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Components Recognition by the Generalized Hough Transform Using Multiple Two-dimensional Parameter Spaces

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Abstract

The generalized Hough transform is a method for extracting similar figures to the template figure in an image. The generalized Hough transform needs huge memory for the four-dimensional parameter space which represents positions, scales and rotation angles of objective figures and requires processor power for conversing addresses from an image space into the parameter space. The paper proposes a method using multiple two dimensional parameter spaces for reducing the volume of the parameter space and for performing high speed processing. As the experimental result, the method provided high rate repeatability on the position, the scale and the rotation angle of extracted figures and performed short processing time.

1 Introduction

For automating assembly processes by machine vision technologies, measurement of positions, sizes and rotation angles of objects in an image is often required. The normalized correlation matching algorithm[1] is used for industrial image processing as the general-purposed method. However, this method is difficult to be applied to matching process when objects have different sizes and rotation angles from a template.

The generalized Hough transform[2] is known as a method which can be applied to different sizes and rotation angles. The generalized Hough transform is a robust method because objects are extracted by voted results into a parameter space which represents poses of objects. On the other hand, the generalized Hough transform needs a huge parameter space for voting process and much computational cost for transforming process. A method by hierarchical matching[3], a method by randomized matching[4] and a method by the separated parameter spaces[5][6] were proposed for the efficient matching process. In this paper, by substituting a four-dimensional parameter space that is necessary for the conventional generalized Hough transform for multiple two-dimensional parameter spaces, a method for measuring positions, sizes and rotation angles of objects in an image is proposed. This method purposes to measure poses of industrial components mainly.

2 The generalized Hough transform

As shown in Fig.1, in the template registration phase in the generalized Hough transform, a base point $O(x_o,y_o)$ is set in the template figure. About each edge point $P_i(x_i,y_i)$ on the template figure , the edge direction angle θ_i, the length r_i and the angle α_i of the segment P_iO are determined as geometrical parameters. Then, the template table is made as θ_i is a key and r_i and α_i are data.

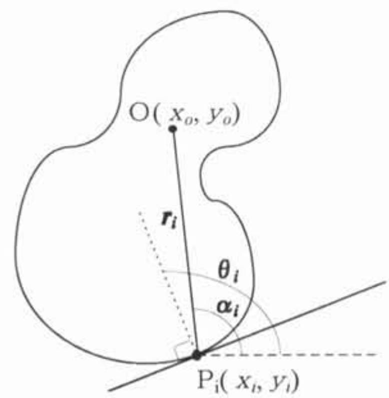

Fig.1 Geometric parameters for the generalized Hough transform

In the matching phase, the range and the resolution of positions(x,y), sizes S and rotation angles ϕ of objective figures as against the template figure are set. The four-dimensional parameter space that is composed of these dispersed four kinds of parameters is prepared. When the figure with the scale S_u and the rotation angle ϕ_v is the object for extracting, the edge direction angle θ_j is determined in an edge point $Q_j(x_j,y_j)$ in an image, and θ_i that is near to the value of θ_j- ϕ_v is searched in keys of the template table. By using the value of r_i and α_i that correspond with θ_i, the candidate coordinates (x_c,y_c) for the base point of an object figure is determined by following expressions.

$$x_c=x_j+ r_i\cdot S_u\cdot \cos(\alpha_i+ \phi_v) \quad (1)$$

$$y_c=y_j+ r_i\cdot S_u\cdot \sin(\alpha_i+ \phi_v) \quad (2)$$

Then, voting process for increasing a value stored in the coordinates (x_c,y_c,S_u, ϕ_v) in the four-dimensional parameter space is executed. Calculating candidate coordinates for the base point and voting process to coordinates are executed about all dispersed values of S and ϕ . After voting process for all edge points in an image is completed, coordinates which have many accumulated votes express positions, scales and rotation angles of similar figures to the template figure. In case of ranges of positions of objects are broad and a high precise position is required, the generalized Hough transform needs a huge four-dimensional parameter space.

