A Study on the Sync Guidance of the Multi-Lasers with the Micro-Vision

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Abstract: In the application of the multi-beam laser accumulation for high energy, it is a key technology to guide the lasers into a micro area precisely and quickly. This paper proposes a laser spot identify and laser track sync control method, with the micro-vision feedback, parameterizing the laser spot based on the spot's counter characteristics. At the same time, the method is optimized in identifying the mass center and distinguishing the overlapped areas for the laser spots. The distributed method is verified by simulation and experiments. Compared with existing method, the sync control one guides lasers as the same precision but is 4 time higher efficiency under a 4 beam lasers experimental result.

Key Words: Multi-Laser, Micro-Vision, Image Identification, Track Synchronous Guidance

1 INTRODUCTION

Since laser has high energy, precise direction and high uniformity, it has been widely used in military, medical treatment, and manufacturing etc. Now, non-traditional manufacturing is a research hotspot based on ultra-high energy laser [1,2]. In accomplish welding of special materials and 3-D printing field [3], multi-beams lasers are used to focus on a micro point for releasing a high energy instantly in a unit volume. In practice, a key technology is how to sight on the micro target of the multi-beam lasers at the same time efficiency and precision. For example, reference [4,5] proposes a special experimental systems by focusing almost a hundred beams of high energy lasers in a 10 mm diameter cylindrical cavity to produce megajoule energy within 1 millisecond. The whole guidance time of the laser is more than 1 hour.

For the alignment of multi-beam of lasers, laser tracks are normally automatically aligned with positioning laser (low energy, high lighting laser) for saving energy. In practice, a micro-vision system is designed as the feedback, and a complicated automatic control algorithm is designed based on the laser spot contour in the image, so that a servo system guides the laser track automatically. Traditional method [6,7] can guide only one laser at once with a very low efficiency, although the system works automatically. It is a key to identify and control the track of the multi beam lasers at the same time for increasing guiding efficiency [8].

The aim of this study is to develop a novel sync control approach for multi-beam lasers. An experimental setup of guiding lasers synchronously based on vision feedback is developed. Combining the contour feature of the positioning laser spot in the micro-vision feedback, it is parameterized as a vector to describe the laser guidance. A sync control method with the changing parameters of the laser vector is developed. The method realizes the recognition of multi-beam laser spots and synchronously fast aligning of multi-beam laser. Especially, it can verify the overlapped lasers.

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The rest of this study is organized as follows. In section II, an experimental system of multi-beam lasers is setup, it supports the experiment of 4 beam lasers guidance synchronously with micro vision feedback. In Section III, the sync control strategy of multi-beam laser is developed based on spot vector of laser in feedback image. In section IV, The experiment results show that the established strategy is valid. 4 lasers are guided to a micro target at the same time.

2 SYSTEM SETUP

At the first, a multi-beam laser system is setup as shown in fig.1 for solving the track control. To get a clear image, a CCD is installed at the focal point of the optical lens, and the object will appear in a reasonable operating range. When the laser is projected on the object directly, it can't be observed by the vision system because of the scattering. In order to solve this problem, the vision system is improved. Firstly, the CCD and optical lens are separated, and the CCD center is arranged to be coupling with the axis of the optical lens. Secondly, optical lens is located between the object and the CCD, and a reflecting mirror is installed around the optical lens. The object is adjusted to be conjugated with the reflecting mirror.

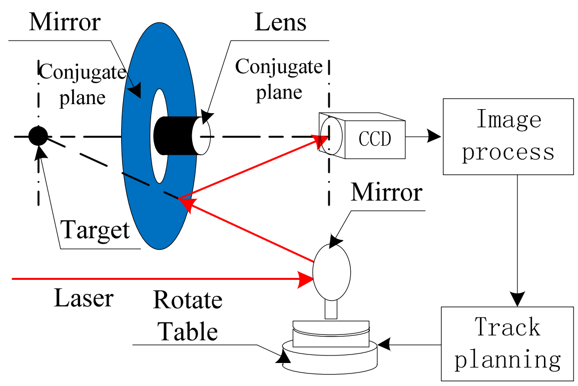

Fig 1. Multi-beam laser system assembly

Based on above platform, a servo system is formed using the micro-vision feedback. Position feedback of the 2D rotation platform (including rolling and pitching motors) is achieved by extracting the centers of the image laser spots.

The reflecting mirror is actuated by servo system to control the position of the laser spot on the CCD. Track planning based on image processing is the key to realize the sync control of multi-beam lasers. The control structure of the laser track constitutes as fig.2.

