Subpixel edge extraction of part ant colony optimization-based and dimensional measurement

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Abstract

Put forward a method combined improved ant colony and Zernike moment to detect image subpixel edge aiming at traditional ant colony algorithm’s drawback of long time consumption and easily to be affected by noise. The methods improved parameters from clustering centre setting, clustering operator selecting and pheromone updating, then extracted subpixel image edge based on Zernike moments. Therefore, the result of image edge extraction is good and effective. Lastly, least square fitting is used to locate coordination of image edge and bearing of SKF 32308 J2/Q dimensions such as inner and outer diameters were measured. The result shows that the algorithm proposed can well to measure circular parts dimensions and has high precision.

Keywords: Subpixel, Ant Colony Optimization, Bearing, edge detection

1 Introduction

Vision inspection as non-contact measurement has widely been paid a wide attention, and was focused on geometry and surface quality detection [1, 2]. Method of vision inspection can be divided into visual detection region-based and edge detection according to different principle of computer vision [3, 4]. Edge detection depends on the change of part image greyscale, and is high stable and fixed. Therefore, edge extraction algorithm with high accuracy is a basis of vision inspection. Commonly algorithms of edge inspection locate image edge by operator depending upon change of image neighbourhood grey, e.g., Roberts, Prewitt, Sobel, Laplacian and Canny operators. It is difficult to satisfied with result of edge detection for all those traditional operators because of large calculation, a long time, poor anti-interference ability [5, 6]. Moreover, pixel-level edge detection has been unable to meet the need of detection with the continuous increasing of machining precision. Many scholars began to study subpixel image edge extraction algorithms. e.g., Lyvers et al proposed spatial moment method for edge detection, but calculation are huge [7]. Nowadays, ant colony algorithm was applied to digital image processing by experts all over the world. e.g., Hoseine studied hybrid ant colony algorithm to optimize image in details, effectively enhance the contrast of the image [8]. However, the noise cannot be effectively removed due to the same selection probability between noise and edge during ant searching process. XUE Qin presented image segmentation algorithm based on ant colony gradient operator, which it can be segmented from the similar background and target grey value image [9]. WANG Dong applied Sobel operator and ant colony algorithm to search local edge, which detect more effective infrared image [10]. However, above improved algorithms are unable to avoid drawbacks of the gradient and ant colony algorithm that time for searching non-edge region is long, and detection of edge orientation is limited. Therefore, a method combined improved ant colony and Zernike moment to detect image subpixel edge was proposed, the method improved parameters from clustering centre setting, clustering operator selecting and pheromone updating, and then extracted subpixel image edge with high speed and accuracy based on Zernike moments. The dimension of type SKF 32308 J2/Q bearing was measured in the experiment to testify the accuracy of measurement.

2 Ant Colony Optimization

2.1 ANT COLONY ALGORITHM

Ant colony algorithm (ACA) is an optimization algorithm proposed by Italian researchers M. Dorigo etc. in 1991. In the past ten years, ACA has been successfully applied to the combinatorial optimization problems [11-13]. Feeding on ants, they can always find the optimal path from nest to food source. When the path is blocked, ants can bypass the barrier and find other optimal path again.
Many ants foraging behaviour made up a positive feedback of information process that formed the optimal path. Its essence is a constant clustering process. The formulation of ACA in image edge detection can be described as follows.

Each pixel $X_j (j = 1, 2, ..., N)$ from original image is supposed to an ant, and then the pixel is taken as two-dimensional vectors of grey and gradient. Now the similarity between pixel $X_j$ and $X_i$ is represented by Euclidean distance, so

$$d_y = \frac{1}{\eta_y} = \sqrt{\sum_{k=1}^m p_k (x_{ak} - x_{bk})^2}, \quad (1)$$

where $m$ is ant pixel dimension and $m$ equal to 2, $p$ represents weight factor, $\eta_y$ is heuristic function. The formula of ant pheromones in paths is computed as follows.

