ResearchGate

See discussions, stats, and author profiles for this publication at: https://www.researchgate.net/publication/281687485

A Fast and Robust Detection Algorithm for Extraction of the Centre of a Structured Light Stripe

Article *in* Lasers in Engineering · January 2015

CITATIONS
6

READS
531

4 authors, including:

Qiucheng Sun
Changchun Normal University
17 PUBLICATIONS **263** CITATIONS

SEE PROFILE

All content following this page was uploaded by Qiucheng Sun on 16 January 2016.

The user has requested enhancement of the downloaded file.

Lasers in Eng., Vol. 0, pp. 1–11
Reprints available directly from the publisher
Photocopying permitted by license only

©2014 Old City Publishing, Inc.
Published by license under the OCP Science imprint,
a member of the Old City Publishing Group

A Fast and Robust Detection Algorithm for Extraction of the Centre of a Structured Light Stripe

Q.C. SUN[1,*], Y.Q. HOU[2], Q.C. TAN[3] AND Z.Y. XU[1]

[1] *School of Mathematics, Changchun Normal University, Changchun 1300031,China*
[2] *College of Mechanical Science and Engineering, Changchun University, Changchun 130012, China*
[3] *College of Mechanical Science and Engineering, Jilin University, Changchun 130012, China*

Fast and robust extraction of the centre of a structured light stripe from the image is the key to high precision measurement in laser triangulation measurement. In this paper a new algorithm for extracting light stripe centre is given and the algorithm can be divided into three steps. First, the edge points of light stripe are detected in pixel-level by the Sobel operator. Second, the grey gradient direction of the edge points are calculated as the normal direction of light stripe curve, and the cross-section of light stripe can be obtained along the normal direction. Finally, a closed solution for extracting light stripe centre is given based on spatial moment theory, and the sub-pixel coordinates of light stripe centre can be obtained in all cross-sections. The experimental result demonstrates that this moment-based detection algorithm is more robustness against the noise, and its run time is much faster than the other methods. The above advantages indicate this algorithm is more suitable for on-line accurate detection.

Keywords: Laser triangulation measurement, light stripe, centre, Sobel operator, spatial moment, robustness, sub-pixel detection

1 INTRODUCTION

As one of the active three-dimensional (3-D) measurement technologies, the laser triangulation method, which is based on line structured light scanning, has been widely used in quality-control and reverse engineering due to its simplicity

*Corresponding author: Tel: +86 (0)135 0433 8377; Fax: +86 (0)431 8509 4216;
E-mail: sunqiucheng@mail.ccut.edu.cn

and robustness [1-3]. In practice, the most often used structured light pattern is usually generated by fanning out a laser beam into a sheet-of-light. When a sheet-of-light intersects with an object, a bright light stripe can be seen on the surface of the object. By viewing this light stripe from a point of view, the observed distortions in the stripe can be translated into height variations [4]. Since laser beam has a certain line width, the light stripe will also have the pixel width in the image. So, the image coordinates of light stripe centre need to be detected firstly in order to implement calibration and 3-D measurement. However, the changing in the texture and surface of measured object, as well of the noise in the measurement environment, will affect the imaging of light stripe, and increase the difficulty of extracting the light stripe centre. In the actual measurement, therefore, fast and robust extraction of the centre of the structured light stripe in the image is the key to improving the measurement precision.

In previous works there are mainly two groups of methods for extracting the light stripe centre, one is in pixel level [5, 6], and the other is in the subpixel level [7-15]. Pixel level methods are usually used for the measurements being of not high accuracy. For high accuracy requirements, however, a larger number of subpixel level methods have been presented. In the work of Luo *et al* [7] the observed stripe in the image is modelled as two edges that are close together. Then, a line is obtained by using an outlier-excluding least-squares method for each of the edges of the stripe, and the mean line of the stripe is determined by bisecting the angle formed by the lines. When the distortion of light stripe is large, accuracy of the detection method will be affected. To detect the centre of light stripe Apolinar and Muñoz *et al* [8] fitted the pixels to a continuous function by Bezier curves and the bisection method was applied to find the maximum of curve. Although the algorithm has better robustness, the running time is too long. In the work of Družovec *et al* [9] a robust algorithm for determining line centre within a video positional measuring system is proposed, in which the influence of contamination is considered. Because the system requires high precision of hardware design, its application is restricted. Steger [10] proposed a method to extract light stripe centre based on the Hessian matrix of image intensity function at a pixel. It has high location precision and has been widely used in vision measurement applications; however, due to multiple convolutions on the whole image the method is slow and cannot meet the requirement of real-time processing. Ho *et al* [11] proposed a method predicting light stripe width by modelling its irradiance as two-dimensional (2-D) Gaussian profile. Although the method could enhance the performance of light stripe centre detection, it is time consuming in optimization procedure. To improve the detection speed Ho *et al* [12] moved on to propose a closed form method assuming light stripe irradiance can be approximated as one-dimensional (1-D) Gaussian profile. The cost of this is that the detection precision will be affected by the noise and imaging quality.

