Optik 127 (2016) 912–915

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

An extraction method of laser stripe centre based on Legendre moment

Qiucheng Sun[a], Renyun Liu[a,*], Fanhua Yu[b]

[a] School of Mathematics, Changchun Normal University, Changji Highway (North) 677, Changchun, China
[b] Department of Computer Science and Technology, Changchun Normal University, Changchun, China

ARTICLE INFO

Article history:
Received 25 February 2015
Accepted 30 October 2015

Keywords:
Line structured light
Laser stripe centre
Legendre moment

ABSTRACT

Stable and efficient extracting the centre of laser stripe in image is a challenging computer vision problem. Existing methods are mainly based on the Gaussian and parabola distribution of laser stripe. However, the new beam-shaping technology is developed to make the light intensity of laser stripes with a uniformly distribution instead of Gaussian distribution. This paper proposes a fast and robust algorithm for laser stripe centre extraction based on Legendre moment theory. The proposed method can be summarized as follows: first, an ideal one-dimensional light intensity model of laser stripe is given based on the uniformly distribution; second, a closed-form solution for extracting the centre from every transversal section of laser stripe is derived based on conservation laws of Legendre moment; finally, a smoothing spline algorithm is used to eliminate noise as well as maintain the original features of the centre points. The experimental results show that the method has good robustness and accuracy.

1. Introduction

As a typical active vision measurement method, line structured light technique is widely used in non-contact precision measurement of geometrical parameters due to its simplicity and robustness. Normally, a line structured light system is basically composed of a CCD camera and a line laser projector rigidly fixed with respect to the camera. In the measurement, the laser projects a laser stripe over an object, and the shape of the laser stripe in the acquired images makes it possible to calculate 3D information about the shape of the object. Such measurement mainly includes two steps: first to extract the laser stripe centre in the acquired images, second to triangulate these centres and recover range data based on the working principle of laser triangulation. Since the stripe extraction error dominates the reconstruction precision once the system has been calibrated, the extraction of laser stripe centre from an image is one of the most important procedures throughout the whole measurement process.

So far, there are many methods presented to extract the laser stripe centre, e.g. Gaussian approximation, Center of mass, Besel approximation, and Parabolic estimator, etc. The main difference among these methods is that the laser profile is considered to correspond to the different profile. For example, the laser profile is assumed to be a parabola in Steger's approach [1]. The approach extracts laser stripe centre based on the Hessian matrix of image intensity function at a pixel, and has a high location precision. In Ref. [2], to detect the centre of laser stripe, the laser profile is fitted to a continuous function by Bezier curves, and the bisection method is applied to find the maximum of curve. The above two methods are robust to noise, however their computational complexity and memory requirement are high. Because the laser source emits a widened laser stripe that approximates a Gaussian profile in the transversal directions, a lot of methods are proposed based on Gaussian approximation currently. For example, Ho [3] proposed a method predicting laser stripe width by modelling its irradiance as 2D Gaussian profile. Subsequently, the laser stripe irradiance is approximated as 1D Gaussian profile in his next work to improve the run time [4]. In view of Gaussian distribution, it also facilitates computing the laser stripe centre by centroid estimation of each transversal section [5,6]. In [7] a comparison between the algorithms of Gaussian approximation and Center of mass is presented, and it concludes that the two algorithms display performance within the same range. Other works, such as [8], indicate that the Center of mass is the method which produces the best results.

Because the distribution of light intensity in the Gaussian laser stripe is not uniform, the profile of light intensity will change when the projection angle of the laser changes. It will lead to inconsistent

* Corresponding author. Tel.: +86 043186168377/079.
E-mail address: liurenyun1970@163.com (R. Liu).

http://dx.doi.org/10.1016/j.ijleo.2015.10.196
0030-4026/

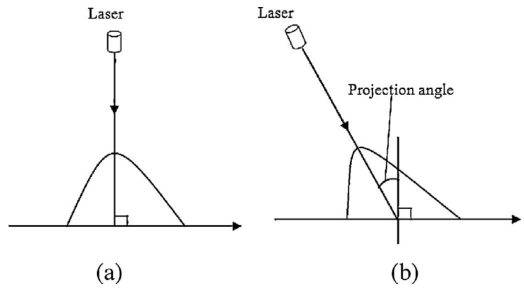

Fig. 1. Gaussian distribution of light intensity. (a) Projection angle is 0°; (b) projection angle is not 0°.

