Research on error Analysis of LED chips visual positioning system

Shihua Gong, Diyi Zhou, Ziyue Wang, Delong Li, Huaiqing Lu
State Key Lab of Digital Manufacturing Equipment and Technology, School of Mechanical Science and Engineering, Huazhong University of Science and Technology, Wuhan 430074, PR China
Email: 424149491@qq.com

Abstract. With the continuous development of intelligent equipment, the chip positioning accuracy requirements are also constantly improving. In this paper, a mathematical model of the LED chips positioning system based on the characteristics of the system is constructed. And then, an error analysis method based on Monte Carlo is proposed, which is able to obtain the impact factors of various sources of error, such as calibration error, image processing error and motion control error. By analyzing the influence factors of these error sources, we can know that calibration error is the main source of error affecting positioning accuracy.

1. Introduction
As the fourth generation of green lighting source, LED has the advantages of low energy consumption, high photoelectric conversion efficiency and high brightness. It has been widely used in traffic lights, LCD backlights, automotive lights, advertising displays and other places [1], [2]. As LED production capacity is expanding, LED chip sorters (shown in Fig.1) need to be improved continually [3]. In the chip sorting processing, the most critical step is the positioning of the chip. Due to the dimensional change of the sorting chip, the deformation during the movement caused by the high acceleration start and stop of the motion platform, the illumination environment and other changes directly affect the positioning accuracy and sorting efficiency [4].

The positioning process of the chip includes three parts: image processing [5], motion control [6] and calibration [7]. By analyzing the error of each part and perfecting the error distribution mechanism, we find that it is an important part to improve the positioning accuracy of the LED chip. In order to analyze the influence of various errors on the system, many scholars have done some researches. Yuan J et al establish the model of pipeline analog-to-digital converter and analyze the effects of linear and nonlinear calibration errors on the linearity of the pipeline analog-to-digital converter. A compensation algorithm based on its characteristics is proposed, which is able to compensate the common pipeline analog-to-converter problems of capacitor mismatch and finite operational amplifier variable gain without the long convergence issue [8]. Mok H S et al analyze the influence of resolver generates periodic position errors on position loop control, an algorithm is proposed that reduces torque ripple components by applying a simple torque ripple compensation method to the current controller [9]. Avargel YS et al introduce an estimation error analysis for nonlinear system identification in the short-time Fourier transform domain. Aiming at two types of under modeling errors, proposing different methods to achieve lower mean-square error [10].
In this paper, the mathematical model of transformation from visual coordinate system to the target coordinate system is established. According to the error distribution, the Monte Carlo analysis method [11] is used to estimate the final positioning error, and the impact factors of each error is obtained. According to the size of the influence factor, the error distribution is performed to compensate the main error and improve the final positioning accuracy of the chip sorter.

2. System model construction and Source of error analysis

The visual feedback system consists of image acquisition system, image processing system and motion control system, as shown in Fig.2, motion control system based on visual feedback and compensation is constructed. The CCD camera catches photos and the image capture card transmits image information to the host computer, and then the host computer sends the motion control command to the motion controller, the servo motor drives the ball screw to realize the positioning of chips.

2.1. calibration error

In the installation process of the camera and the two-dimensional platform, there is inevitably an angular deviation as shown in Fig. 3. Therefore, the acquired image information cannot directly reflect the actual motion displacement of the two-dimensional platform, which has a certain influence on the precise positioning of the LED chip. The $\alpha$, $\beta$, $\gamma$ angles obtained by the laser interferometer are $U_\alpha(−0.3,0.3)$, $N_\beta(0,0.2833)$, $N_\gamma(0,0.5687)$ respectively.

2.2. image processing error

The image algorithm process directly affects the accuracy of chip positioning. It is mainly divided into two parts: sub-pixel edge extraction and template matching. After the image is pre-processed, the outer contour of the chip is obtained by the minimum circumscribed rectangle, and the modified Canny operator is used to extract the sub-pixel edge contour of the chip. Finally, the chip center is obtained by fitting the edge contour of the sub-pixel. According to the obtained template, the chip center is selected as the feature point for positioning.
The systematic error of the image is mainly derived from image algorithms, environmental disturbances and noise. In order to detect image errors, we can detect the repeatability of chip positioning by taking repeated pictures of the chip and recording the pixel coordinates of one of the chips. The experimental results are shown in Fig. 4 and the repetition degrees of the X and Y axes are ±0.09 pixels and ±0.15 pixels respectively.

2.3. motion control error
The motion control system consists of a motor drive and two AC servo motors. The XY two-dimensional platform is driven by a ball screw with a maximum speed of 500 mm/s. The platform positioning process adopts the coarse-precision two step positioning method. Fast feed through encoder feedback to the target position, and then the visual feedback compensation error is used to complete the precise feed. Control system diagram is shown in Fig. 5.

