Optik 125 (2014) 6570–6575

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

The high precision positioning algorithm of circular landmark center in visual measurement

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ARTICLE INFO

Article history:
Received 22 November 2013
Accepted 20 June 2014

Keywords:
Zernike moments
Center location
Error compensation

ABSTRACT

For vision measurement in the center circle landmark location problem, an improved center of the ellipse based on Zernike moments sub-pixel positioning algorithm was proposed. First, using Sobel operator edge of the image pixel level positioning and then use the constructed Zernike moments to solve the model, combined with Zernike orthogonal polynomials and completeness and plural moment magnitude rotational invariance calculated edge sub-pixel position; followed by analysis of the principle deviation generated by the moments template and ideals model, a correction formula was proposed to compensate and improved edge criterion used to image sub-pixel edge positioning; finally, using the least-squares ellipse fitting algorithm fitting circle center, reverse edge point, filtered residuals larger point, and then precise positioning of the ellipse center. The experimental results show that this method has good stability and high positioning accuracy can be efficiently used in many applications.

1. Introduction

In optical measurements, the circular mark of the rotation invariance and easy to implement, etc., are widely used in target identification and localization. Since the perspective projection transformation is often transformed into a circular target ellipse, so vision measurement system, the center of the ellipse, fast and precise positioning are of great significance [1].

At present, domestic and foreign scholars affect central oval object detection and localization factors focused on the following aspects: camera lens distortion [2–5], edge detection algorithm [6,7], fitting algorithm [8–10] as well as the center of the circle center asymmetric projection causes deviation [11–13]. Literature [14] used gray moment and curvature to maintain access to elliptical pattern sub-pixel edge, and then directly fitted ellipse center coordinates of the calculation method although only the first three gray moment, but gray moment solving speed, noise immunity sex, the positioning accuracy is not high. Literature [15] proposed a parameter fitting quadratic curve type cannot ensure the edge positioning accuracy while the current method of using the geometric characteristics of over-reliance on the coarse positioning geometric information, underutilized image gray value information, leading edge location is not enough accurate. Literature [11] gives the center deviation compensation method requires prior knowledge of camera parameters is known, combined with the knowledge of epistolary constraint; the calculation process is more complex.

This paper focuses on the center of the circle edge detection algorithm error factor, presents an improved algorithm about center sub-pixel positioning of the circular marks based Zernike moments. The algorithm first target on the edge of a circular course location; then according to the edge of the rough location pixel level edge information as a result of amended moment templates generated by the principle of deviation; application improved Zernike moments judgment that the edge of the condition for the sub-pixel positioning. Sub-pixel edge on access points to calculate the least squares fit circular mark coordinates of the center point through a reverse edge, filtered residuals larger point, and then fitting the coordinates of the center circle flag, to achieve circular mark point precision positioning.

The following section, we describe the basic and improved principles of the algorithm with detection of the sub-pixel edge, then locate the center of the features. Section 3 presents the analysis of the improved algorithm performance. Experiments with synthetic and real data are described in Section 4. Finally, we discuss the experimental results of the proposed algorithm and conclude the paper.

2. Description of the algorithm

2.1. Position at the early edge

Elliptical target image of the whole image is often only a small part. According to the rough location of the ellipse center position

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http://dx.doi.org/10.1016/j.ijleo.2014.08.042
0030-4026/

and the length of long axis, extract ellipse "region of interest" (ROI, region of interest), locate the edge only in the region of interest, can improve the speed of the algorithm.

First, mark the edge of the elliptical primary positioning information for pixel-level, image edge point detection can be a tough order differential edge detection operator—Sobel to achieve, specific steps as follows:

(1) The use of the operator within the image $F(x, y)$ point (i, j) to calculate the gray axis (x, y) in both directions along the partial derivative of S_x and S_y.
(2) Calculate gradient using the formula $g(i,j) = \sqrt{S_x^2 + S_y^2}$. Let the threshold value is t, when $g(i,j) > t$, the point is the edge point.

Using the Sobel operator edge detection, obtained pixel coordinates $(x_1, y_1, \cdots, x_n, y_n)$ of the image $F(x, y)$.

2.2. Effective edge detection

The general equation of an ellipse:

$$F(\alpha, p) = Ax^2 + Bxy + Cy^2 + Dx + Ey + F = 0, \tag{1}$$

wherein, $\alpha = [A\,B\,C\,D\,E\,F]$, $p = \left[x^2\,xy\,y^2\,x\,y\,1\right]^T$. For any edge point (x_i, y_i) on the ellipse, $F(\alpha, p)$indicates the algebraic distance $F(\alpha, p) = 0$ to that point, introduce the constraint $\|\alpha\|^2 = 1$ and establish the following objective function:

$$F(\alpha) = \min \sum_{i=1}^{n} F^2(\alpha, p_i) + M\left(\|a\|^2 - 1\right)^2. \tag{2}$$

Among them, M means the penalty factor, thus converted into nonlinear least squares problems. Center coordinates can be calculated:

