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

Lixiong Gong[1]*, Xiangsheng Kong[2], Yong Liu[3], Min Huang[4]

[1]*School of Mechanical Engineering, Chongqing University of Technology, Chongqing 400054*

[2]*Department of Computer and Information Engineering, Xinxiang University, Xinxiang He'nan 453003*

[3]*School of Construction Machinery, Chang'an University, Xi'an Shanxi 710064*

[4]*MBA Education Center, Chongqing University of Technology, Chongqing 400050*

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 Zerinke 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 grayscale, 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 Zerinke 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_i and X_j is represented by Euclidean distance, so

$$d_{ij} = \frac{1}{\eta_{ij}} = \sqrt{\sum_{k=1}^{m} p_k (x_{ik} - x_{jk})^2} \ , \tag{1}$$

where m is ant pixel dimension and m equal to 2, p represents weight factor, η_{ij} is heuristic function. The formula of ant pheromones in paths is computed as follows.

$$\tau_{ij}(t) = \begin{cases} 0 & (d_{ij} \le r) \\ 1 & (d_{ij} > r) \end{cases}, \tag{2}$$

where r is given threshold. When distance of ant pixel d_{ij} 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

$$P_{ij}(t) = \frac{\tau_{ij}^{\alpha}(t) \eta_{ij}^{\beta}(t)}{\sum_{s \in S} \tau_{is}^{\alpha}(t) \eta_{is}^{\beta}(t)}, \tag{3}$$

where α and β 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.

$$\tau_{ij}(t+1) = (1-\rho)\tau_{ij}(t) + \tau_{ij}, \tag{4}$$

where ρ represents volatile coefficient of pheromone, $1-\rho$ is residual factor of pheromone, the scope of ρ belongs 0 to 1. τ_{ij} is incremental pheromone in loop, and computed by formula (5).

$$\tau_{ij} = \sum_{k=1}^{m} \tau_{ij}^{k} \ . \tag{5}$$

And then

$$\Delta \tau_{ij}^{k} = \frac{Q}{d_{ij}}, \tag{6}$$

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:

$$d_{ij} = \sqrt{\sum_{k=1}^{3} p_k (x_{ik} - c_{jk})^2} \ , \tag{7}$$

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

(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.

$$\tau_{ij}(t+1) = (1-\rho)\tau_{ij}(t) + \tau \ , \tag{8}$$

$$\tau_{imean} = mean(\tau_{i1}, \tau_{i2}, ..., \tau_{is}) \ , \tag{9}$$

Gong Lixiong, Kong Xiangsheng, Liu Yong, Huang Min

$$\begin{cases} \tau_{ij} \geq \tau_{imean} & \tau = \tau_{imean} \\ \tau_{ij} < \tau_{imean} & \tau = \tau_{ij} \end{cases}, \qquad (10)$$

where $\tau_{i1}, \tau_{i2}, ..., \tau_{is}$ is a respective pheromone increment optional path, and τ_{imean} 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 nth order Zernike moment of image $f(x, y)$ is

$$A_{nm} = \frac{n+1}{\pi} \iint_{x^2+y^2 \leq 1} f(x, y) V_{nm}^*(\rho, \theta) dx dy, \qquad (11)$$

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.

Figure1 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, ϕ is angle between vertical edge and *X* axis. If image is rotated angle ϕ clockwise, which is parallel the *Y* axis, as shown in Figure 2, and Figure3 is profile of rotated ideal step-edge model.
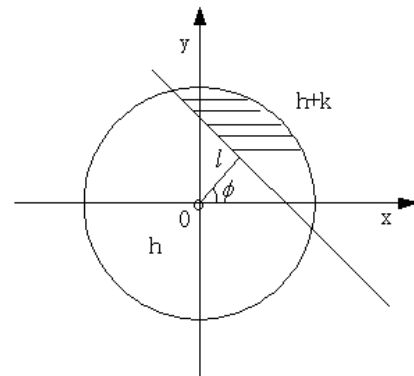