$$\tau_y (t) = \begin{cases} 0 & (d_y \leq r) \\ 1 & (d_y > r) \end{cases}, \quad (2)$$

where $r$ is given threshold. When distance of ant pixel $d_y$ is less than or equal to $r$, ant pheromones of the path is 1, or else is 0. Any pixel transition probability from $X_i$ to $X_j$ is described that

$$P_{ij} (t) = \frac{\tau^\alpha_y (t) \eta^\beta_y (t)}{\sum_{s=3}^{S} \tau^\alpha_s (t) \eta^\beta_s (t)}, \quad (3)$$

where $\alpha$ and $\beta$ are selected path impact factors of ant clustering, respectively. $S$ is feasible path sets of ant, and $s$ is an optional path. Pheromone of each path is adjusted by formula (4) with the continuous ant’s moving.

$$\tau_y (t+1) = (1 - \rho) \tau_y (t) + \tau_y, \quad (4)$$

where $\rho$ represents volatile coefficient of pheromone, $1 - \rho$ is residual factor of pheromone, the scope of $\rho$ belongs to [0, 1]. $\tau_y$ is incremental pheromone in loop, and computed by formula (5).

$$\tau_y = \sum_{k=1}^{m} \tau^k_y, \quad (5)$$

And then

$$\Delta \tau^s_y = \frac{Q}{d_y}, \quad (6)$$

where $Q$ is an integer greater than 0.

### 2.2 OPTIMIZED ANT COLONY ALGORITHM

The time of ant search process is very long because of blind and random finding. Therefore, the paper sets clustering centre to guide ant to run together, and proposes pheromone updated algorithm to void premature, which improve accuracy and rapidity of edge detection.

1. Initial clustering centre setting

There are some image segmentation errors because one-dimensional grey histogram used by the traditional ant colony algorithm cannot express local spatial information. The two-dimensional grey histogram is clustered in the paper, namely the initial cluster centre is composed of histogram of the pixel and neighbourhood mean grey distribution. The steps are as follows.

**Step1.** Draw 2D grayscale of measured original image.

**Step2.** For the best one-dimensional projection on two-dimensional grayscale, reduce dimension.

**Step3.** Select peak as the initial clustering centre from one-dimensional projection histogram.

2. Classification and calculation for clustering centre

Taking the pixel grey value, neighbourhood characteristic value, the pixel point gradient value as the first feature point, second point, third point, and when the gradient value of clustering centre is zero, then setting neighbourhood features as eight. If there are large points of clustering centre relatively, we can decide the clustering centre into image edge point centre, then set neighbourhood feature value as six, else take it as noise points clustering centre, set neighbourhood feature value as 3. The distance from pixel points to clustering centre is that:

$$d_y = \sqrt{\sum_{k=1}^m p_k (x_{ak} - c_{jk})^2}, \quad (7)$$

where $C_j$ is clustering centre, and $C_j = (c_{j1}, c_{j2}, ..., c_{jM}), j = 1, 2, ..., M$.

3. Updating pheromone

Traditional ant colony algorithm identified similar typical ants to the same class, which can lead to pheromone that is not searched reduce to zero and perhaps emerge wrong image segmentation problems. Therefore, this paper proposed global adaptive updated pheromone algorithm.

$$\tau_y (t+1) = (1 - \rho) \tau_y (t) + \tau, \quad (8)$$

$$\tau_{mean} = mean(\tau^{i1}, \tau^{i2}, ..., \tau^{in}), \quad (9)$$
\[
\begin{align*}
\tau_{1} & \geq \tau_{\text{mean}} \quad \tau = \tau_{\text{mean}}, \\
\tau_{i} & < \tau_{\text{mean}} \quad \tau = \tau_{i},
\end{align*}
\]  

(10)

where \(\tau_{1}, \tau_{2}, \ldots, \tau_{n}\) is a respective pheromone increment optional path, and \(\tau_{\text{mean}}\) is mean of pheromone increment. It can be seen pheromone increment is mean value when a path pheromone increment is exceed to mean value, which can ensure ants search are not in less paths. The optimized ant colony algorithm is described as follows.