In this paper a new algorithm for extracting light stripe centre is given based on spatial moment theory. Since the spatial moment [16] is a integral operator which is time-saving and robust, the proposed method is more suitable for on-line accurate detection. An evaluation of the proposed algorithm's performance is also included here using comparison with the Gauss-based methods proposed in [12, 13].

2 DETERMINING THE CROSS-SECTION OF THE LIGHT STRIPE

In this section the edge points of light stripe are detected by Sobel operator [17] firstly, then the grey gradient direction of the edge points are calculated as the normal direction of light stripe curve. So the cross-section of light stripe can be obtained along the normal direction of edge points.

2.1 Detection of the edge point

Sobel operator is one of the pixel-level edge detection algorithms, and it can detect edge by calculating partial derivatives in 3 × 3 neighbourhood. The reason for using Sobel operator is that it is insensitive to noise and it has relatively simpler masks than other two-order operators such as Laplacian operator. According to the Sobel operator the partial derivatives in the *x*- and *y*-directions are calculated as

$$\begin{aligned} S_x = &\{I(x+1,y-1)+2I(x+1,y)+I(x+1,y+1)\} \\ &-\{I(x-1,y-1)+2I(x-1,y)+I(x-1,y+1)\} \end{aligned} \tag{1a}$$

and

$$\begin{aligned} S_y = &\{I(x-1,y+1)+2I(x,y+1)+I(x+1,y+1)\} \\ &-\{I(x-1,y-1)+2I(x,y-1)+I(x+1,y-1)\} \end{aligned} \tag{1b}$$

where $I(x,y)$ is the discrete grey distribution of image. The gradient value of each pixel is calculated according to $g(x,y)=\sqrt{S_x^2+S_y^2}$, then a threshold value, t, is selected. If $g(x,y)>t$ then this point is regarded as an edge point. The Sobel operator also can be expressed as the form of two masks, as shown in Figure 1. Two masks are used to calculate S_x and S_y, respectively. By this way all the edge points of light stripe can be detected in pixel-level by means of the operator, as shown in Figure 2.

2.2 Determining the normal direction

In order to obtain the cross-section of light stripe the normal directions of the edge points need to be determined first. In this paper the grey gradient of the edge point is approximated as the normal direction of light stripe curve. So,

-1	-2	-1
0	0	0
1	2	1

-1	0	1
-2	0	2
-1	0	1

FIGURE 1
Masks of the Sobel operator.

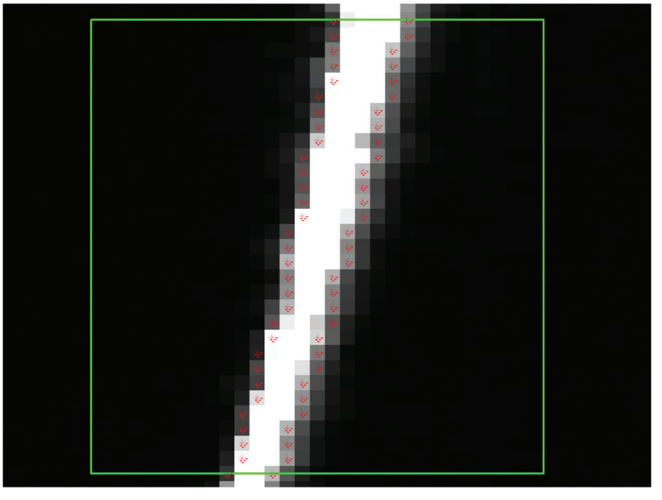


FIGURE 2
Edge points of the light stripe.