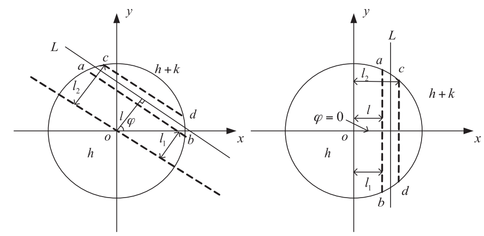
$$\begin{cases} X_c = \dfrac{BE - 2CD}{4AC - B^2} \\ Y_c = \dfrac{BD - 2AE}{4AC - B^2} \end{cases}. \tag{3}$$

Major and minor axes, respectively were:

$$\begin{cases} a^2 = \dfrac{2\left(AX_c^2 + CY_c^2 + BX_cY_c - 1\right)}{A + C + \sqrt{(A - C)^2 + B^2}} \\ b^2 = \dfrac{2\left(AX_c^2 + CY_c^2 + BX_cY_c - 1\right)}{A + C - \sqrt{(A - C)^2 + B^2}} \end{cases}. \tag{4}$$

Effective rounded edge detection is an iterative law, which can be removed in an iterative process void residuals greater than the average of the edge points. Edge points to keep in force until the residual convergence. Specific steps as follows:

(1) Get the edge from the edge point location coordinates, obtained ellipse fitting center $O_I = \left(\hat{X}_{c,I}, \hat{Y}_{c,I}\right)$, and the length of the shaft $\left(\hat{a}_I, \hat{b}_I\right)$, I as the number of iterations.
(2) Calculate the residuals: $\varepsilon_{I,j} = \dfrac{\left(x_{I,j} - \hat{X}_{c,I}\right)^2}{\hat{a}^2} + \dfrac{\left(y_{I,j} - \hat{Y}_{c,I}\right)^2}{\hat{b}^2} - 1$ of each edge point of this iteration, Which $j \in E_I$, E_I represents the iteration of the set of all edge points; $\left(x_{I,j}, y_{I,j}\right)$ represents coordinates of each edge point. Residual sum of squares is $S_I = \sum \varepsilon_{I,j}^2$, calculated $\bar{\varepsilon}_I = \sqrt{S_I / N_E}$ as the average residuals, N_E as the number of elements in the collection E_I.
(3) Determine the residuals of each edge points $\varepsilon_{I,j}$ and the average size of residuals $\bar{\varepsilon}_I$, if less than the average residuals is recorded as valid edge point, otherwise referred to as invalid edge points.



(a) The original image edge (b) After rotating of the image edge

Fig. 1. The ideal model of sub-pixel edge detection.

Discard invalid point edge collection of information is reduced to E_{I1}.
(4) By the set of edge points E_{I1}, fitting an ellipse to recalculate the axis $\left(\hat{a}_I', \hat{b}_I'\right)$ and the center $O_{I1} = \left(\hat{X}_{c,I}', \hat{Y}_{c,I}'\right)$, when the distance between O_I and O_{I1} is smaller than the threshold value and $E_I = E_{I1}$, the end of the calculation; otherwise repeat step (2).

2.3. Improved Zernike moment circular center location algorithm

Ghosal and Mehrotal first proposed Zernike orthogonal moment to detect sub-pixel edge [16], in their algorithm to create the ideal step gray scale model. Through the image of three different orders Zernike moments computation model 4 parameters to determine these four parameters is determined based on the edges of objects in the image edges. Literature [17] does not consider the template effect is improved for Ghosal algorithm, the extracted edge Ghosal algorithms with improved but still thick, and thus the lower edge of the positioning accuracy. Based on the analysis algorithm of Ghosal, the algorithm in this paper conditions for improved edge judgment calculated Zernike 7×7 template coefficient and the Z_{00}, Z_{10}, Z_{20} extended to the coefficient templates Z_{31}, Z_{40}.

Fig. 1 shows an image of the ideal model for the sub-pixel edge detection. Wherein, the circle is a unit circle, the parts by the unit circle contains representatives of the ideal edge, the gray value on both sides of the inner L, respectively, is h and $h+k$, k as the gray-scale difference, l as the origin to the edge of the theoretical distance, φ as the angle between l and x axis. In the Fig. 1(a), the two dotted lines ab, cd corresponding to the different conditions of the order of Zernike moments of image edge, l_1, l_2 as the distance between the original dot to the lines ab, cd, the values were given by Eq. (14). Fig. 1(b) is the model after the rotation angle φ by the (a).

Zernike moments two-dimensional image can be expressed as:

$$Z_{nm} = \frac{n+1}{\pi} \iint_{x^2+y^2 \le 1} f(x,y) V_{nm}^*\left(\rho, \theta\right) dxdy. \tag{5}$$

Under the conditions of two-dimensional images of discrete Zernike moments can be expressed as:

$$Z_{nm} = \frac{n+1}{\pi} \sum_x \sum_y f(x,y) V_{nm}^*\left(\rho, \theta\right), \tag{6}$$

where, "*" denotes the complex conjugate, $V_{nm}\left(\rho, \theta\right)$ is the integral kernel function, expressed in polar coordinates as follows:

$$V_{nm}\left(\rho, \theta\right) = \sum_{s=0}^{(n-|m|)/2} \frac{(-1)^s (n-s)!\, \rho^{n-2s}}{s!\left(\frac{n+|m|}{2} - s\right)!\left(\frac{n+|m|}{2} - s\right)!} e^{-im\theta}. \tag{7}$$