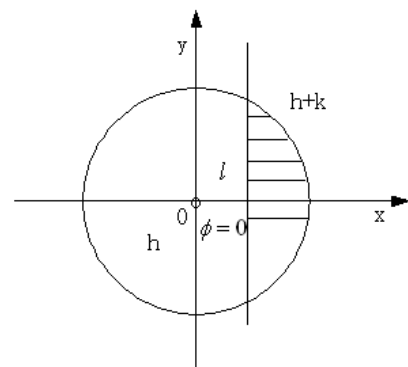FIGURE 1 Ideal step-edge model

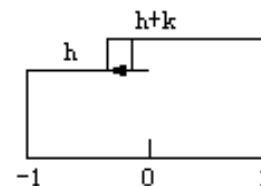FIGURE 2 Rotated ideal step-edge model

FIGURE 3 Profile of rotated ideal step-edge

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

$$\iint_{x^2+y^2 \leq 1} f'(x, y) y dy dx = 0. \qquad (12)$$

The important feature is rotational invariant of Zernike moment. If an image is rotated by angle ϕ, 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.

$$A'_{00} = A_{00} = h\pi + \frac{k}{2}\pi - k\sin^{-1}(l) - kl\sqrt{1-l^2}, \qquad (13)$$

$$A'_{11} = A_{11}e^{j\phi} = \frac{2k}{3}(1-l^2)^{2/3}, \tag{14}$$

$$A'_{20} = A_{11} = \frac{2k}{3}l(1-l^2)^{2/3}. \tag{15}$$

Simultaneous equation, then

$$l = \frac{A_{20}}{A'_{11}} \qquad K = \frac{3A'_{11}}{2(1-l^2)^{3/2}}. \tag{16}$$

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

$$\begin{bmatrix} x_s \\ y_s \end{bmatrix} = \begin{bmatrix} x \\ y \end{bmatrix} + \frac{Nl}{2} \begin{bmatrix} \cos(\phi) \\ \sin s(\phi) \end{bmatrix}, \tag{17}$$

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

Step1. Calculate moments A_{00}, A_{11} and A_{20} using image template an convolution.

Step2. Calculate moments A_{00}, A_{11} and A_{20} after rotated ϕ angle by means of rotational invariant.

Step3. Calculate l and k by formula (16).

Step4. Determine step-grey threshold of τ.

Step5. 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.

FIGURE 4 SKF 32308 J2/Q bearing original image

Step 1. Bear image pre-processing and enhancing contrast

The pre-processing of bearing image is designed by nonlinear spatial filter, which the centre is -8 and other is Laplasse filters that mean value is one with 3*3 to enhance image edge and deduce noise, as shown in Figure5. Figure6 is enhanced grey image after pre-processing. It can be seen from Figure6 that bearing image can be described in detail and help to divide image edge based on the ant colony algorithm in the next step.

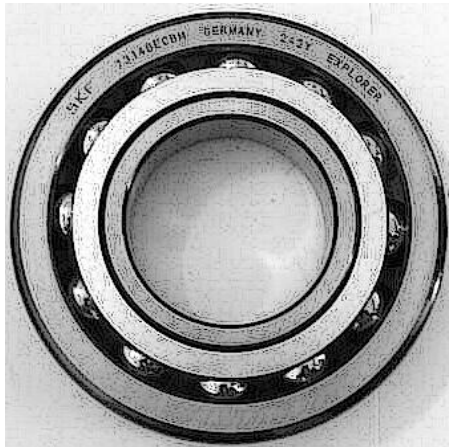FIGURE 5 Bearing image after spatial filter

243

FIGURE 6 Bearing image enhanced processing

Step 2. Image segmentation optimized ant colony algorithm-based aiming at pre-processing image

