Hierarchical Eigen Template Matching for Target Detection

Koshiro Yata
Faculty of Engineering, Kumamoto University
2–39–1, Kurokami, Chyuou-ku, Kumamoto, Japan 860–8555
`yata@navi.cs.kumamoto-u.ac.jp`

Gou Koutaki, Keiichi Uchimura
Graduate School of Science and Technology, Kumamoto University
2–39–1, Kurokami, Chyuou-ku, Kumamoto, Japan 860–8555

Michiaki Kan, Daisuke Asai, Makoto Takeba
HIKARI Co.,Ltd.
418–4, Minaminoda, Tohon, Ehime, Japan 791–0297

Abstract

The template matching is the basic technique of the object detection such as the defect inspection and OCR (Optical Character Recognition). It has a problem which requires a lot of computational time for detecting the XY displacement and the rotational angle of the target object. We have proposed the eigen template method for this problem. The proposed method can efficiently calculate correlation between images. However, when an input image is complicated, the method failed to detect the target object correctly. Additionally, the computational time of the method remains large still. In this paper, we propose the edge based eigen template method with robustness for the complex image compared with the previous method. Moreover, we describe an efficient matching algorithm for the eigen template method using the narrowing down process. In the evaluation experiments, we show that the proposed method can detect the target object faster and more robust to the complex image than the previous methods.

1   Introduction

Template matching is the basic technique of the image processing for the object detection such as OCR(Optical CharacterRecognition), vision sensor of factory automation, and the defect inspection. The template matching can detect the XY displacement and the rotational angle of the target object from the input image captured by the CCD camera.

In the real environment, the accuracy, the throughput (processing speed) and the robustness are required for the template matching. The accuracy of the detection of XY displacement with sub-pixel order and the accuracy of the detection of rotational angle with sub-degree order are required. For the throughput, the processing time is required within 1 second per image. For the robustness, the template matching has to detect for the input image with the various appearance such as the illumination variance, the noise, the occlusion and the chipped part. In order to fill those requirements, many template matching techniques have been developed over the years [2]-[6].

The correlation based method evaluates the correlation between the input image and the template image. For example, NCC (Normalized Cross Correlation) is well known [3]. The NCC is robust for the illumination variance and the noise, however the calculation cost of NCC is very expensive. This algorithm calculates the correlation of the two image with changing the displacement and the angle of the template image, and detects the peak of the correlation as the detected position. However, this approach is time consuming. Thus, the rotational search with the coarse rotational pitch is used. However it causes the low accuracy of the detection. Recently RIPOC(Rotation Invariant Phase Only Correlation) method is used for template matching. RIPOC method can detect the XY displacement and the rotational angle with high accuracy, and the processing cost is low [5].

Eigen template method using eigen decomposition have proposed as a new correlation based template matching method [1]. This method has a high accuracy as the same as NCC and less computation than NCC. However, when an input image is complicated, the method failed to detect the target object correctly. Additionally, the computational time of the method remains large still.

In this paper, we propose the edge based eigen template method with robustness for the complex image compared with the previous method. Moreover, we describe an efficient matching algorithm for the eigen template method using the narrowing down process. In the evaluation experiments, we show that the proposed method can detect the target object faster and more robust to the complex image than the previous methods.

2   Principles of Eigen Template Method

In this section, firstly we introduce a principle of the eigen template method [1], and propose the edge based eigen template method.

2.1   Eigen template method

The similarity of the input image $f(x, y)$ and the template image $T(x, y; \theta)$ ($T(x, y; \theta)$ is the rotated against the original template image $T(x, y)$ with the angle θ) is calculated as the following Equation (1).

$$g(\theta) = \iint f(x, y)T(x, y; \theta)dxdy. \qquad (1)$$

$g(\theta)$ is expanded by the orthogonal basis functions $\varphi_n(\theta), (n = 0, 1, 2, \cdots)$ along the direction of axis θ. The following equation is obtained by arranging it.

$$g(\theta) = \sum_{n}^{\infty} \left[\iint dx dy f(x,y) \times \right.$$
$$\left. \left\{ \int T(x,y;\theta)\varphi_n(\theta)d\theta \right\} \right] \varphi_n(\theta). \qquad (2)$$

Here,

$$E_n(x,y) \equiv \int T(x,y;\theta)\varphi_n(\theta)d\theta. \qquad (3)$$

$E_n(x,y)$ becomes the new template image calculated by the inner product between the template $T(x,y;\theta)$ and the basis functions $\varphi_n(\theta)$, and the correlation along all angle can be calculated immediately by convoluting with $E_n(x,y)$.

