Optimization of Character Image Matching based on Artificial Bee Colony Algorithm

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Abstract. When template matching is used to detect printing defects in industrial production, the characters to be tested are not consistent with the main structure of template characters, which leads to detection errors and false defects. In order to solve this problem, this paper proposes a character image matching optimization based on artificial bee colony algorithm, using the improved artificial bee colony algorithm to find the optimal parameter model and optimize the parameter model, so that the character image matching effect is the best. The experimental results show that the improved artificial bee colony algorithm can obtain good image registration results in a relatively short time.

1. Introduction

On the market of medical equipment, food, production tools of production date printing on the packaging, now in general use packaging materials production line inkjet or thermal transfer printer to print production date. The reason of machine breakdown and packing material migration, vibration and other factors in the process of marching, may appear the wrong printing, printing, printing defects such as fracture, ink pollution characters. In order to improve the production efficiency of production line, enterprises often use image matching method to detect whether the production date is printed wrong.

Template matching is a very important recognition technology in the field of image recognition [1]. The advantages of this matching method are high recognition rate and simple matching algorithm, so it has been widely used [2]. At present, many scholars have made good achievements in template matching. Qixinwei et al. proposed a multi-scale template matching algorithm for rotating images, which obtained the ring projection of the scaled template through the transformation of the ring projection vector, and had a good effect for template matching of multi-scale rotating images [3]. Liuzhiyuan et al. proposed an improved feature point matching algorithm based on rectangular template matching. Using the 2D coordinates of feature points, a new parameter "interior point index" is calculated and used to extract the template from the input image. This algorithm improves the accuracy of feature point matching [4]. Liuruiming et al. proposed a template matching method for human eye positioning based on projection coefficient template and nonlinear correlation. In this method, the projection coefficient based on the Karhunen-Loeve transformation basis function is used as the template, and the matching degree method of nonlinear correlation measurement is proposed to reduce the calculation cost [5]. Matingxia et al. proposed a new joint matching method. This method overcomes the difficulty of single template matching and improves the matching accuracy under complex conditions [6]. Image registration can be classified into two categories according to the way of feature selection: registration based on grayscale image and registration based on feature points. Feature-based image registration requires that the image has rich and stable texture or structural features, and the character structure of the production date of the packaging bag is simple, so it cannot guarantee to obtain enough stable and reliable feature points or
edges, so this method is not applicable. Therefore, the gray feature registration of the whole image is adopted in this paper.

The registration method based on image gray information has some difficulties: how to make the best image matching effect and the minimum detection error. Therefore, this paper proposes a character image matching optimization method based on artificial bee colony algorithm. In this method, the gray feature registration of the whole image is adopted. In order to ensure that the structure of character defects is not destroyed, affine transformation of linear transformation is used to map the detected characters, and artificial bee colony algorithm is used to optimize the matching parameters of character image.

Artificial bee colony algorithm, proposed by Karaboga in 2005, is a global optimization algorithm based on swarm intelligence. Artificial bee colony algorithm has been applied and improved in many aspects. Zhaobaohua et al. proposed a new search equation QABC algorithm based on the idea of quasi-affine transformation, which greatly improved the cooperation ability between particles and enhanced the exploitability of artificial bee colony algorithm [7]. Fatehbouradara et al. proposed a contractive artificial colony planning, which periodically reduces the number of food sources of bee colonies rather than using a fixed number of artificial colonies, which can have a better application effect in path planning [8]. Lilingsun et al. proposed an agent assisted multi-colony artificial colony (SAMSABC), which has certain advantages in solving complex numerical optimization problems [9]. Zhou Xinyu et al proposed an improved ABC algorithm based on multi-elite guidance, which utilized valuable information of elite individuals to guide search without loss of population diversity [10].

In this paper, a character image matching optimization method based on artificial bee colony algorithm is proposed to make the characters to be measured match the main structure of the template characters, and the defect area obtained by the shadow method can be minimized.

2. Related Work
Our optimization algorithm is an improvement of artificial bee colony algorithm, which is used to match the gray features of the whole image. The following will introduce the basic work of gray feature matching based on the whole image and artificial bee colony algorithm.

2.1. Grayscale feature matching based on the whole image
In this paper, the gray feature registration based on the whole image is adopted, and the affine transformation of linear transformation is used to map the detection characters. The purpose of registration is to make the character to be tested match the main structure of the template character, so that the mismatch area between the detected character image and the template is as small as possible.

