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Adaptive merit function in SPGD algorithm for beam combining*

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The beam pointing is the most crucial issue for beam combining to achieve high energy laser output. In order to meet the turbulence situation, a beam pointing method that cooperates with the stochastic parallel gradient descent (SPGD) algorithm is proposed. The power-in-the-bucket (*PIB*) is chosen as the merit function, and its radius changes gradually during the correction process. The linear radius and the exponential radius are simulated. The results show that the exponential radius has great promise for beam pointing.

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Beam combining is an effective technology for achieving high energy laser output[1-3], and the system would go through random disturbance as well as the dynamic turbulence. The precise beam pointing is the most crucial issue in the combining technology. Many devices and methods have been proposed to solve the beam pointing, such as the fast steering mirror (FSM)[4] and the adaptive fiber optics collimator (AFOC)[5]. Among all of the instruments, FSM is the most promising instrument for beam combining and laser communication[6,7]. The target-in-the-loop (TIL) configuration is widely used in the combining system[4,8]. A device mounted in the transmitting plane or the receiving plane is used to get the feedback signal. Then the optimized algorithm is applied to accomplish the beam pointing process. Among all the algorithms, stochastic parallel gradient descent (SPGD) algorithm has received a lot of attentions due to faster convergence speed and high bandwidth. A serial of improvements has been considered[9-11]. However, the algorithm still has some problems in the application of the beam combining. The chosen of the merit function remains a crucial issue for such a circumstance. In this paper, an adaptive merit function for the SPGD algorithm is proposed and verified. The merit function changes when the correction process is operated. The simulation result shows that consequence of the beam combining is not acceptable when the merit function is fixed during the correction process. On the contrary, the adaptive merit function is promising for achieving satisfactory result.

The merit function which can be used for beam pointing during the combining process can be arbitrary function with an extremum when the correction process is ideal. The power-in-the-bucket (*PIB*) is proper for beam combining for it stands for the total energy inside a circle. The radius of the circle is fixed during the correction process for most applications. However, we propose a method in which the radius of the circle is variable with different weights. The simulation results show that the adaptive merit function can achieve faster convergence speed and more promising result compared with the conventional algorithm. Besides, the adaptive merit function is also suitable for the situation in which the system would go through random jitter and atmospheric turbulence.

The steps of the adaptive merit function can be described as:

1) Set a group of initial control parameters $\{c_i\}$.

2) Generate a group of small perturbations $\{\delta c_i\}$ that satisfy the Bernoulli probability distribution with zero mean.

3) Apply the perturbations on the control parameters to get the merit functions (*PIB*) as $J(c_1+\delta c_1, c_2+\delta c_2, \ldots, c_N+\delta c_N)$ and $J(c_1-\delta c_1, c_2-\delta c_2, \ldots, c_N-\delta c_N)$.

4) Evaluate the gradient using the approximate formula and update the control parameters as

$$c_i^{(n+1)}=c_i^{(n)}+\gamma\delta c_i[J(c_1+\delta c_1, c_2+\delta c_2, \ldots, c_N+\delta c_N)-J(c_1-\delta c_1, c_2-\delta c_2, \ldots, c_N-\delta c_N)],\ i=1,2,\ldots,N, \quad (1)$$

where n stands for the iterative number, and γ represents

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the gain coefficient of the SPGD algorithm.

5) Update the radius of the merit function (*PIB*).

6) If the control parameters don't satisfy the requirement, go to step 2) and repeat steps 2)—5).

The conventional SPGD algorithm which fixes the radius of the merit function can cause difficulties in real applications. The size of light spot can expand, and the light spots of all the beams can not be arranged regularly because of the turbulence. Then the radius of the merit function is tough to choose. When the radius is big, the *PIB* can remain at high level thus making the correction hard to converge. Otherwise, a small radius can also cause non-convergence as well. The proper radius cannot be derived through analytical method because the turbulence remains unknown and keeps changing in the real application. The adaptive merit function doesn't need to choose the radius in advance. Instead, a proper range of radius is chosen as the parameter of the merit function.

The *PIB* values with different radii during the correction process using the conventional algorithm is illustrated in Fig.1(a). Fig.1(b) shows the intensity in the axis during the correction process with different radii. The insets of Fig.1(a) and (b) are the partial enlarged view of the curves near the x-axis. The correction process with small radius cannot combine the light spot. However, the correction process with big radius still cannot achieve promising result according to Fig.1(b).

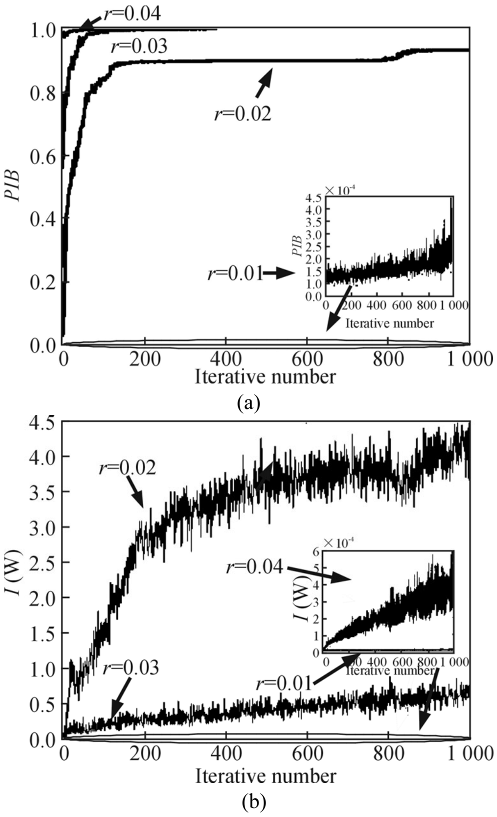

Fig.1 (a) The *PIB* curves and (b) the intensity in the axis during the correction process with different radii

The radius of the merit function is updated with different weights in this paper, including the linear weight, the quadratic weight and the exponential weight.