**Step1.** Initialize ant colony parameters and setting number of cycles.

**Step2.** Use the two-dimensional grayscale measured image to find clustering centre and partitioning image edge, target points, noise and others by Laplasse operator.

**Step3.** Compute similar function, heuristic function between pixel points and clustering centre of measured image.

**Step4.** Select the maximum probability of clustering centre.

**Step5.** Update pheromone and calculating the clustering centre value.

**Step6.** Execute Step 4 again, and moving in circles, until it reaches the set of cycle number.

Subpixel edge detection with Zernike moment

It is common algorithm to extract subpixel image edge using spatial moment. Reference [14] computed four parameters according to six spatial moments. However the algorithm is very complex and inefficient. In this paper, we proposed Zernike moment to detect image edge that reduce computation and complexity, the algorithm can calculate four parameters only by three Zernike moments.

**Definition1.** The \(n^{th}\) order Zernike moment of image \(f(x, y)\) is

\[
A_{nm} = \frac{n+1}{\pi} \int_{-1}^{1} \int_{-\pi}^{\pi} f(x, y) V_{nm}^{*}(\rho, \theta) d\theta d\rho.
\]  

(11)

where \(V_{nm}^{*}(\rho, \theta)\) represents integral function, \(m\) and \(n\) are integers, which are satisfied with condition that \(n \geq 0\) and \(n - |m|\) is even number.

Figure 1 is ideal unit circle step-edge model, where \(k\) is step-gradients, \(h\) is grey background and the grey value of shade is \(h+k\), and \(l\) is vertical distance from circle centre to edge, \(\phi\) is angle between vertical edge and \(X\) axis. If image is rotated angle \(\phi\) clockwise, which is parallel the \(Y\) axis, as shown in Figure 2, and Figure 3 is profile of rotated ideal step-edge model.

**Setting rotated image** \(f'(x, y)\) is symmetric about \(X\) axis, then

\[
\int_{-\pi}^{\pi} \int_{-1}^{1} f'(x, y) y dy dx = 0.
\]  

(12)

The important feature is rotational invariant of Zernike moment. If an image is rotated by angle \(\phi\), and only the phase is shifted before and after rotation, the amplitude keeps unchanged. The step Zernike moments of rotational image can be derived combined with Figure 3.

\[
A'_{\text{00}} = A_{\text{00}} = h\pi + \frac{k}{2} \pi - k \sin^{-1}(l) - kl\sqrt{1-l^2},
\]  

(13)
\[ A_{11} = A_i e^{ik} = \frac{2k}{3} (1-l^2)^{2/3}, \]  
\[ A_{20} = A_i = \frac{2k}{3} l(1-l^2)^{2/3}. \]  

Simultaneous equation, then

\[ l = \frac{A_{20}}{A_{11}} \quad K = \frac{3A'_{11}}{2(1-l^2)^{1/2}}. \]  

Template size of edge detection is \( N \times N \), the calculation of Zernike moments of edge is shown in formula (17).

\[
\left[ \begin{array}{c}
  x_i \\
  y_i
\end{array} \right] = \left[ \begin{array}{c}
  x \\
  y
\end{array} \right] + \frac{Nl}{2} \left[ \begin{array}{c}
  \cos(\phi) \\
  \sin(\phi)
\end{array} \right],
\]  

where \((x, y)\) is origin of coordinates in Figure 1, \((x_i, y_i)\) is subpixel coordinate of image edge. In the algorithm, four parameters can be computed by three Zernike moments, i.e., \( \phi, l, k, h \). And \( \delta = 1/\sqrt{2} \) pixel, \( \tau \) is threshold that can be chosen freely in fact. Now algorithm of subpixel edge detection Zernike moments-based is described as follows.