The motion control part error includes the steady-state error of the control system and the positioning error of the ball screw. During the chip positioning process, the maximum displacement of the motion is 1.2 mm. The motion control card sends a 2mm motion command to the motor. The laser displacement sensor measures the actual displacement of the two axes. The experiment is repeated ten times and the control error is ±2μm.

2.4. mathematical model construction of LED chip positioning system
In order to construct the mathematical model of the transformation from target positioning of the camera coordinate system to the chip coordinate system, it is required to solve the rotation matrix in the coordinate transformation.

When the camera coordinates are rotated by the α angle around the Z axis, the relationship between the actual coordinate relationship and the image coordinates is shown in Eq. (1). After the camera coordinates are rotated by γ and β around X and Y, the actual coordinate relationship and image coordinates are shown in Eq. (2). Finally, the mathematical model between the LED chip positioning system and each random error is shown in Eq. (3).

\[
\begin{align*}
    x' &= P_x \cos \alpha - P_y \sin \alpha \\
    y' &= P_y \cos \alpha + P_x \sin \alpha \\
    W_x &= \frac{x'}{\cos \beta} = P_x \cos \alpha - P_y \sin \alpha \\
    W_y &= \frac{y'}{\cos \beta} = P_y \cos \alpha + P_x \sin \alpha \\
    W_x &= P_x \cos \alpha - P_y \sin \alpha + e_x \\
    W_y &= P_y \cos \alpha + P_x \sin \alpha + e_y
\end{align*}
\]  

(1)

(2)

(3)

3. Research on error analysis

3.1. Introduction to Monte Carlo Method
Monte Carlo method, also known as random sampling or statistical test method, traditional empirical methods can not get satisfactory results because they are not able to approach the real physical process, and Monte Carlo method can solve the problem because it can realistically simulate the actual physical process. The solved problem is linked to a fixed probability model, and a computer is used to
implement statistical simulation or sampling to obtain an approximate solution to the problem. The basic principle is as follows.

Assuming the function \( Y = f(X_1, X_2, \ldots, X_n) \), where the probability distributions of the variables \( X_1, X_2, \ldots, X_n \) are known. But in practical problems, \( f(X_1, X_2, \ldots, X_n) \) are often unknown. The Monte Carlo method uses a random number generator to extract the values of each set of random variables \( (x_1, x_2, \ldots, x_n) \), then determine the value of function \( Y \) according to the relationship between \( Y \) and \( X_1, X_2, \ldots, X_n \).

Sampling multiple times \( (i = 1, 2, \ldots, n) \) repeatedly, we can get a batch of sample data \( y_1, y_2, \ldots, y_n \) of function \( Y \), when the number of simulations is enough, the probability distribution and numerical characteristics of the function \( Y \) which is similar to the actual situation can be acquired.

The basic steps of Monte Carlo are as follows:

1. The approximate distribution of the relevant basic variables and their distribution parameters statistically are determined;
2. All basic variables are sampled according to statistical characteristics, and statistical processing is performed to obtain simulation results;
3. The independent sampling process is repeated, and the simulation results are statistically processed to obtain the solution and accuracy estimation of the problem.

3.2. Error analysis based on Monte Carlo Method

The accuracy of Monte Carlo analysis is closely related to the number of samples taken. Therefore, this experiment uses MATLAB to randomly generate 10^6 samples for estimation. According to the distribution characteristics of each error, the random distribution of error factors such as image processing, motion control and angular deviation is determined. Substituting the data generated from MATLAB into the Eq. (3) to obtain the corresponding sample values. The standard deviation of the \( X \) and \( Y \) axis positioning results, which are calculated separately. The ratio \( \mu \) of the target positioning standard deviation to the standard deviation of the measured parameters is the influence factor of each error on the final positioning accuracy.

When \( \mu < 1 \), it indicates that the error variable is transmitted to the final positioning error through the scaling down, and the influence factor is low; when \( \mu = 1 \), it indicates that the error variable is transmitted to the positioning error equivalently; when \( \mu > 1 \), it indicates that the error is transmitted to the positioning error through scaling up, and the influence factor is high.

3.3. Main source of error

Firstly, a set of measurement data is selected for the target positioning calculation. The parameters of the relevant variables measured are as follow. In the calibration error, the angular deviation between camera and two-dimensional platform are \( \alpha = 2.78^\circ, \beta = 0.18^\circ, \gamma = 0.60^\circ \). In the image processing, \( P_x = 672.5\mu m, P_y = 551.5\mu m \). In the motion control error process, \( e_x = e_y = 1.7 mm \). Substituting these data into the Eq. (3), the moving distance in the corresponding chip coordinate system is 645.5341\( \mu m \). 582.0259\( \mu m \).