In the step, the image edge of Figure6 is detected using optimized ant colony algorithm. In the experiment, we compare different image edge segement reults for Sobel operator, Canny operator, traditional ant colony algorithm and optimized ant colony algorithm proposed in the paper. The experimental results are shown in Figure7, Figure8, Figure9 and Figure10.
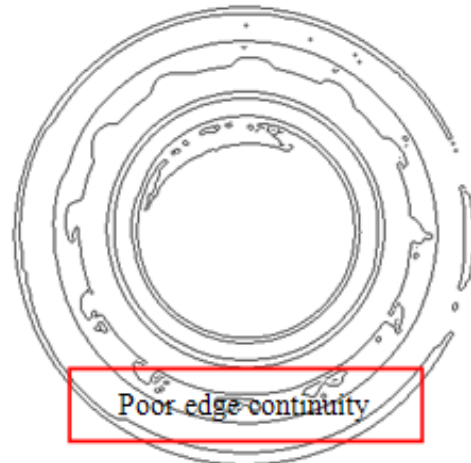

FIGURE 7 Sobel operator image sementation

FIGURE 8 Canny operator image sementation
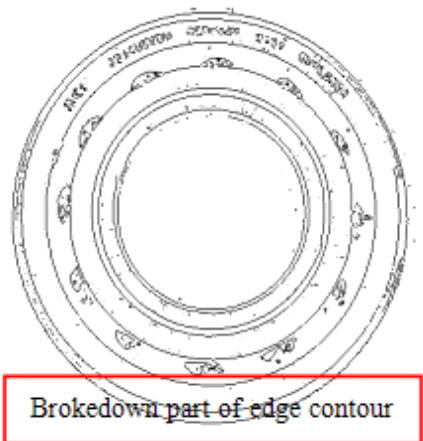

FIGURE 9 Traditional ant colony algorithm

FIGURE 10Optimized ant colony algorithm

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*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

244

least square algorithm. Figure11 draws bearing inner and outer diameters and circular centre location.

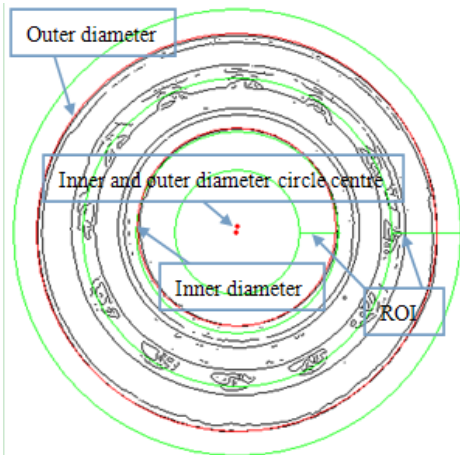*Step 5.* Calibrating bearing and converting pixel to real dimension (unit: mm).

FIGURE 11 Subpixel fitting of bearing inner and outer diameters and circular centre

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

$$K = d/d_{pixel} \ , \tag{18}$$

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 SFK 32308 J2/Q to measure the inner and outer diameters. Measured results were shown in Table 1.

TABLE 1 Measured results

Number	Coordinate of inner diameter circular centre (pixel)	Inner diameter dimension (mm)	Coordinate of outer diameter circular centre (pixel)	Outer diameter dimension (mm)
1	(304.01, 245.32)	40.01	(303.90, 248.94)	90.02
2	(303.88, 248.92)	39.99	(304.01, 245.33)	89.98
3	(304.16, 248.24)	40.00	(303.52, 245.23)	89.97
4	(302.94, 246.96)	40.00	(304.12, 245.23)	90.01
5	(304.89, 247.74)	40.02	(303.13, 246.11)	90.03
6	(304.20, 245.12)	39.97	(304.22, 245.83)	90.02
7	(304.22, 245.41)	40.01	(304.45, 245.43)	89.99
8	(305.44, 245.31)	39.97	(305.09, 246.31)	90.02
9	(301.36, 248.21)	39.97	(304.12, 246.23)	89.98
10	(303.17, 249.28)	40.02	(305.12, 246.35)	90.02

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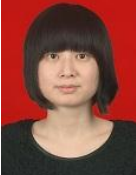
(3) Compared to standard bearing of SKF 32308 J2/Q, the parameter errors measured inner and outer diameters are within allowed scope, and meet the requirements of precision measurement.