the normal direction of edge point, (x_0,y_0) can be expressed as (S_{x_0}, S_{y_0}) where

$$S_{x_0} = \{I(x_0+1, y_0-1) + 2I(x_0+1, y_0) + I(x_0+1, y_0+1)\} \\ - \{I(x_0-1, y_0-1 + 2I(x_0-1, y_0) + I(x_0-1, y_0+1)\} \tag{2a}$$

and

$$S_{y_0} = \{I(x_0-1, y_0+1) + 2I(x_0, y_0+1) + I(x_0+1, y_0+1)\} \\ - \{I(x_0-1, y_0-1) + 2I(x_0, y_0-1) + I(x_0+1, y_0-1)\} \tag{2b}$$

In this way the normal directions of all the edge points are calculated, as shown in Figure 3. Then, the cross-section of light stripe can be obtained along the normal direction of edge point.

3 THE ALGORITHM FOR EXTRACTING THE LIGHT STRIPE CENTRE

In previous methods [12, 13] the grey distribution in the cross-section of light stripe is often considered as a Gaussian profile, as shown in Figure 4. However, due to limit of the camera sampling depth in the process of acquiring the image, real grey distribution is shown in Figure 5. This phenomenon would lead to low-precision detection using above methods. So, this paper presents a new algorithm based on the spatial moment theory to determine the location of light stripe centre.

First, an ideal 1-D grey model of light stripe is given, as shown in Figure 6. The model is characterized by four parameters: background intensity, h, grey contrast, k, and both sides of light stripe, l^1 and l_2. The light stripe is considered as a rectangular pulse which is confined to the range of −1 to 1 and the location of light stripe centre is $\frac{l_1 + l_2}{2}$. The moments of a continuous function, $f(x)$ of order p are defined by

$$M_p = \int_{-1}^{1} x^p f(x)dx \qquad p = 0,1,2,3....... \tag{3}$$

where $f(x)$ is the ideal 1-D light stripe model, and the desired moments can be found using Equation (3). Since sample moments, which are obtained by calculating grey values of the light stripe, can be used to estimate the first four moments: M_0, M_1, M_2 and M_3, the following equations can be obtained:

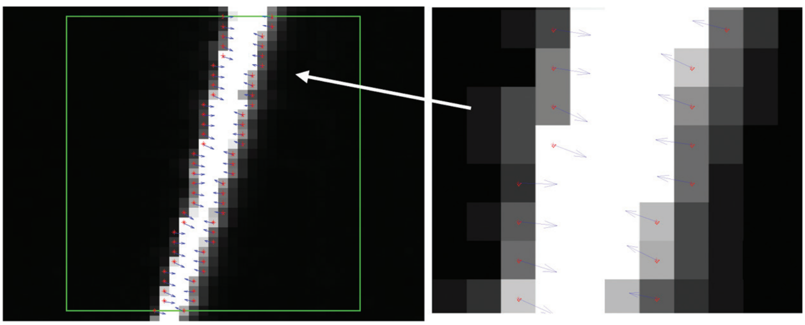


FIGURE 3
Normal directions of the edge points.

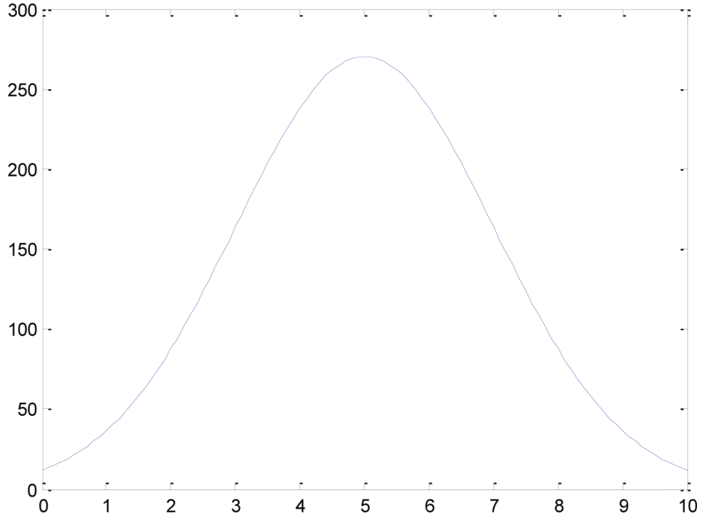


FIGURE 4
Grey distribution as a Gaussian profile.

