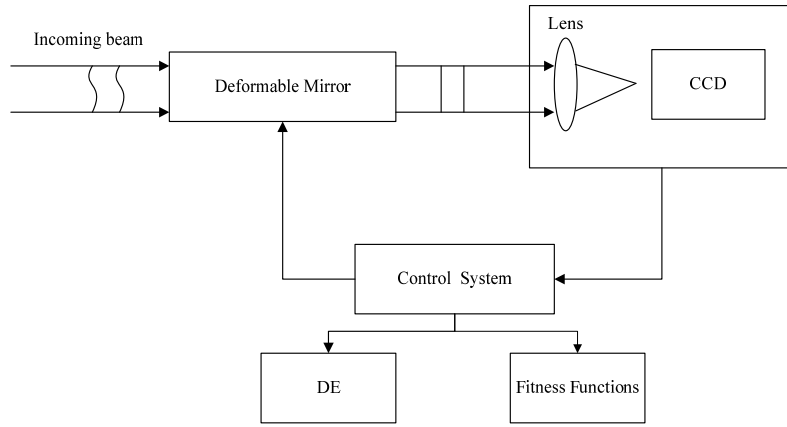


Fig. 1. Schematic diagram of the wavefront sensor-less adaptive optics system.

where $I(x, y)$ is the light intensity distribution of the incoming beam in the image plane, $I_0(x, y)$ is the ideal light distribution in the image plane. S_8 reduces to minimum when distortion is eliminated.

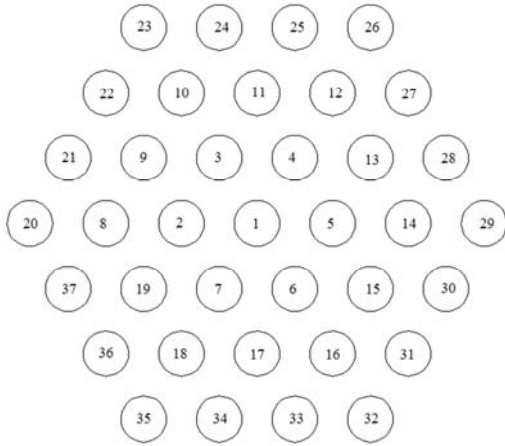


Fig. 2. Configuration of 37-element deformable mirror.

3. Differential Evolution

In wavefront sensor-less correction system, the optimal voltages of DM are solved by the intelligent optimization algorithm. The differential information is used to generate a new individual in DE algorithm [14]. The new individual is generated by two individuals added the weighted difference information. The objective function is used to evaluate the combination of the individuals.

The individual can be represented as $X = (x_{i1}, x_{i2}, \dots, x_{iD})$ ($i = 1, 2, \dots, N$) in the D dimensional space. The changed individual $V = (v_{i1}, v_{i2}, \dots, v_{iD})$ can be represented as the following equations:

$$V_i^{k+1} = X_a^k + w(X_b^k - X_c^k), \quad (2)$$

where a, b and c are integers 1 through N, i is different from them, w is a scale factor which is used to control the difference scale between two individuals, k is the current calculation step.

The parent and offspring with the given probability are crossed for generating the new individual $M = (m_{i1}, m_{i2}, \dots, m_{iD})$.

$$m_{ij}^{k+1} = \begin{cases} v_{ij}^{k+1}, & \text{rand}(j) < p \\ x_{ij}^k, & \text{Otherwise} \end{cases} \quad (3)$$

where $\text{rand}(j)$ is the random number in the range $[0,1]$, p is cross probability in the range $[0,1]$.

The parent X_i^k and the individual M_i^{k+1} are used for generating the offspring X_i^{k+1} using the following equations:

$$X_i^{k+1} = \begin{cases} M_i^{k+1}, & f(M_i^{k+1}) < f(X_i^k) \\ X_i^k, & \text{Otherwise} \end{cases}, \quad (4)$$

where f is the objective function.

4. Results and Analysis

DE is applied to the adaptive optics system with a 37-element DM. The initial individual consists of a group of random mirror voltages. For analyzing optimization ability, we also give corresponding fitness evolution curve. Fitness curve during the control algorithm's 500 iterations is presented in Fig. 3.