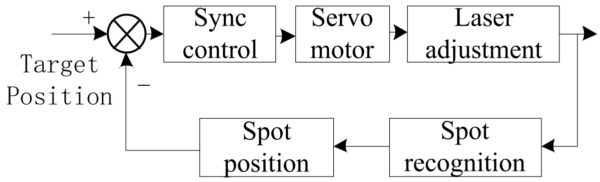

Fig 2. Sync control flowchart of the multi-beam lasers

To improve the precision of the vision feedback, a microscopy camera is used. The field depth of the microscopy camera is only 0.43 mm, and only monocular vision system can be build. Calibration of the microscope is carried out using monocular 2D calibration method to build camera coordinate. Image center is set to be the target of the laser. The displacement of a pixel is 3.45 μm as calibrated.

3 Length SYNC CONTROL OF MULTI-BEAM LASERS

To control the laser spot's position precisely, it is needed to calculate the coordinate of the laser spot at real-time using image feedback. The laser spot in the image of microcopy CCD forms an irregular filled circle. The characteristics of the laser spots' contours have great different. When the adjacent spots are overlapped, it is difficult to distinguish the overlapped spots, which effect the laser spots align. It is necessary to develop a novel method to describe the laser spot simply and clearly.

Laser spot is formed by a series of high light gray images. To achieve a better recognition result in the track control process, the laser spot is distinguished by 3 parameters of searching area, centroid coordinate and contour vector, as shown in fig. 3. Searching area is a square area in which the laser spot is to be found. The searching area is obtained from two neighboring frames of image, based on the information of servo parameters and the estimation of the maximum moving distance of the laser spot. The searching areas can separate various laser spots and reduce image processing calculation time. The centroid coordinate is the centroid of the laser spot contour, namely, the objective position of the track control. The contour vector is defined as follows: the amplitude of the vector is the equivalent radius of the area enveloped by the contour, the direction of the vector is from the centroid to the objective position.

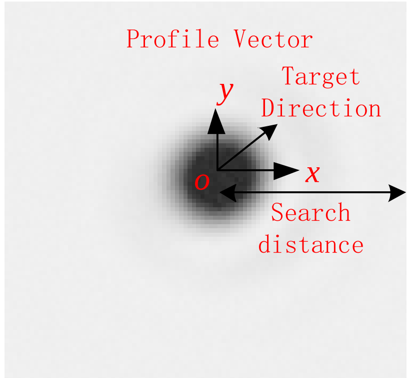

Fig 3. Define of a laser spot.

The sync track control process is divided into recognition and sync control, based on the differences of the laser spots and track. Multi beams laser are manipulated into the view field of the camera in the recognition phase, and alignment of multi-beam laser is realized in the sync control process.

3.1 Laser Spot Recognition

Laser spot recognition algorithm is show in fig. 4, where n and N represents the recognized and the total lasers respectively. Image noise will be introduced in the image capture process because of the lighting and the mechanical vibration, and the noise effect the recognition precision of the laser spot. To eliminate the noise, median filter is used in the image pre-processing by taking the mean value of the neighboring 3 frames images. Furthermore, recognition of the laser spot will be disturbed by extra contours existed on the image, like the target object, etc. The extra contours will be filtered by differentiating the basic image from every frame.

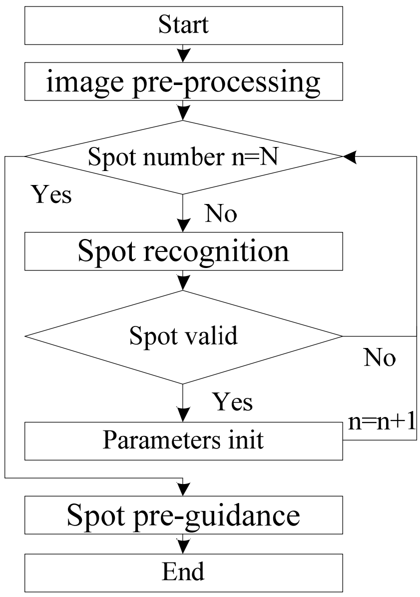

Fig 4. Laser spot recognition fellow.

The major work of the laser spot recognition is inter-frame difference. The prior frame, current frame and their difference are defined as I_p, I_c, and dI respectively. If dI satisfies condition (a) in Eq. (1), binaryzation and contour extraction is conducted. While a new contour is extracted, condition (b) is used to judge the new contour (for the first laser spot, the judge process is unnecessary.)

$$\begin{cases} I_c - I_p = \mathrm{d}I > G_0 & (a) \\ (x-x_i)^2 + (y-y_i)^2 > d_0^2 \ (i = 1,...,n) & (b) \end{cases} \quad (1)$$

where G_0 is the threshold of the difference image, and if grayscale change is smaller than the threshold G_0, no extraction of the contour will be conducted. (x, y) and (x_i, y_i) are the random points on the new and the recognized contours. d_0 is the distance threshold of the laser spot recognition, and it is greater than the diameter of the biggest laser spot.