3 Template registration phase

This chapter describes about the template registration phase. First, each edge point that composes the template figure is extracted. Differential values Δx_i to the x-direction and Δy_i to the y-direction on a pixel $P_i(x_i,y_i)$ are obtained by the Prewitt operator, and the edge intensity E_i is calculated by the next expression.

$$E_i=(\Delta x_i^2+ \Delta y_i^2)^{1/2} \quad (3)$$

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Edge points	θ_i	r_i	α_i
1	θ_1	r_1	α_1
2	θ_2	r_2	α_2
•	•	•	•
•	•	•	•
i	θ_i	r_i	α_i
•	•	•	•
•	•	•	•
N	θ_N	r_N	α_N

Fig.2 Template table

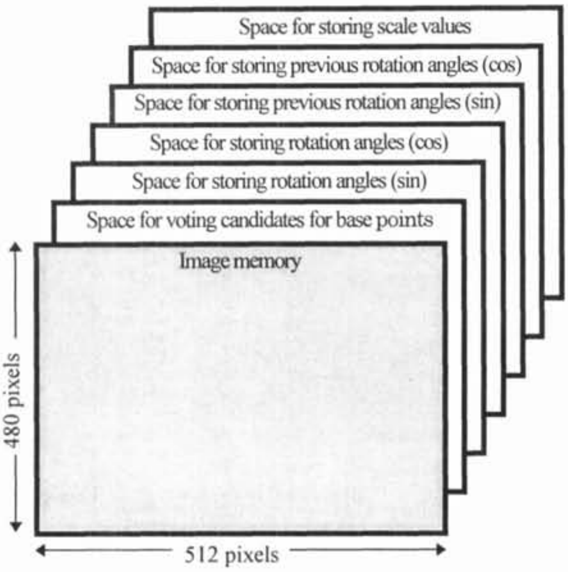


Fig.3 Parameter space configuration

When the edge intensity E_i is more than a constant, this pixel is considered as the edge point, and the edge direction angle θ_i is calculated by the next expression.

$$\theta_i = \tan^{-1}(\Delta y_i / \Delta x_i) \quad (4)$$

And, geometrical parameters r_i and α_i shown in Fig.1 are determined. These geometrical parameters are determined on all edge points. The set of θ_i, r_i and α_i is regarded as an one element in the template table shown in Fig.2. When the template figure has N edge points, the number of elements in the template table is also N.

4 Matching phase

4.1 Configuration of two-dimensional parameter spaces

All parameter spaces used for this method are two-dimension. As it is shown in Fig.3, each parameter space has 512×480 pixels corresponding each other. The space for voting candidates for base points is used for storing accumulated votes to the candidate coordinates for base points of objective figures, and each coordinates has 16 bits depth. The space for storing rotation angles is used for storing sine values and cosine values of rotation angles of objective figures, and each coordinates has 16 bits depth. The space for storing previous rotation angles is used for storing sine values and cosine values of rotation angles of objective figures at the previous voting process, and each coordinates has 16 bits. This space purposes to evaluate changes of sine values and cosine values of rotation angles. The space for storing scale values is used for storing scales of objective figures, and each coordinates has 16 bits depth.

4.2 Calculating candidate coordinates for base points

As shown in Fig.4, it is supposed that an objective figure has a scale S and a rotation angle ϕ as against the template figure. And, it is supposed that the point P_j is corresponded to the point P_i on the template figure. The edge direction angle θ_j at the point P_j is represented by the following expression.

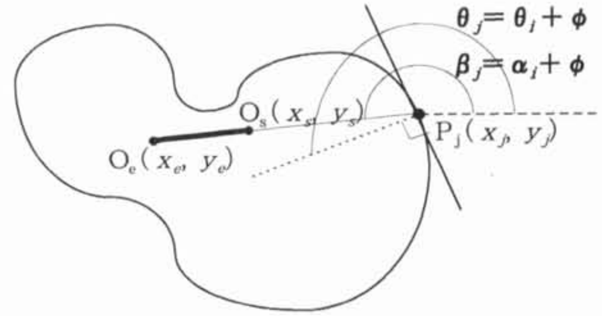


Fig.4 Candidates of the base point

$$\theta_j = \theta_i + \phi \quad (5)$$

And, the direction angle β_j to the candidate for the base point from the point P_j is represented by the following expression.

$$\beta_j = \alpha_i + \phi \quad (6)$$

From expression(5) and expression(6), β_j is represented by the following expression.

$$\beta_j = \alpha_i + \theta_j - \theta_i \quad (7)$$

Then, it is supposed that the maximum scale of objective figures is S_{max} and the minimum is S_{min}. The candidate coordinates $O_s(x_s, y_s)$ for the base point is calculated by the following expressions using θ_i, α_i and r_i in the template table when the scale is S_{min}.