According to the error analysis step, the randomly generated \( 10^6 \) samples are respectively combined with the random error sequence of each variable and the measured values of other variables into the established mathematical model to calculate the moving distance in the corresponding chip coordinate system. The influence factors of the six variables is calculated which are shown in Table 1. From the influence factors of the X and Y axis positioning errors in the table to the error of each measurement variable, it can be seen that the motion control error is directly transmitted to the positioning error equivalently, and the steady state error can be reduced by adjusting the PID parameters. The X and Y axis rotation angle errors are transmitted to the positioning error with a ratio of \( 10^8 \rightarrow 10^2 \), which has less influence on the final positioning accuracy. The Z axis rotation angle error is amplified to a final positioning error by a factor of about 10, and a calibration algorithm is needed to compensate for the rotation angle error around the Z axis. The X and Y axis errors in the image
processing process have certain influence on the X and Y axis positioning errors of the chip platform. It is necessary to improve the image processing algorithm and reduce the image repeatability.

| Influence factors | Error sources | Calibration | Image processing | Motion control |
|-------------------|---------------|-------------|------------------|----------------|
| X axis            | α             | 9.6334      | 4.9124×10⁻⁹     | 0.0254         | 4.9946         | 0.2425         | 1               | 0               |
| Y axis            | β             | 11.7468     | 0.0458          | 4.0709×10⁻⁹    | 0.2425         | 4.9944         | 0               | 1               |

4. Experiment

In order to verify the effectiveness of the error analysis algorithm, after using the improved calibration algorithm [7], we selected 100 wafer blue film chips for positioning test to detect the positioning accuracy of the system. The results are shown in Fig.6(a). Before the compensation error, the positioning error of the system is within 40μm. The main error sources are the calibration error in the image acquisition process, the error in the image processing, and the transmission error and Wafer film deformation error of the chips. From the Fig.6(b), it can be seen that the improved calibration algorithm compensates the installation angle error of the camera, and the positioning error of the system is controlled within 15μm, which greatly improves the positioning accuracy of the system.

5. Conclusion

According to the characteristics of the visual feedback platform, this paper constructs the mathematical model from camera coordinate system to chip coordinate system by analyzing the measurement variables such as image processing process, motion control model and installation angle. Acquiring the obeyed random distribution of variables by the measured parameters of error distribution. Monte Carlo analysis method is used to estimate the positioning error of the target, and the influence factors of each variable on final positioning error can be obtained, which has a certain theoretical reference value on improving the positioning accuracy of the system. By analyzing the experimental results, we can draw the following conclusions. The installation angle error around the X and Y axis has less influence on the positioning accuracy; The installation angle error around Z has a great influence on the final positioning error; and the influence of image processing error on the motion control error is relatively low. Therefore, compensating the error caused by the α angle deviation by the calibration algorithm is a key part to improve the positioning accuracy of the visual feedback system. By adopting the improved calibration algorithm, the camera installation angle error is compensated, the system positioning accuracy is effectively improved, and the effectiveness of the error analysis is verified.

In this paper, a method for determining the main error source based on Monte Carlo Method is proposed. The main error is compensated to improve the system positioning accuracy, which provides some theoretical help for error distribution and precision control in practical application.
Acknowledgments
This research is supported in part by National Key Research and Development Program of China (No. 2016YFC0105306).

References
[1] Karl T L. Oil-led development: social, political, and economic consequences[J]. Encyclopedia of energy, 2007, 4(8): 661-672.
[2] Agénor P R. A theory of infrastructure-led development[J]. Journal of Economic Dynamics & Control, 2010, 34(5):932-950.
[3] Shiang W J, Lin Y H, Rau H. A Dispatching Rule Study of a LED Sorting System[J]. Key Engineering Materials, 2010, 419-420:4.
[4] Chung K, Crane M M, Lu H. Automated on-chip rapid microscopy, phenotyping and sorting of C. elegans[J]. Nature Methods, 2008, 5(7):637.
[5] Zhong F, He S, Li B, Blob analyzation-based template matching algorithm for LED chip localization[J]. International Journal of Advanced Manufacturing Technology, 2015:1-9.
[6] Gong S, Lu H, Zeng Z, et al. Vibration suppression of rotating arm in LED chip sorter using feedforward-feedback control with an optimal curve[J]. Precision Engineering, 2019,56:513-523.
[7] Wang Z, Gong S, Li D, et al. Error analysis and improved calibration algorithm for LED chip localization system based on visual feedback[J]. International Journal of Advanced Manufacturing Technology, 2017, 92(9-12):1-10.
[8] Yuan J , Fung S W , Chan K Y , et al. An Interpolation-Based Calibration Architecture for Pipeline ADC With Nonlinear Error[J]. IEEE Transactions on Instrumentation and Measurement, 2012, 61(1):17-25.
[9] Mok H S , Kim S H , Cho Y H . Reduction of PMSM torque ripple caused by resolver position error[J]. Electronics Letters, 2007, 43(11):646.
[10] Avargel Y , Cohen I . Undermodeling-Error Quantification for Quadratically Nonlinear System Identification in the Short-Time Fourier Transform Domain[J]. IEEE Transactions on Signal Processing, 2010, 58(12):6052-6065.
[11] Peters T , Meyer B , Stuike-Prill R , et al. A Monte Carlo method for conformational analysis of saccharides[J]. Carbohydrate Research, 1993, 238(none):49-73.