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Original research article

High precision Fast Line Detection of alignment and coupling for planar Optical Waveguide device

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ABSTRACT

Machine vision is widely used in alignment between planar optical waveguide chip and optical fiber array. Optical component edge detection is one of the key steps of machine vision in alignment. This paper has proposed a line detection algorithm based on the progressive probabilistic Hough transform (PPHT) and iteratively reweighted least squares (IRLS) algorithm for alignment between planar optical waveguide chip and optical fiber array. The experiment results show that the detection angle error is less than 0.005° and the time consumption is less than 0.5 s through the proposed algorithm. Besides, it also can accurately fit optical component edge with some non-random factors. Therefore, the proposed new algorithm has the advantages of high precision, fast computing speed and good robustness, and it can successfully realize the high-precision fast line detection of optical component edge.

1. Introduction

Planar optical waveguide devices are the foundation of optical fiber communication system and optical fiber sensor system. With the development of optical fiber communication, alignment and between planar optical waveguide chip (POW chip) and optical fiber array (OFA) have become the focus of many industries [1,2]. In general, the alignment is performed passively and actively. During passive alignment, the two optical components may be placed according the expected desired orientation. Machine vision can be used in passive alignment to locate the position of the two optical components, then used to guide the movement of the motor stage for the alignment. The automated coupling technology between planar optical waveguide chip and optical fibers has been developing rapidly in the past few years [3,4]. However, the research on high precision detection of position and pose for planar optical waveguide chip and optical fibers is insufficient, and the accuracy and stability cannot meet the requirement of automated alignment and coupling [5,6].

The major task for machine vision system is to recognize line feature of the optical component edges accurately and quickly by way of the position and pose parameters, such as angle deviation and axial gap [6]. However, the damage appeared in optical component manufacturing and smudginess appeared in alignment make the line detection of edge difficult. Therefore, a high precision line detection method has been a key issue in the process of machine vision for planar optical waveguide chip and optical fibers alignment.

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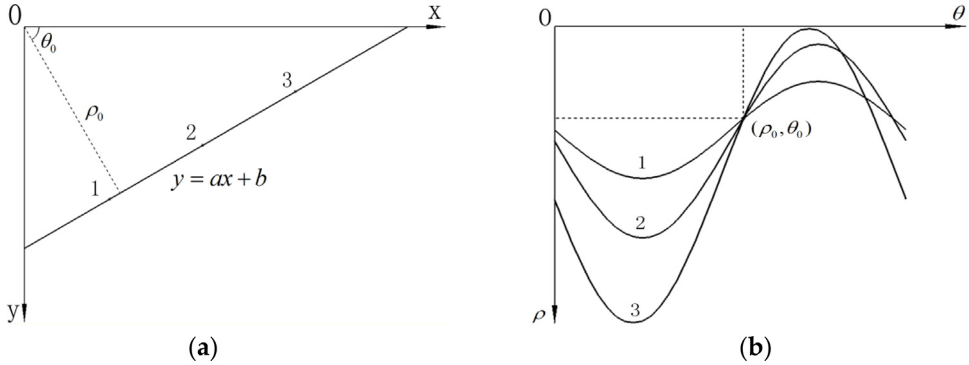

Fig. 1. Principle of Hough transform. (**a**) Image space; (**b**) Parameter space.

Hough transform (HT) and least square (LS) method as the conventional line detection methods are widely used in machine vision. The standard Hough transform (SHT), as a global optimal algorithm, has the character of well stability and good robustness. However, when it is asked for the high precision, the SHT will be considered to have slow computing speed, waste of store space and poor real-time capability because of its exhaustive searching. In view of these shortcomings, some improved algorithms have been proposed by the related scholars. The well-known improvement is random Hough transform (RHT) [7], which has been proposed by Xu L et al. The RHT utilizes the many-to-one mapping and random sample selection to alleviate the computational and storage load. Kiryati et al. provided another efficient version of the Hough transform,the probabilistic Hough transform (PHT) [8], which maintains the SHT voting scheme but by using a relatively small sampling. Matas J. et al. proposed the Progressive Probabilistic Hough Transform (PPHT) [9,10]. Unlike the PHT, where PHT is performed on a pre-selected fraction of input points, PPHT minimizes the amount of computation needed to detect lines by removing the supporting points in the corresponding lines and reducing the vote counts. In Ref. [9], the above improvements are compared in the aspect of time consumption. Among them, the PPHT has fastest operation speed, which is very suitable for the real-time line detection.

For the LS line fitting method, the influence of random error on linear precision is considered and high detection precision is obtained, which can make up for precision deficiency of the HT. However, the detection result error of the LS will increase significantly when the detected edges contain some non-random factors such as damage and burr. In this case, some robust methods can be used. The most well-known approaches is the M-estimator method [10–12].The iteratively reweighted least squares (IRLS) method is based on the M-estimator technique that iteratively solves an optimization problem.

In this paper, a new line detection algorithm based on the PPHT and IRLS is proposed, which is the PPHT-IRLS algorithm. In Section II, the proposed algorithm with its underlying theory and principle is presented. The main algorithm flow description of line detection of the optical component edge is shown in section III. In Section IV, the experimental study on optical component images for output quality and computational efficiency is given. Finally, conclusions are reported in Section V.

2. Algorithm principle

2.1. Principle and implementation of PPHT

The basic idea of the SHT is to utilize the point-line duality, and the transform rule is a mapping from image space to parameter space [13]. For the straight lines transform, the mapping is manifested as a corresponding relation between the point of image space and the sinusoidal curve of parameter space, as is shown in Fig. 1. The relationship is also defined by

$$\rho = x\cos\theta + y\sin\theta \quad (0 \le \theta < 180) \tag{1}$$

where ρ is the normal distance from the origin to the line, and θ is the angle between the normal and x-axis.

The PPHT is an improvement based on the SHT. It maintains the standard Hough transform rule, but only a fraction of the supporting points have to vote before the corresponding accumulator bin reaches a count that is non-accidental. The PPHT for line segments detection is described in Algorithm 1. The thresholds (Tn, Tg and Tl) are decided by the angle resolution and input image information [7]. In practice, the resolution parameter can be set up based on the requirement of detection precision, and the thresholds parameter can be regulated repeatedly in the experimental test. The detected segments are added as endpoints set into the output list.

Algorithm 1. PPHT for line segments detection.