Fig. 4 shows the Zernike modal coefficients of fitting residual error after using DE algorithm to reconstruct the distorted wavefront. The modal coefficients of fitting residual error are close to 0, which indicates that the wavefront obtained by DE is very similar with the incident distorted wavefront.

We evaluated the reconstruction performance of DE through comparing with the target. Fig. 5 shows one result of the wavefront reconstruction. The reconstructed wavefront by using DE has only a small difference with the target, and the residual root

mean square (RMS) of the reconstructed wavefront is equal to 0.037λ (the relative error of about 16.0 %). Experimental result indicates that DE is validated to perform well for wavefront reconstruction.

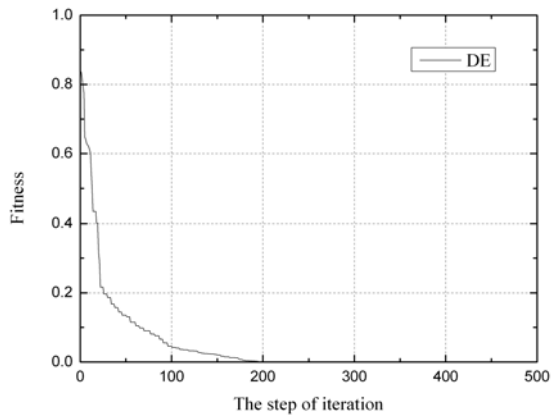


Fig. 3. Fitness evolution curve of DE algorithm in iterative process.

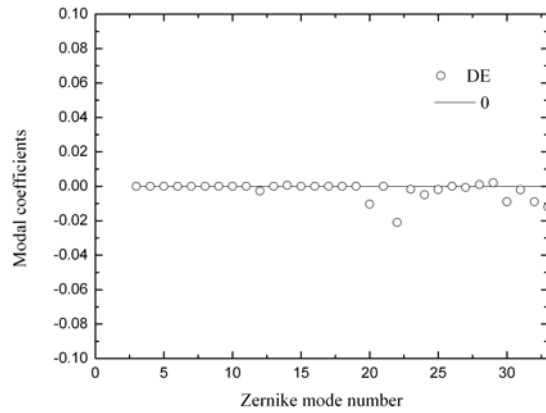


Fig. 4. Modal coefficients of residual error based on DE.