$$x_s = x_j + r_i \cdot S_{min} \cdot \cos(\alpha_i + \theta_j - \theta_i) \quad (8)$$

$$y_s = y_j + r_i \cdot S_{min} \cdot \sin(\alpha_i + \theta_j - \theta_i) \quad (9)$$

The candidate coordinates $O_e(x_e, y_e)$ for the base point is calculated by the following expressions when the scale is S_{max}.

$$x_e = x_j + r_i \cdot S_{max} \cdot \cos(\alpha_i + \theta_j - \theta_i) \quad (10)$$

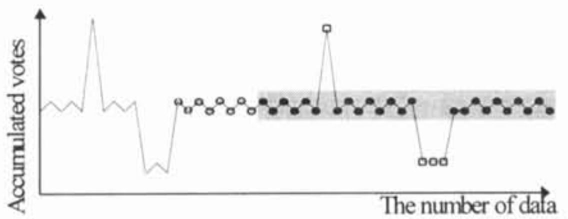
$$y_e = y_j + r_i \cdot S_{max} \cdot \sin(\alpha_i + \theta_j - \theta_i) \quad (11)$$

Because the true base point exists on the segment that joints the point $O_s(x_s, y_s)$ and the point $O_e(x_e, y_e)$, all points on the segment O_sO_e in the space for voting candidates for base points are candidates for voting process described in the section 4.4.

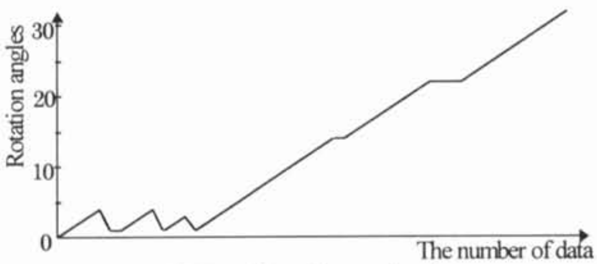
4.3 Storing rotation angles

The sine value and the cosine value of $\phi = \theta_j - \theta_i$ that represents the rotation angle of an object figure are stored in each coordinates(x,y) on the segment O_sO_e in the space for voting candidates for base points. Both the averaged sine values of all sine values and the averaged cosine values of all cosine values which are addressed to the coordinates(x,y) previously are stored into the coordinates(x,y). In the Hough transform, some noisy votes may be included in accumulated votes. Because the number of votes are accumulated by one in the space for voting candidates for base points, noisy votes do not influence the resulted votes relatively for the purpose of extracting the base point. But the purpose for determining the rotation angle, because the averaged value is renewed using noisy values, even if the number of noisy values is few, the resulted error increases. In this method, noisy values are removed using only two-dimensional spaces by the following processes.

First, a difference between a sine value which is addressed to the coordinates(x,y) and a previous sin value which is stored in the spaces for storing previous rotation angle is obtained. The process is also executed about a cosine value. And, when these difference which are less than constants appear R times continuously, an averaged sine value and an averaged cosine



(a) Selection of data for rotation angles



(b) Transition of accumulated votes

Fig. 5 Extraction of data for rotation angles and change of accumulated votes

values of the previous number of R sine values and R cosine values are calculated. These averaged sine value and cosine value are set as the standard values for selecting following rotation angles. Only sine values and cosine values that are close to the standard values are selected after the standard values are set. Selected sine value and cosine value are added to the accumulated sine value and the accumulated cosine value which are addressed to the coordinates(x,y) previously, and the averaged sine value and the averaged cosine value are calculated. And then, the new averaged sine value and the new averaged cosine value are stored into the coordinates(x,y) in the space for storing rotation angles. These averaged values are used as the new standard values for selecting following sine values and cosine values. Therefore, the averaged sine value of all selected sine values and the averaged cosine value of all selected cosine values are stored in the space for storing rotation angles. Fig.5(a) shows a state for extracting rotation angles in case R=8. The number of eight data shown in white circles which are close to previous data are extracted. The averaged value of these eight values is set as the standard value for selecting following data. Only data shown in black circles in the shadow area that are close to the standard value are selected after setting the standard value. The averaged value which means the standard value is calculated whenever a new data is selected. On the other hand, data shown in squares that greatly differ from the standard value are ignored as noisy values.