After N laser spots are recognized, they are still not full image in the view of the microscopy camera. Pre-guidance can make all the laser spots clear and complete in image. Specifically, a random point (x_i, y_i) (i=1, …, N) on the laser spot is chosen to be its centroid, and default direction is toward the target point. Then drive the laser spot toward the default direction to move d_0.

We finish the whole process of laser spot recognition.

3.2 Multi-Beam Laser Sync Control

Based on the parameter setting of the laser track servo system, laser spots moving distance of the adjacent frames are restricted within its searching area. After the laser spots recognition, image processing will not be on the whole image but only the contours in N searching areas.

It is the primary task to determine the centroid and contour vector of the laser spot for precise guide of the multi-beam laser. Because of the irregularity of the laser spots, the centroid and contour vector of the laser spot can't be precisely obtained by contour recognition and curve fitting. To solve this problem, a multi-beam laser sync control algorithm is developed based on the centroid searching and contour vector, and the whole procedure is shown in fig. 5.

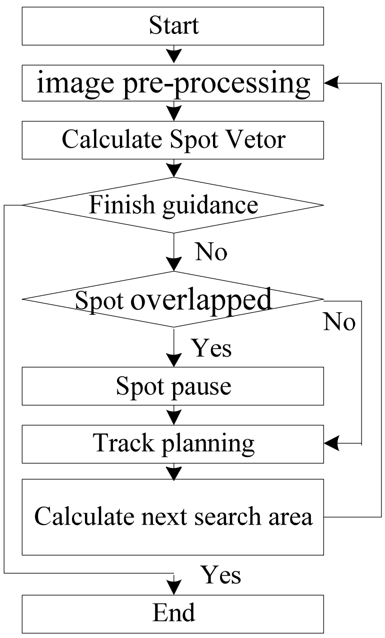

Fig 5. Synchronous guidance fellow of the multi lasers.

With the pre-processed laser spots image, firstly, unidirection binarization is conducted in the searching area to reduce the effect of lighting and scattering of the laser spots. Specific method is given by (2)

$$g(x_m, y_n) = \begin{cases} g(x_m, y_n); & g(x_m, y_n) \geq g_0 \\ 0; & g(x_m, y_n) < g_0 \end{cases} (m, n = 1,...,W) \quad (2)$$

where $g(x_m,y_n)$ is the gray value of the pixels in the searching areas, g_0 is the threshold of the laser spot recognition, W is the edge length of the searching square. Unidirection refers to the situation than when the gray value is bigger than the threshold the gray value is used, to calculate the centroid of the laser spot in the following steps.

After the unidirection binarization of the image, the precise centroid (X_i, Y_i) and amplitude of the contour vector R_i is obtained through gray value searching of every laser spot. The solution is written in the form

$$X_i = \frac{\sum_{m=1}^{W}\sum_{n=1}^{W} x_m \cdot g(x_m, y_n)}{\sum_{m=1}^{W}\sum_{n=1}^{W} g(x_m, y_n)}, Y_i = \frac{\sum_{m=1}^{W}\sum_{n=1}^{W} y_n \cdot g(x_m, y_n)}{\sum_{m=1}^{W}\sum_{n=1}^{W} g(x_m, y_n)} \quad (3)$$

$$R_i = \frac{\sqrt{\sum_{m=1}^{W}\sum_{n=1}^{W} g(x_m, y_n)}}{\pi} \quad (4)$$

where R_i is the eigenvalue of laser spot 1, so its gray value difference is not considered in the calculation.