The radius with linear weight can be written as

$$r = a \times k + b , \tag{2}$$

where a and b are the coefficients which control the values in the beginning and at the end, and k is the iterative number. The *PIB* curve during the correction process is illustrated in Fig.2(a). Fig.2(b) shows the intensity in the axis during the correction process. It can be inferred from Fig.2(b) that the correction can achieve a promising result.

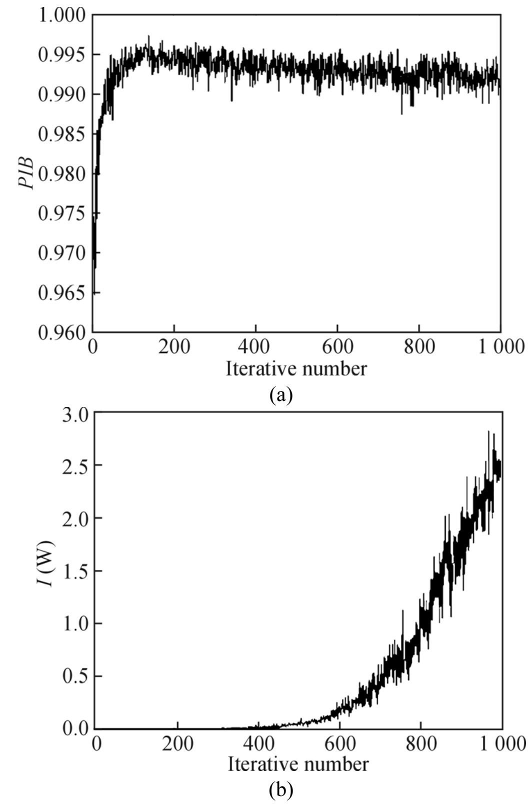

Fig.2 (a) The *PIB* curve and (b) the intensity in the axis during the correction process with the linear radius

The combining effect is shown in Fig.3. It can be seen from Fig.3 that the six light spots emerge and become one light spot under the correction, and the light spot in Fig.3(b) has some flares due to the atmospheric turbulence.

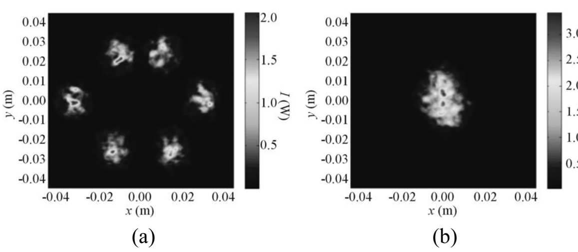

Fig.3 The intensity distributions in the target plane when the correction process using linear radius is (a) begun and (b) done

The radius with the exponential weight can be expressed as

$$r = a \cdot \exp(-k) + b, \quad (3)$$

where a and b are the coefficients which control the initial and last values of radius, respectively, and k is the iterative number.

Fig.4 shows the *PIB* curve and intensity in the axis during the correction process. It can be obtained by comparing Fig.4(b) with Fig.2(b) that the exponential weight achieves a better correction result than the linear weight.

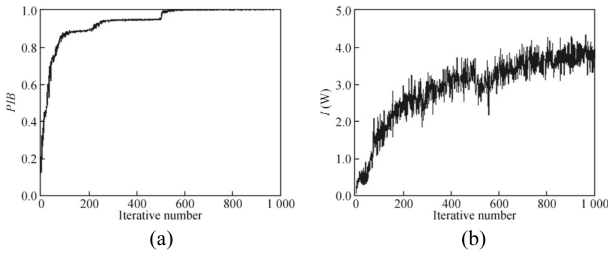

Fig.4 (a) The PIB curve and (b) the intensity in the axis during the correction process with the exponential radius

Fig.5 shows the intensity distribution after correction using the exponential radius. The radius of the light spot is much smaller which indicates that the adaptive merit function is beneficial to the correction of beam steering in beam combining.

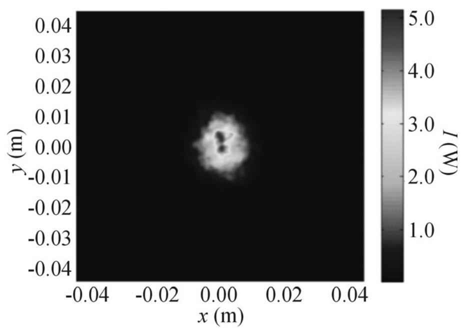

Fig.5 The intensity distribution in the target plane when the correction process using the exponential radius is done

In this paper, an adaptive merit function for the SPGD algorithm is proposed and tested. The adaptive merit function can ease the difficulties in choosing the proper parameter of the merit function. The simulation results show the great promise of this method. The result using exponential radius is better than that using linear radius in the simulation. The radius of the light spot in the target plane is reduced efficiently when the exponential radius is applied. This method can be utilized when the turbulence exists in the system.

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