Then, we consider the approximation of the Equation (2) by truncating the finite series expansion M. We select the M-basis function $\varphi_n(\theta)$ as the eigen functions of the template images $T(x,y;\theta)$ in the order of the eigenvalue from the largest to the smallest.

$$g(\theta) \approx \sum_{n}^{M} \left[\iint f(x,y)E_n(x,y)dxdy \right] \varphi_n(\theta) \qquad (4)$$

Accutally, the parameter of the angle is discretized such as $\theta = \{\theta_1, \theta_2, ..., \theta_N\}$, and the vector $\boldsymbol{\varphi_n}$ and the template $T_i(x,y) = T(x,y;\theta_i)$ are obtained. The eigen-vectors $\boldsymbol{\varphi_n}$ and the eigenvalues λ_n are obtained by solving the following eigen problem,

$$\boldsymbol{C}\boldsymbol{\varphi_n} = \lambda_n \boldsymbol{\varphi_n}. \qquad (5)$$

Where, the elements of i-th row and j-th column of covariance matrix $\boldsymbol{C}$ are given by the follows.

$$C_{i,j} = \sum_{x,y} (T_i(x,y) - \mu_i)\left(T_j(x,y) - \mu_j\right) \qquad (6)$$

Where, μ_i is the mean value of the intensity of the template $T_i(x,y)$. We call the new image $E_n(x,y)$ as "Eigen Templates ".

2.2 Edge based eigen template method

In edge based detection, we use the following image similarity instead of the simple correlation Equation (1).

$$g_s(\theta) = \iint f_x(x,y)T_x(x,y;\theta)dxdy$$
$$+ \iint f_y(x,y)T_y(x,y;\theta)dxdy. \qquad (7)$$

Where, f_x and f_y are the x-derivative and y-derivative image of the input image f respectively, and T_x and T_y are the x-derivative and y-derivative image of the template image T respectively. Those derivative images are generated by convoluting the following Canny edge kernel [7]. Equation (7) means that the image similarity is evaluated by the difference of an edge direction.
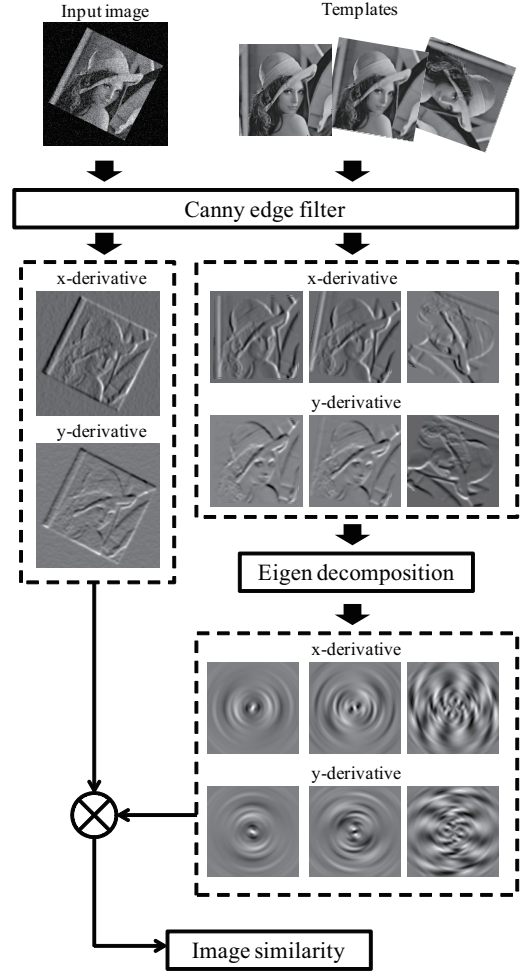

Figure 1. Flowchart of edge based eigen matching

Then, $g_s(\theta)$ is expanded by the orthogonal basis funcsions $\varphi_{x,n}(\theta)$ and $\varphi_{y,n}(\theta)$ as same as the Equation (2).

$$g_s(\theta) \approx \sum_{n}^{M} \left[\iint f_x(x,y)E_{x,n}(x,y)dxdy \right] \varphi_{x,n}(\theta)$$
$$+ \sum_{n}^{M} \left[\iint f_y(x,y)E_{y,n}(x,y)dxdy \right] \varphi_{y,n}(\theta) \qquad (8)$$

Where, $\varphi_{x,n}(\theta)$ and $\varphi_{y,n}(\theta)$ are eigen functions of the templates T_x and T_y obtained by solving eigen value Equation (5). $E_{x,n}(x,y)$ and $E_{y,n}(x,y)$ are eigen templates of the templates T_x and T_y respectively defined as,

$$E_{x,n}(x,y) \equiv \int T_x(x,y;\theta)\varphi_{x,n}(\theta)d\theta$$
$$E_{y,n}(x,y) \equiv \int T_y(x,y;\theta)\varphi_{y,n}(\theta)d\theta \qquad (9)$$

We call the new image $E_{x,n}(x,y)$ and $E_{y,n}(x,y)$ as "Edge Based Eigen Templates".