Another laser spot centroid fitting method is based on the Gaussian energy distribution. Experimental result shows that the spot energy function conforms to Gaussian distribution, which is given by

$$g(x, y) = e^{\frac{(x-x_0)^2}{2\sigma_x^2} + \frac{(y-y_0)^2}{2\sigma_y^2}} \quad (5)$$

where x_0 and y_0 is the spot center coordinate. On both sides, the logarithmic formula is written in the form

$$\begin{aligned} G(x, y) &= \ln g(x, y) \\ &= k_x(x-x_0)^2 + k_y(y-y_0)^2 \\ &= Ax^2 + By^2 + Cx + Dy + E \end{aligned} \quad (6)$$

Based on Eq. (6), the spot centroid can be fit by the way of polynomial distributed. The minimum objective function is constructed as

$$L = \sum_i [G(x_i, y_i) - f(x_i, y_i)]^2 \quad (7)$$

To get the derivative of the coefficient of Eq. (7) and ∂L=0, the coefficients equation is shown as

$$\begin{bmatrix} \sum_i x_i^4 & \sum_i x_i^2 y_i^2 & \sum_i x_i^3 & \sum_i x_i^2 y_i & \sum_i x_i^2 \\ \sum_i x_i^2 y_i^2 & \sum_i y_i^4 & \sum_i x_i y_i^2 & \sum_i y_i^3 & \sum_i y_i^2 \\ \sum_i x_i^3 & \sum_i x_i y_i^2 & \sum_i x_i^2 & \sum_i x_i y_i & \sum_i x_i \\ \sum_i x_i^2 y_i & \sum_i y_i^3 & \sum_i x_i y_i & \sum_i y_i^2 & \sum_i y_i \\ \sum_i x_i^2 & \sum_i y_i^2 & \sum_i x_i & \sum_i y_i & 0 \end{bmatrix} \begin{bmatrix} A \\ B \\ C \\ D \\ E \end{bmatrix} = \begin{bmatrix} \sum_i x_i^2 f(x_i, y_i) \\ \sum_i y_i^2 f(x_i, y_i) \\ \sum_i x_i f(x_i, y_i) \\ \sum_i y_i f(x_i, y_i) \\ \sum_i f(x_i, y_i) \end{bmatrix} \quad (8)$$

Further to get the derivative of $G(x, y)$ with respect to x and y, and make it equal to 0, the maximum energy available position (x_0, y_0), which is used as the spot centroid, is in the form

$$x_0 = -\frac{C}{2A}, y_0 = -\frac{D}{2B} \quad (9)$$

In above calculation of the centroids and contours of the laser spots, only one laser spot is considered in the special searching area. In practice, because of the initial positions of the laser spots, moving trajectories and distances to the targets, results in fig. 6 will appear in the image. For the case in (a) and (b), where two laser spots enter the same searching area, centroids of the two contours are calculated separately to be A and B, and the distances to the contour vector of the laser spot A_0 in previous frame are also calculated as dA and dB. If the distance is bigger than threshold d0 in (a), then laser spot A is considered to be the current searching laser spot, otherwise, the two laser spots can't be separated in (b), in which the two laser spots are completely overlapped, the movement of the optical path of the laser will pause until the contours in the searching area can be separated.

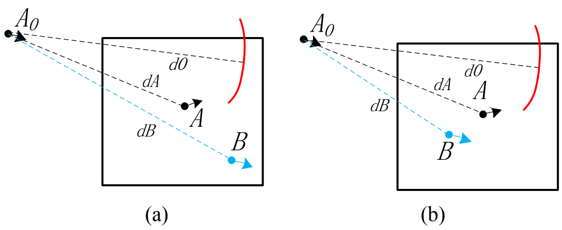

Fig 6. Laser spot separate scheme

When two laser spots are overlapped in one searching area, the judging gist is the equivalent radius R_i of the laser spot. If the equivalent radius $R > R_i$ (i=1, …, N), the laser spots are taken as overlapped. If the above criterion can't separate the overlapped laser spots, guide both laser spots to the target position until they can be separated.

In the laser spot track planning in fig.6, to ensure the stability of the algorithm, moving speed of the laser spot are determined, which is based on the maximum period of image processing and the pre-set maximum distance between two adjacent frames along their contour vector direction.

The multi-beam laser sync control is finished. All the beams of laser are moving toward a target position automatically to realize the goal of energy fusion.

4 EXPERIMENT

To verify the effectiveness of the multi-beam laser sync control method, experiments of 4 beam lasers are conducted on the multi-beam laser setup. After filtering and focusing for the laser device, clear laser spot is appear on the image with the diameter of 100 µm (36 pixels).

Results are shown in fig. 7. In (a) four laser spots are recognized in the CCD view. In (b) track control of the 4 laser spots are completed, and they entered the ideal area of 400µm. In (c) two laser spots appeared in one searching area and overlapped, and they were separated and aligned well by the proposed algorithm effectively.