4.4 Voting to candidates for the base point

Only when the value in the coordinates(x,y) in the space for storing rotation angles is changed, the value in the coordinates(x,y) in the space for voting candidates for base points is increased by one as voting process. Fig.5(b) shows a transition of accumulated votes. Before the standard value for selecting rotation angles data is set, that is until continuous eight data appear in this sample, the number of votes is initialized to one whenever a data which has large difference between a previous data appears. The number of votes is accumulated after the standard value is set.

4.5 Storing scales

Only when the value in the coordinates(x,y) in the space for storing rotation angles is changed, the scale S is stored into the coordinates(x,y) in the space for storing scale values. Because the coordinates(x,y) means the internal divided point on the segment O_sO_e which combines the point O_s corresponding to the scale S_{min} and the point O_e corresponding to the scale S_{max}, the scale S is calculated by the following expression.

$$S=\{(x-x_s)^2+(y-y_s)^2\}^{1/2}(S_{max}-S_{min})/\{(x_e-x_s)^2+(y_e-y_s)^2\}^{1/2}+S_{min} \quad (12)$$

At the edge point P_j shown in Fig.4, voting process and storing rotation angles and storing scales are executed using all geometric parameters in the template table. Then, processes described above are executed at all edge points other than the point P_j.

4.6 Calculating coordinates of base points

Coordinates which have the accumulated votes more than a constant and their neighboring coordinates are extracted in the space for voting candidates for base points. Coordinates of base points of objective figures are calculated as gravitational centers using accumulated values in extracted coordinates.

4.7 Calculating rotation angles and scales

The same coordinates as extracted coordinates for calculating coordinates of base points in the section 4.6 are extracted in the space for storing rotation angles and in the space for storing scale values. The median in values in extracted coordinates in the space for storing rotation angles is made the

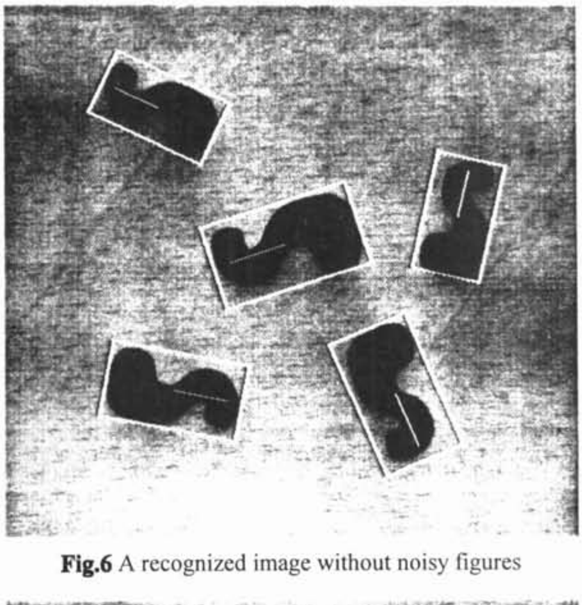


Fig.6 A recognized image without noisy figures

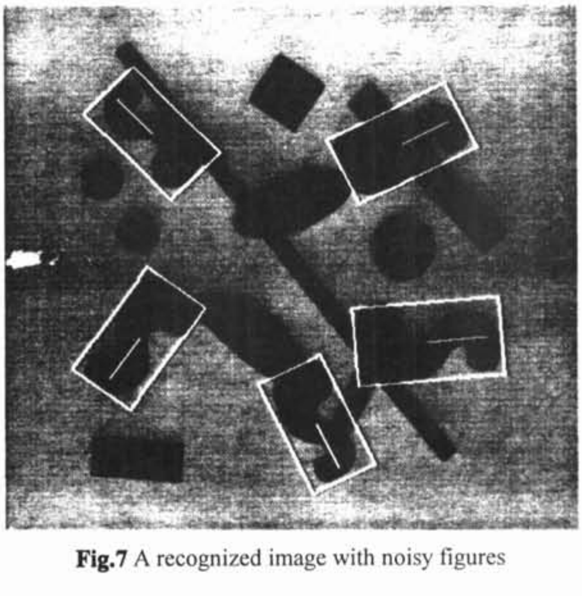


Fig.7 A recognized image with noisy figures

Table 1 Comparison of processing time

Methods \ Test images	Image in Fig.6 sec	Image in Fig.7 sec
Conventional generalized Hough transform using four-dimensional parameter space	128	288
Proposed generalized Hough transform using two-dimensional parameter spaces	25	55

rotation angle of an objective figure. The median in values in extracted coordinates in the space for storing scale values is made the scale of an objective figure.