Acknowledgments

References

[1] Malassiotis S, Strintzis M G 2003 Stereo vision system for precision dimensional inspection of 3D Holes *Machine Vision and Applications* **15**(2) 101-13

[2] Hong ZH Y, Yang Y Y, Deng SH X 2010 Research on laser measurement system of hot-rolling wheel size *Chinese Journal of Electronic Measurement and Instrument* **24**(7) 686-91 *(In Chinese)*

[3] Sun Qiucheng, Tan Qingchang, Tang Wusheng, et al. 2010 Shaft diameter measuring method based on CCD *Journal of Jilin University: Engineering and Technology Edition* **40**(5) 1273-7 *(In Chinese)*

[4] Dong Hongyan 2008 *Research on some techniques in edge detection* Changsha: National University of Defense Technology

[5] Canny J 1986, A computational approach to edge detection *IEEE Transactions on Pattern Analysis and Machine Intelligence* **8**(6) 679-98

[6] Zhang Yu-jin 2001 *Image segmentation* Science Press:Beijing

[7] Lyvers E P, Mitchell O R, Akey M L, et al. 1989 Subpixel Measurements using a moment-based edge operator *IEEE Transactions on Pattern Analysis and Machine Intelligence* (11) 1293-309

[8] Pourya Hoseini, Mahrokh G, Shayesteh 2013 Efficient contrast enhancement of images using hybrid ant colony optimisation, genetic algorithm, and simulated annealing *Digital Signal Processing* **23** 879-93

[9] Xue Qin, Chen Wei, Luo Jun-qi 2007 Research on image segmentation by ant colony algorithm based on gratitude operator *Computer Engineering and Design* **28**(23) 5660-3

[10] Wang Dong, Zhang Jing-Zhou 2011 Edge Detection of Infrared Image Based on Sobel and Ant Colony Algorithm *Journal of Henan University of Science and Technology: Natural Science* **32**(6) 38-41

[11] Dorigo M, Birattari M, Stutzle T 2006 Ant colony optimization: artificial ants as a computational intelligence technique *IEEE Computational Intelligence Magazine* **11** 28–39

[12] Dorigo M, Maniezzo V, Colorni A 1996 Man, and Cybernetics, Ant System: optimization by a colony of cooperating agents *IEEE Trans on System* **26**(1) 29-41

[13] Zhang Wei, Pan Xiao-hong, Liu Zhi, et al. 2012 Manufacturing service scheduling strategy on cloud model ant colony optimization *Computer Integrated Manufacturing Systems* **18**(1) 201-7

[14] Yu H H 1997 A visual search system for video and image databases *Proc of International Conference on Multimedia Computing and Systems, IEEE Computer Society:Washinston DC* 517-24

[15] Sun Wei, Zhang Xiao-rui, Tang Hui-qiang, et al. 2011 Lane Coordination Detection Based on Hough Transformation and Least Square Fitting *Opto-Electronic Engineering* **38**(10) 13-9

Authors

Lixiong Gong

Current positions, grade: Chongqing University of Technology, Lecturer.
University studies: Wuhan University of Technology (2007-2010), Ph.D.
Scientific interest: Quality control and measurement, Vision image detection, Advanced manufacturing and informatization.
Publications: more than 20 publications

Xiangsheng Kong

Current positions, grade: Xinxiang University, Lecturer.
University studies: PLA Information Engineering University, China (1999-2003), Bachelor.
Scientific interest: system analysis & design, software testing.
Publications: 9 publications.

Yong Liu

Current positions, grade: Doctoral candidate of Chang'an University.
Scientific interest: signal processing, Advanced manufacturing.

Min Huang

Current positions, grade: Master candidate of Chongqing University of Technology.
Scientific interest: ERP, Management information system, MBA