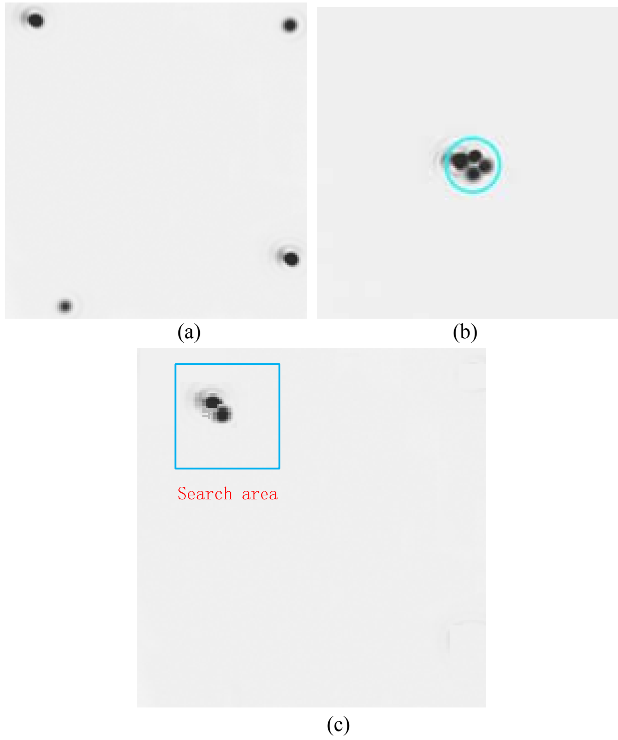

Fig 7. Experimental result of 4 beam lasers

In 10 experiments of 4 beam laser track sync control, all the laser spots are successfully guided into a 400 µm diameter ideal area. The whole guidance time is between 15 to 24 second, which is quarter of the separate laser control method. The algorithm improves the effectiveness of the automatic track control.

The results show that the Gauss energy distribution method can get a better centroid of the laser, and the position error is within 5µm. The counter characteristics of the spots conform to the Gauss distribution.

5 CONCLUSION

This paper has presented a track sync control method for aligning the multi-beam laser to one micro target position. The microcopy camera was used as the vision feedback to recognize the laser spot in image. The developed method can solve the laser spots overlap, and separate them in the multi-beam laser sync control process. At the same time, it is valuable for improving the effectiveness of the laser spots recognition and the motor track calculation. The simulated and experimental results have shown that the sync control strategy has accurately and quickly guide 4 beam lasers to the target region. The period of position was reduced from above 100 second of the separate control process to within 24 second. For the future application of more beams laser, image expansion and segmentation can be used to optimize sync control.

REFERENCES

[1] H. M. Chen, Development Trend and Present Situation of China and Oversea Laser Processing Industry, Laser Technology and Applications, No.9, 1-11, 2004.

[2] Q. Wu, J. K. Gong, G. Y. Chen, et al, Research on Laser Welding of Vehicle Body, Optics & Laser Technology, No.6, 1-7, 2007.

[3] D. Y. Fan, X. M. Zhang, Laser fusion and high power laser: history and progress, Physics, Vol.39, No.9, 589-596, 2010.

[4] M. L. Spaeth, K. R. Manes, C. C. Widamayer, et al, National Ignition Facility Wavefront Requirements and Optical Architecture, Optical Engineering, Vol.43, No.12, 2854-2865, 2004.

[5] D. E. Wang, D. X. Hu, W. J. Dai, et al, Far Field Irradiance Profile Control in Inertial Confinement Fusion Drive Facility with Adaptive Optics, Chinese Journal of Lasers, Vol.38, No.3, 0312002-1-6, 2011.

[6] G. Liu, Research on the Multi-target Tracking Algorithm and Implementation, North Western Polytechnical University, 2009.

[7] H. H. Liu, G. Yu, 3D Adaptive Measuring and 6D Manufacture Trace Genetating For the Complex Border of Cardies, Chinese Journal of Mechanical Engineering, Vol 40, No.12, 155-159, 2004.

[8] J. T. Su, Study on Path Planning and High Precision Track Control for Unconstrained Mobile, JiLin University, 2006.

[9] R. El-Agmy, H. Bulte, A. H. Greenaway, et al, Adaptive Beam Profile Control Using a Simulated an Nealing Algorithm, Optics Express, Vol.13, No.16, 6085-6091, 2005.

[10] Z. Y. Wang, Z. Q. Zhuang, J. S. He, et al, Wavelet Coefficients Generalized Gaussian Distribution Image Retrieval Algorithm Based on Shape, ACAT Electronica Sinica, Vol. 31, No. 5, 765-768, 2003.

[11] J. H. Hou, C. Y, Xiong, J. W. Tian, et al, Study of Gaussian Mixture Model for Image Wavelet Coefficients, Computer Applications, Vol. 26, No. 3, 579-581, 2006.