Thus, it is shown that the edge based similarity can be calculated by convoluting the edge based eigen templates to the input image. Figure.1 shows the flowchart of the edge based eigen template matching.
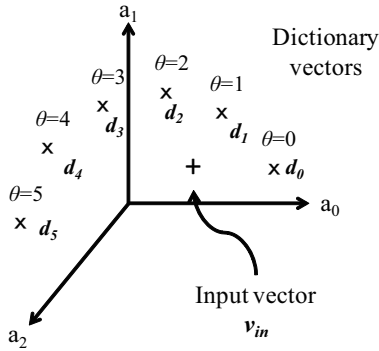
Figure 2. Dictionary search using feature vectors

(a)Template image (b)Edge images (c)Eigen template images

x-derivative $E_{x0}(x,y)$ $E_{x1}(x,y)$ $E_{x2}(x,y)$
y-derivative $E_{y0}(x,y)$ $E_{y1}(x,y)$ $E_{y2}(x,y)$

Figure 3. Examples of edge based eigen templates

(a)Target non chipped   (b)Target chipped

Figure 4. Examples of input images

3 Narrowing Down Process of Rotational Angle Estimation

The eigen template method can reduce the number of convolution compared with NCC. However, the computational time of the method remains large still. Thus, in order to reduce the number of operation, we propose a narrowing down process.

The rough direction of the target object is estimated from the response values of eigen templates. For the estimation, the K-eigen templates ($K < M$, M is an approximation order of Equation (8)) are used. The eigen template method can efficiently calculate correlation between images. However, the computational time of the method remains large still. Thus, we use a dictionary search for the rough estimation of the rotation. Actually, we use the nearest neighbor search.

First, the examples from N-rotational templates are registered to the dictionary. Each example has a vector $\boldsymbol{d_\theta}=(a_0, a_1,\ldots, a_{K-1})$ which has K-response value obtained by convoluting the rotational template with the K-eigen templates. For example, the vector of 30[deg] template is defined as $\boldsymbol{d_{30}}=(a_0, a_1, \ldots,a_{K-1})=(T_{30} \otimes E_0, T_{30} \otimes E_1, \ldots, T_{30} \otimes E_{K-1})$. Here, T_{30} is the 30[deg] rotated template image from the original template image.

Secondary, in the detection process, the input vector $\boldsymbol{v_{in}}$ which has K-response value obtained by convoluting the input image with the eigen templates. Then, the input vector $\boldsymbol{v_{in}}$ is compared with the dictionary's examples $\boldsymbol{d_\theta}$. The nearest neighbor example $\boldsymbol{d_{best}}$ is extracted, and it's rotational angle is adopted as the estimated rough angle. Figure.2 shows the dictionary search. In this case, for the input vector $\boldsymbol{v_{in}}$, the nearest neighbor vector $\boldsymbol{d_1}$ is extracted and the rough rotational angle is estimated as 1[deg]. In the nearest neighbor search, we use an ANN (Approximated Nearest Neighbor search) with kd-tree. ANN can accelerate to estimate the rough rotational angle.

After the rough rotational angle of the target object was estimated by the proposed method, it searches for the angle of the neighborhood in detail.

4 Experiments

In order to evaluate the proposed method, we performed simulation experiments and real environment experiments with CCD camera and XYθ mechan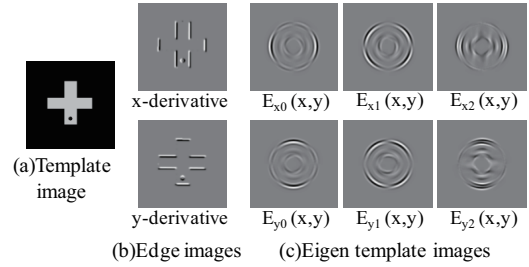ical stage. In the experiments, the propos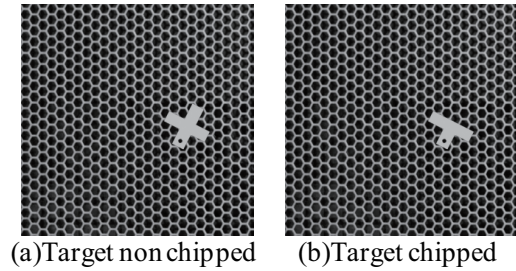ed method is compared with some previous method such as NCC and RIPOC and the prevous eigen template method (EIGEN). The detected results XY and θ are compared with the reference position, then the positional and rotational errors are evaluated.

We used 3.2GHz computer personal computer in the experiments.

4.1 Simulation experiments

We evaluate our method using a simulation image. The target object is shown in Fig.3(a). The eigen templates of Fig.3(a) are shown in Fig.3(c).