**Step 1.** Calculate moments \( A_{00}, A_{11}, A_{20} \) using image template an convolution.

**Step 2.** Calculate moments \( A_{00}, A_{11}, A_{20} \) after rotated \( \phi \) angle by means of rotational invariant.

**Step 3.** Calculate \( l \) and \( k \) by formula (16).

**Step 4.** Determine step-grey threshold of \( \tau \).

**Step 5.** Find pixel points that meet condition of \( k \geq \tau \cap l \leq \delta \), then the point is subpixel edge, we can compute the subpixel coordinate by formula (17).

### 3 Experiment and Discussion

In experiment, bearing of SKF 32308 J2/Q was studied and tested. Geometric parameters of bearing mainly include inner and outer diameters. The camera used is Costar brand, and the lens is a Pentax made in Japan. The original image is obtained as shown in Figure 4.

The objective of this experiment is to acquire bearing image, measure geometric size and verify the accuracy of image edge detection proposed algorithm by comparison. The steps and image-processing algorithm are presented as follows.
Step 2. Image segmentation optimized ant colony algorithm-based aiming at pre-processing image

In the step, the image edge of Figure 6 is detected using optimized ant colony algorithm. In the experiment, we compare different image edge segment results for Sobel operator, Canny operator, traditional ant colony algorithm and optimized ant colony algorithm proposed in the paper. The experimental results are shown in Figure 7, Figure 8, Figure 9 and Figure 10.

From above Figures, it can be known Sobel operator are poor results in unclear edge of image segmentation, and Canny operator have some broke down in edge contour, traditional ant colony algorithm appear poor edge continuity and easy to affected by noise. Obviously, optimized ant colony algorithm proposed in the paper has intact and full edge contours of image, and speed of segmentation is rapid and effective.

Step 3. Image subpixel edge detection Zernike moment-based

Assuming each pixel points gray value $f(x, y)$ is constant, then the gray of neighbourhood of image $(x, y)$ and $M$ of template $9 \times 9$ can be calculated by convolution, we can get Zernike moment and edge parameters. The subpixel edge points of bearing inner and outer rings can be determined according to judgement criterion of edge.

Step 4. The least square fitting and determining the inner and outer diameters of bearing and circular centre

While the bearing subpixel edge is located, the edge points must be fitted in order to define the bearing inner, outer diameter and circular centre of geometry parameters. The least square fitting is very effective in all of sub-pixel fitting methods; reference [15] explained the
least square algorithm. Figure 11 draws bearing inner and outer diameters and circular centre location.

Step 5. Calibrating bearing and converting pixel to real dimension (unit: mm).

Selecting standard bearing to calibrate and convert pixels size to real dimension by formula (18).

\[
K = \frac{d}{d_{\text{pixel}}}.
\]

where \( K \) is converted equivalence by Calibration, the value is 0.5455 pixels/mm in the paper.

After above steps are completed, we select 10 bearings that type is SKF 32308 J2/Q to measure the inner and outer diameters. Measured results were shown in Table 1.

The inner and outer diameters of standard bearing SKF 32308 J2/Q are respective 40mm and 90mm. It can be seen from Table 1 that mean error of measured inner diameter is 0.016mm, and outer diameter is 0.020mm, so the measurement accuracy meets measured demands.

4 Conclusions

Image edge detection is an important field of image processing. A method combined improved ant colony and Zernike moment is proposed to detect image subpixel edge in the paper. There are some conclusions are drawn in the paper.

(1) Ant colony algorithm is wide application for image classification and edge detection, but the precision is limited and time cost is large. Methods proposed in the paper optimize parameters from clustering centre setting, clustering operator selecting and pheromone updating. The result of image edge extraction is good and effective.

(2) The image subpixel edge can quickly be identified by Zernike moments, which only need three Zernike moments to calculate four parameters. Due to reduce computation and complexity, the algorithm can be applied to image subpixel identification online.

(3) Compared to standard bearing of SKF 32308 J2/Q, the parameter errors measured inner and outer diameters are within allowed scope, and meet the requirements of precision measurement.

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