5 Experiments

5.1 Extracting figures

Fig.6 shows extracted similar figures to the template figure in a sample image. The number of pixels is 512×480. The maximum scale is S_{max}=1.0 and the minimum scale is S_{min}=0.5. The number of data for setting the standard value for storing rotation angles is R=8. The rectangle that encloses each extracted figure shows the scale, and the direction of the segment drawn from the base point of each figure represents rotation angle. And, Fig.7 shows the resulted image when various kinds of figures are included in the image and some figures are overlapped and chipped.

5.2 Evaluating repeatability

The averaged position, the averaged scale and the averaged rotation angle were calculated using data of extracted five figures in Fig.6 in 100 times processing. Then, the difference between each data in 100 times processing and the averaged data was evaluated as the repeatability. The repeatability of positions resulted ±0.8 pixels in both x and y directions. The repeatability of scales resulted ±0.03. The repeatability of rotation angles resulted ±3 degrees.

5.3 The amount of parameter spaces and processing time

About the total amount of parameter spaces and processing time, this method was compared with the conventional generalized Hough transform. When coordinates in the four-dimensional parameter space have 16 bits depth, the range of scales is from 0.5 to 1.0 by 0.06 and the range of rotation angles is from 0 to 360 degree by 6 degree, the total 480 × 512 × {(1.0-0.5)/0.06} × (360/6) × 2 ≒ 265MB parameter space is required for realizing the precision that is almost equal to this method. On the other hand, this method needs only 480×512×6×2=2.95MB space for six 16 bits two-dimensional parameter spaces as shown in Fig.3 This space is about 1/90 of the four-dimensional parameter space.

Next, processing time for this method was compared with the conventional Hough transform using the four-dimensional parameter space whose amount is 480×512×{(1.0-0.5)/0.1}×(360/18)×2≒49.2MB, because the resolution of scales is limited to 0.1 and the resolution of rotation angles is limited to 18 degree for the realizable experiment. The images used for the experiment were Fig.6 and Fig.7. Pentium-133MHz was used for the processing system. As shown in Table 1, this method is about five times faster than the method which uses 49.2MB four dimensional parameter space. It is estimated that this method is about 27 times faster than the method which needs the 265MB four-dimensional parameter spaces whose resolutions about scales and rotation angles are almost same as this method.

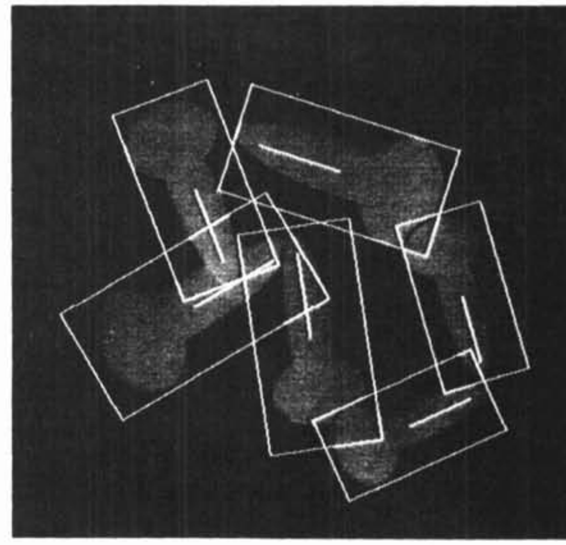


Fig.8 Extracted metal fittings

5.4 Extracting metal fittings

Fig.8 shows extracted metal fittings that have different sizes and are overlapped each other. The processing time was about 30 seconds for extracting metal fittings.

6 Conclusions

The generalized Hough transform using multiple two-dimensional parameter spaces was proposed for extracting arbitrary shaped figures in an image. This method does not need the huge four-dimensional parameter space for the conventional generalized Hough transform because voting into coordinates for candidates of base points, storing scales and storing rotation angles are executed using only two-dimensional parameter spaces. As the experimental result, repeatability about the position, the scale and the rotation angle reached each ±0.8 pixels, 0.25 and ±3 degree. And, the processing time was about 1/27 times shorter than the conventional generalized Hough transform.

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