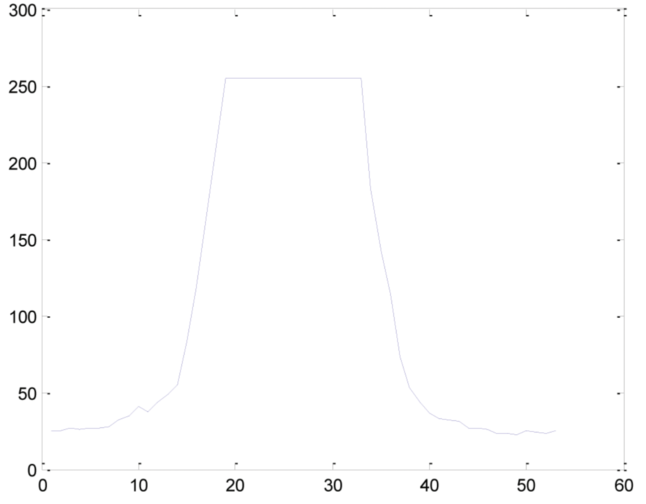


FIGURE 5
Real grey distribution.

$$M_0 = h\int_{-1}^{1} dx + k\int_{l_1}^{l_2} dx = 2h + k(l_2 - l_1) \tag{4}$$

$$M_1 = h\int_{-1}^{1} xdx + k\int_{l_1}^{l_2} xdx = \frac{1}{2}k(l_2^2 - l_1^2) \tag{5}$$

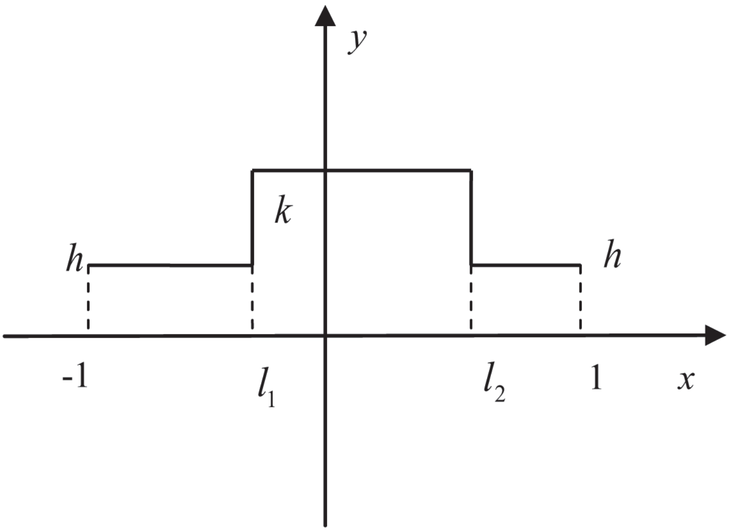


FIGURE 6
Ideal 1-D model of a light stripe.

$$M_2 = h\int_{-1}^{1} x^2 dx + k\int_{l_1}^{l_2} x^2 dx = \frac{2}{3}h + \frac{1}{3}k(l_2^3 - l_1^3) \tag{6}$$

and

$$M_3 = h\int_{-1}^{1} x^3 dx + k\int_{l_1}^{l_2} x^3 dx = \frac{1}{4}k(l_2^4 - l_1^4) \tag{7}$$

Now, when Equation (7) is divided by Equation (5) one will obtain

$$l_2^2 + l_1^2 = \frac{2M_3}{M_1} \tag{8}$$

and subtracting Equation (4) from Equation (6) after it is multiplied by 3 yields

$$k(l_2 - l_1) - k(l_2^3 - l_1^3) = M_0 - 3M_2 \tag{9}$$

and subtracting Equation (5) from Equation (7) after it is multiplied by 2 yields

$$\frac{1}{2}k(l_2^2 - l_1^2) - \frac{1}{2}k(l_2^4 - l_1^4) = M_1 - 2M_3 \tag{10}$$