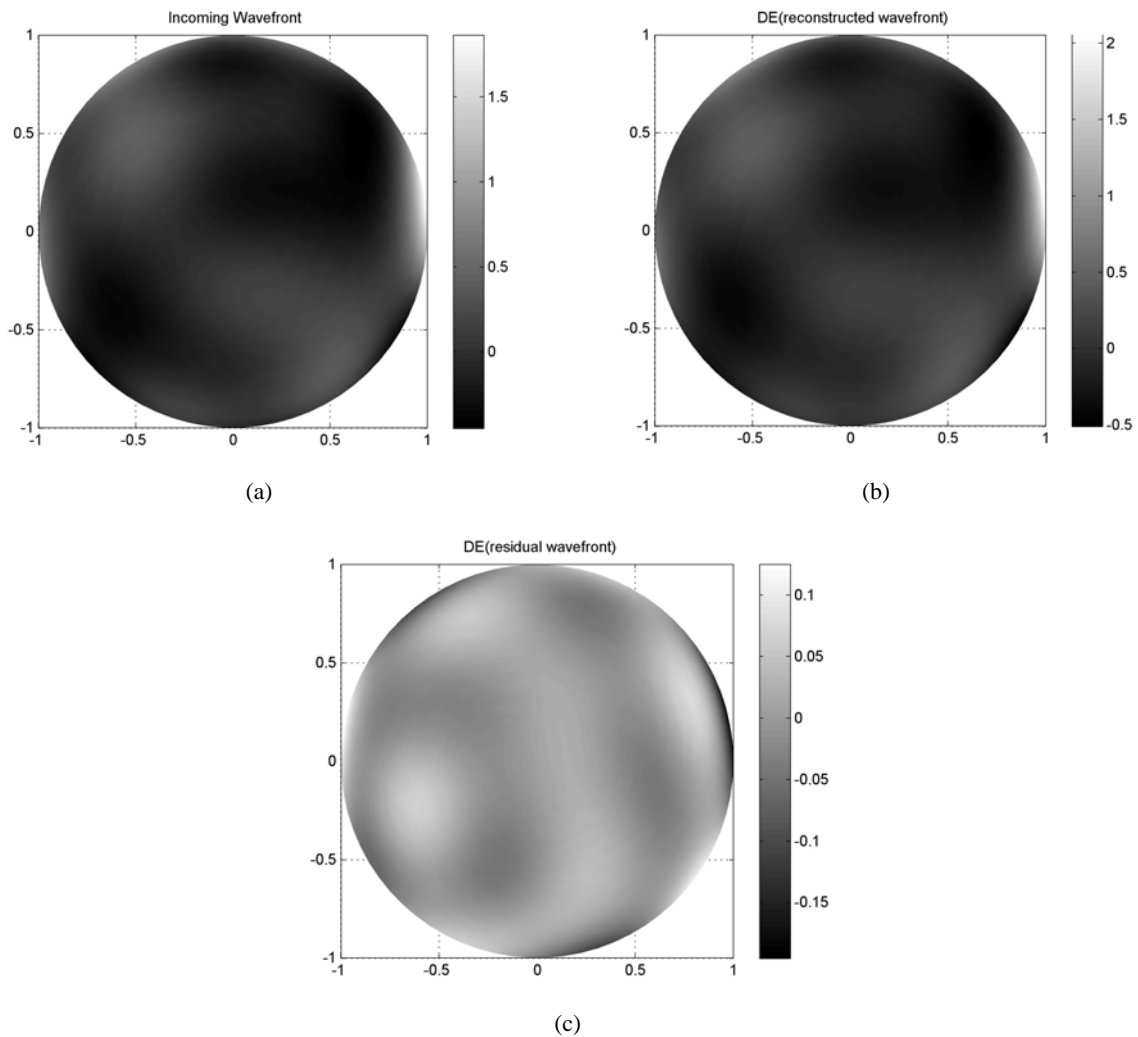


Fig. 5. A result of the wavefront reconstruction with DE algorithm.

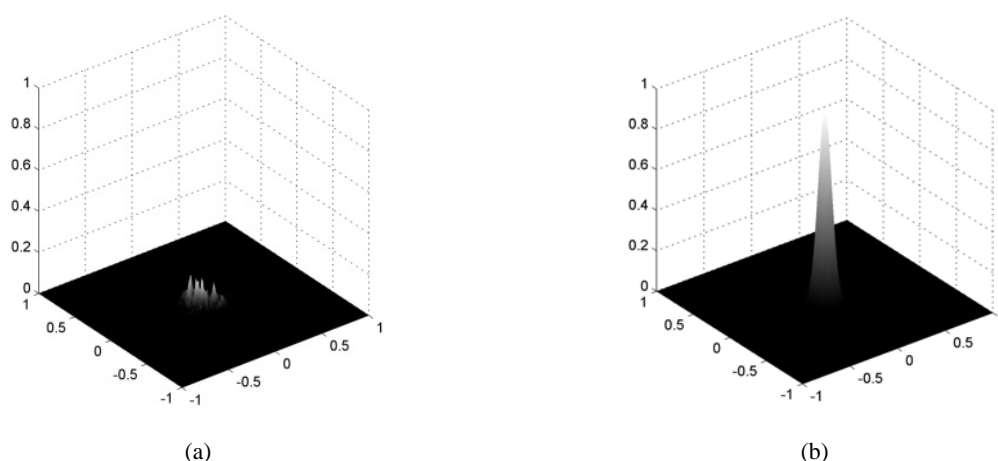


Fig. 6. (a) Light intensity distribution before correction, (b) light intensity distribution after correction with DE.

Strehl ratio (SR) is used to evaluate the imaging quality of the system. Fig. 6 shows light intensity distribution. We can see SR is 0.1 before correction, and SR is 0.961 after correction with DE. Results show that the DE algorithm can obtain good correction effect.

5. Conclusions

The principle of DE algorithm and its applications in adaptive optics system are introduced. The adaptive optics system based on DE can compensate aberration caused by turbulence successfully. To speed the convergence of DE algorithm and save the operating time, the algorithm will be realized through parallelism technique.

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