Figure.4(a), (b) show an example of input image and an example input image with the chipped target. Input image is generated by pasting the target object with randomly XY shift and rotation to the complex background. Then, 100-input images (The total number of Figure.4(a), (b) is 200) are generated. The size of input image is 512×512, and the size of the template is 128×128.

Table 1 and Table 2 show the results for Figure.4(a), (b), respectively. The rotational angle error of NCC is larger than other methods, because the rotational pitch is rough. RIPOC can detect the target very accurately, however, in the case of the chipped target, there are many failures of the detection. The proposed method can accurately detect the chipped target and the proposed method is faster than the previous method. Thus, the narrowing down process works well.

Table 1. Result of target non-chipped : Simulation

Method	Displasement error[pix]	Angle error[deg]	Success rate[%]	Processing time[msec]
NCC	0.36	3.29	96.0	369.23
RIPOC	0.07	0.11	99.0	140.42
Eigen	0.25	0.75	82.0	5569.46
Proposed	0.21	0.24	100.0	659.26

Table 2. Result of target chipped : Simulation

Method	Displasement error[pix]	Angle error[deg]	Success rate[%]	Processing time[msec]
NCC	0.73	3.12	86.0	367.12
RIPOC	0.49	0.99	55.0	138.53
Eigen	0.50	0.75	82.0	5590.71
Proposed	0.38	0.44	100.0	740.29

4.2 Real environment experiments

We evaluate our method using the image captured by CMOS camera. In this experiment, in order to measure the accuracy of detection, the instrument shown in Fig.5 is used.

In this experiment, two types of the images were captured. First, in order to evaluate XY positional accuracy, the images were captured with X stage move step by 0.1[mm]. Secondary, in order to evaluate rotational accuracy, the images were captured with θ stage move step by 1.8[deg]. The size of input images are 512×512[pix], and the size of the template image is 150×150[pix]. Figure.6 shows an example input image (PCB : Printed Circuit Board) and the template image (E-ring) cut from the input image and detection result. It is difficult to detect the target correctly because the background is complex.

Table 4 and Table 5 show the XY positional errors and the rotational errors. NCC could not detect the target correctly because of the rough angle pitch (6[deg]). The proposed method achieved 100% success rate. Additionally, the computational time is 1/9 of the previous method.
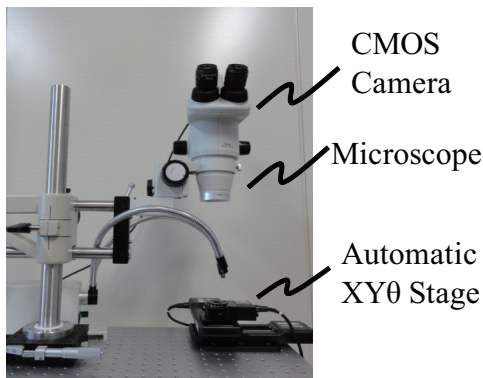

(a)Template image

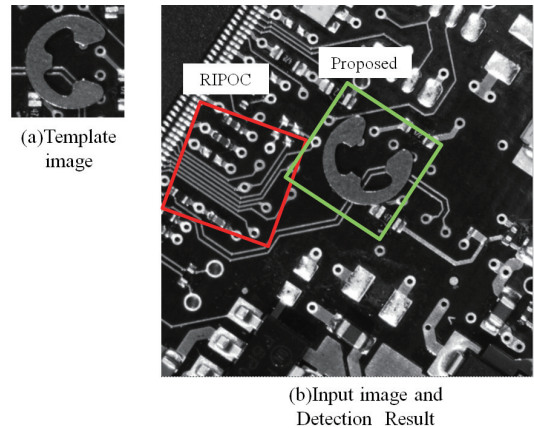(b)Input image and Detection Result

Figure 6. Input image and template

Table 4. Error in rotation : Real environment

Method	Angle error[deg]	Success rate[%]	Processing time[msec]
NCC	2.91	93.0	366.61
RIPOC	0.68	57.0	131.25
Eigen	0.18	100.0	5669.89
Proposed	0.13	100.0	633.74

5 Conclusion

We proposed the eigen template method based on the edge of an image. Additionally, we proposed the efficient search algorithm which used approximate nearest neighbor search for the improvement in computational time. In the experiments, we showed that the proposed method can stably detect of the target object even if the complex image is inputted. Moreover, we showed that the proposed method has reduced computational time greatly compared with the previous method.

Figure 5. Instrument for real environment experiments

CMOS Camera

Microscope

Automatic XYθ Stage

Table 3. Error in displacement : Real environment

Method	Displasement error[pix]	Success rate[%]	Processing time[msec]
NCC	0.70	100.0	370.02
RIPOC	0.44	100.0	129.99
Eigen	0.53	100.0	5671.07
Proposed	0.50	100.0	741.06

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