Now, dividing Equation (9) by Equation (10) will give

$$\frac{k(l_2-l_1)-k(l_2^3-l_1^3)}{\frac{1}{2}k(l_2^2-l_1^2)-\frac{1}{2}k(l_2^4-l_1^4)}=\frac{M_0-3M_2}{M_1-2M_3} \tag{11}$$

Through simplification, Equation (11) can be derived as

$$\frac{1-2\times\left(\frac{l_1+l_2}{2}\right)^2-\frac{l_1^2+l_2^2}{2}}{\left(\frac{l_1+l_2}{2}\right)\cdot(1-(l_1^2+l_2^2))}=\frac{M_0-3M_2}{M_1-2M_3} \tag{12}$$

Now, if we let $x=\frac{l_1+l_2}{2}$, $a=\frac{M_0-3M_2}{M_1-2M_3}$ and $b=l_2^2+l_1^2=\frac{2M_3}{M_1}$, then Equation (12) can be expressed as

$$2x^2+a(1-b)x+\frac{b}{2}-1=0 \tag{13}$$

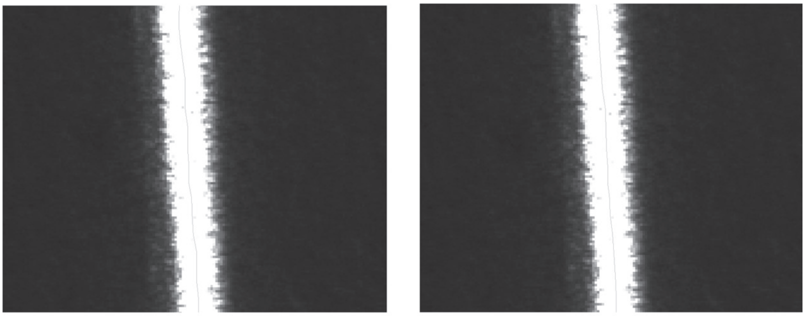
and the solution of Equation (13) is

$$x=\frac{-a(1-b)\pm\sqrt{a^2(1-b)^2-4(b-2)}}{4} \tag{14}$$

and the root which is in the range of [–1, 1] is the desired solution. In this way a closed-form solution for detecting light stripe centre with subpixel accuracy is given.

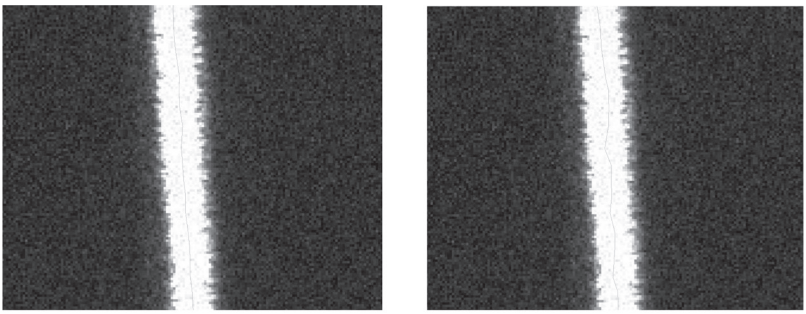
4 EXPERIMENTAL PROCEDURES AND ALGORITHM VERIFICATION

To verify the robustness and run time of the proposed detection method the following experiments were carried out. In the experiments the light stripe, which is emitted by a semiconductor laser is captured by a charge-coupled device (CCD) camera with a 25 mm lens. The light stripe centre in the image are detected by the proposed and Gauss-based method [12, 13], respectively,



(a) (b)

FIGURE 7
Results from detecting the light stripe centre using (a) the proposed method and (b) the Gauss-based method.



(a) (b)

FIGURE 8
Results from detecting the light stripe centre after adding noise using (a) the proposed method and (b) the Gauss-based method.

as shown in Figure 7. Then adding the white Gaussian noise into the image, the light stripe centre in the image is detected again by two methods, as shown in Figure 8. It is can be observed that there is little change in the detection of proposed method. This shows that the method has better robustness against the noise. Moreover, the run time of the proposed and Gauss-based method were tested in this study.