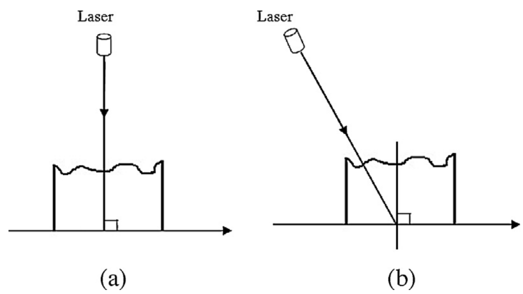

Fig. 2. Uniformly distribution of light intensity. (a) Projection angle is 0°; (b) projection angle is not 0°.

detection of laser stripe centre by means of traditional methods, as shown in Fig. 1. To overcome this problem, the new beam-shaping technology is developed to make the light intensity of laser stripes with a uniformly distribution instead of Gaussian distribution. As shown in Fig. 2, the uniform distribution does not change with variations in the projection angle. In view of the new light intensity distribution, the new method to extract a laser stripe centre should be given.

In this paper, a novel method to extract laser stripe centre is proposed based on Legendre moment. In the work, a new light intensity distribution model of laser stripe is given first. In view of the new model, a closed solution for extracting the laser stripe centre in the transversal section is derived based on Legendre moment. In the end of method, a smoothing spline algorithm is used to obtain a continuous centre curve, which improves the robustness of the algorithm.

2. The proposed algorithm

2.1. Ideal one-dimensional light intensity model

In the laser stripe image, the laser stripe curve is often deformed. Usually, the edge points of laser stripe are extracted by edge detection operator first, and then the transversal section of laser stripe can be obtained along the normal direction of laser stripe curve. The normal direction is determined by calculating the light intensity gradient direction of the edge points, as shown in Fig. 3.

Without loss of generality, it can be assumed that the laser stripes are parallel to the y-axis of the image in next descriptions. As shown in Fig. 4, the new light intensity of laser stripe in a transversal section can be described by a boxcar model $B(x)$ with background.

$$B(x) = \begin{cases} h & x \in [-1, l_1) \\ k & x \in [l_1, l_2] \\ h & x \in (l_2, 1] \end{cases} \tag{1}$$

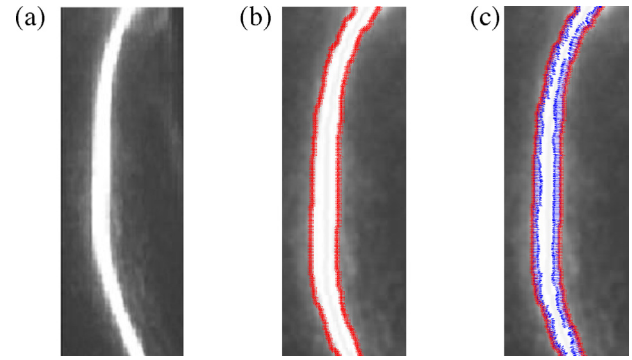

Fig. 3. laser stripe direction. (a) Original image; (b) edge detection of laser stripe; (c) normal direction of laser stripe

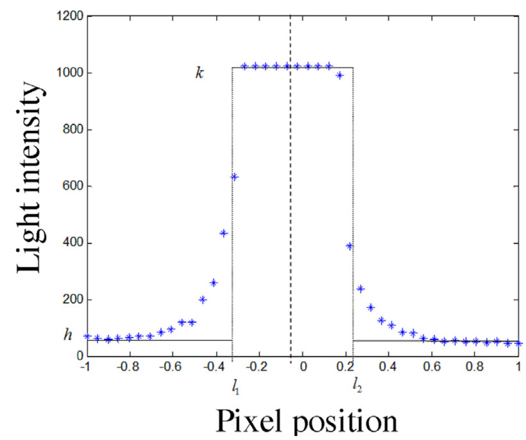

Fig. 4. Boxcar model.

The model is characterized by four parameters: background intensity h, grey contrast k, and both sides of laser stripe l_1 and l_2, and the location of laser stripe centre is $(l_1 + l_2)/2$.

2.2. Closed solution to extract a laser stripe centre

Since the theory of moment is proposed by Hu [10], the moments have been widely and successfully applied in many fields. The moment is an operator for describing the features of object, and it contains the following types: geometry moment, complex moment and orthogonal moment. Because the information redundancy is the least when the orthogonal moment is used for embodying image information, it is widely used in the fields of image processing, and Legendre moment is as a kind of commonly used orthogonal moments. In this section, we attempt to derive a closed solution for extracting the centre of laser stripe based on Legendre moment.

The Legendre moment of a continuous function $f(x)$ of order n are defined by

$$L_n = \frac{(2n+1)}{2} \int_{-1}^{1} P_n(x) \cdot f(x)\, dx, \tag{2}$$

where $P_n(x)$ is Legendre polynomial of order n. The formula of Legendre polynomial is as follows:

$$P_n(x) = \frac{1}{2^n n!} \frac{d^n}{dx^n} \left[\left(x^2 - 1 \right)^n \right], \quad n = 0, 1, 2, \ldots \tag{3}$$