Compared with the Gauss-based methods, the proposed method can shorten the running time by 95%. For example, to detect a cross-section of the light stripe containing 53 pixels, the run time of proposed method is 0.000057 seconds, and the Gauss-based method is 0.001289 seconds. Testing of this new detection method demonstrates that it is more efficient.

5 CONCLUSIONS

A new light stripe centre detection method that combines Sobel operator and spatial moments operator is introduced in this study. Sobel operator is used to detect all probable edge points of light stripe and the normal direction of these points are solved. Thereafter the light stripe centre in the cross-section can be detected by a moment-based method. The test result shows that robustness of the proposed method is better than the Gauss-based method, while the run time of image processing is greatly reduced, indicating this approach is more suitable for on-line accurate light stripe centre detection.

ACKNOWLEDGEMENT

This work described in this paper is partially supported by the National Nature Science Foundation of China under Grant No. 61201084.

REFERENCES

[1] Zhang Z.F., Feng Q.B., Gao Z. and Kuang C.F. A new laser displacement sensor based on triangulation for gauge real-time measurement. *Optics & Laser Technology* **40**(2) (2008), 252–255.
[2] Schalk P., Ofner R. and O'Leary P. Pipe eccentricity measurement using laser triangulation. *Image Vision Computing* **25**(7) (2007), 1194–1203.
[3] Lombardo V., Marzulli T., Pappalettere C. and Sforza P. A time-of-scan laser triangulation technique for distance measurements. *Optics and Lasers in Engineering* **39**(2) (2003), 247–254.
[4] Izquierdo M.A.G., Sanchez M.T., Ibanez A. and Ullate L.G. Subpixel measurement of 3D surfaces by laser scanning. *Sensors and Actuators A: Physical* **76**(1-3) (1999), 1–8.
[5] Jang J.H. and Hong K.S. Detection of curvilinear structures and reconstruction of their regions in grey-scale images. *Pattern Recognition* **35**(4) (2002), 807–824.
[6] Geman D. and Jedynak B. An active testing model for tracking roads in satellite images. *IEEE Transactions on Pattern Analysis and Machine Intelligence* **18**(1) (1996), 1–14.
[7] Luo P.F., Pan S.P. and Chu T.C. Application of computer vision and laser interferometer to the inspection of line scale. *Optics and Lasers in Engineering* **42**(5) (2004), 563–84.
[8] Apolinar J. and Muñoz R. Calibration modeling for mobile vision based laser imaging and approximation networks. *Journal of Modern Optics* **57**(17) (2010), 1583–1597.
[9] Družovec M. and Ačko B. and Godina A. Robust algorithm for determining line centre within a video positional measuring system. *Optics and Lasers in Engineering* **47**(11) (2009), 1131–1138.
[10] Steger C. An unbiased detector of curvilinear structures. *IEEE Transactions on Pattern Analysis and Machine Intelligence* **20**(2) (1998), 113–125.
[11] Ho G..J. and Kim J. Model-based light stripe detection for indoor navigation. *Optics and Lasers in Engineering* **47**(1) (2009), 62–74.
[12] Ho G..J., Jae K.S. and Hyoung J.K. A closed form self calibration of one-dimensional light stripe feature width function for indoor navigation. *IEEE Transactions on Intelligent Transportation Systems* **11**(4) (2010), 942–953.
[13] Fisher R.B. and Naidu D.K. A comparison of algorithm for subpixel peak detection. *Image Technology* (1996), 385–404.

[14] Gonzalez H., Galvan C. and Muñoz J.A. Image processing automatic interferometric calibration system for line scales. *Proceedings of the SPIE* **5190** (2003), 93–102.

[15] Muñoz J.A and Galvan C. Robust line detection for line scale calibration. *Advanced Mathematical and Computational Tools in Metrology and Testing (AMCTMT VIII)*. 23-25 June 2008, Paris, France. pp. 23–25.

[16] Lyvers E.P. and Mitchell O.R. Precision edge contrast and orientation estimation. *IEEE Transactions on Pattern Analysis and Machine Intelligence* **10**(6) (1988), 927–937.

[17] Sobel I. Neighbourhood coding of binary images fast contour following and general array binary processing. *Computer Graphics and Image Processing* **8** (1978), 127–135.

View publication stats