The four basic forms of affine transformation and their symbols are described below.

|   |   |   |   |   |
|---|---|---|---|---|
| (a) | The original image | (b) Translation | (c) The zoom | (d) Rotating | (e) Shear |

Figure 1. Geometric space transformation of images.

2.1.1. Translation. Let the original coordinate be \( P_0 \left( x_0, y_0 \right) \), the translated coordinate be \( P_1 \left( x_1, y_1 \right) \), the horizontal translation distance \( \Delta x \), and the vertical translation distance \( \Delta y \). To unify the calculation format, the matrix expression in the homogeneous coordinate system is as follows:
After translation, the blank area of the boundary is filled with white pixels (grayscale value 255). Pixels beyond the width and height range of the original image can be discarded. The translation effect of a single character is shown in Figure 1(a).

2.1.2. The zoom. The scaling of the image is to stretch or compress the image in the x and y directions respectively. Let the scaling ratio in the x direction be $S_x$ and the scaling ratio in the y direction be $S_y$. In the homogeneous coordinate system, the expression is:

$$
\begin{bmatrix}
    x_1 \\
    y_1 \\
    1
\end{bmatrix} =
\begin{bmatrix}
    S_x & 0 & 0 \\
    0 & S_y & 0 \\
    0 & 0 & 1
\end{bmatrix}
\begin{bmatrix}
    x_0 \\
    y_0 \\
    1
\end{bmatrix} = S \ast \begin{bmatrix}
    x_0 \\
    y_0 \\
    1
\end{bmatrix}
$$

(2)

After zooming out, the blank area outside the image boundary is filled with white pixels. After zooming in, the pixels beyond the original image range can be discarded. The scaling effect of a single character is shown in Figure 1(b).

2.1.3. Rotating. Let clockwise rotation be positive, and the center of rotation be the center of the image. The Angle of counterclockwise rotation is $-\theta$, and the Angle between the line between $P_0$ and the center of rotation and the x-axis before rotation is $\alpha$. The diagram of rotation and the matrix expression are as follows:

$$
\begin{bmatrix}
    x_1 \\
    y_1 \\
    1
\end{bmatrix} =
\begin{bmatrix}
    \cos \theta & \sin \theta & 0 \\
    -\sin \theta & \cos \theta & 0 \\
    0 & 0 & 1
\end{bmatrix}
\begin{bmatrix}
    x_0 \\
    y_0 \\
    1
\end{bmatrix} = R \ast \begin{bmatrix}
    x_0 \\
    y_0 \\
    1
\end{bmatrix}
$$

(3)

2.1.4. Shear deformation. The shear phase transformation of the image corresponds to the shear transformation in the x and y directions respectively. Assuming that the coordinate point $P_0$ is inclined along the x direction and the Angle is $\alpha$ alpha (Figure 3), the shear $dx$ in the x direction and the shear $dy$ in the y direction can be expressed in matrix form as:
\[
\begin{bmatrix}
x_1 \\
y_1 \\
1
\end{bmatrix} =
\begin{bmatrix}
1 & dx & 0 \\
dy & 1 & 0 \\
0 & 0 & 1
\end{bmatrix}
\begin{bmatrix}
x_0 \\
y_0 \\
1
\end{bmatrix}
= Sh \ast
\begin{bmatrix}
x_0 \\
y_0 \\
1
\end{bmatrix}
\]

(4)

Figure 3. Shear deformation.

Because of the jitter of the feeding system or the deflection of the film material during the process; The printing method causes pixel level differences in the stroke width of characters each time printing; During the operation of the rewinder, the film material may be distorted, and the printed characters on the collected images may show shear or rotation in the y direction. Therefore, the parameter search space of affine transformation is six parameters: scaling $S_x$, $S_y$ and translation $\Delta x$, $\Delta y$, rotation Angle $\theta$ and shear $dy$ in the x and y direction.

For the sake of intuition, the order of affine transformation is scaling, shear, rotation, and translation, all of which are based on the center point of the original image. Set the width and height of the original image $Src$ to be $Cols$, $Rows$. Then the affine transformation center is $\left(\frac{Cols}{2}, \frac{Rows}{2}\right)$. Firstly, the original center point of the image is shifted to the origin in the upper left corner, and the translation matrix is $T1$:

\[
T1 = \begin{bmatrix}
1 & 0 & -\frac{Cols}{2} \\
0 & 1 & -\frac{Rows}{2} \\
0 & 0 & 1
\end{bmatrix}
\]

(5)

In order to ensure that the original image information will not be lost due to exceeding the boundary of the original image after shear and rotation transformation, the size of the target image $Dst$ after affine transformation needs to be calculated in advance. Let $M'$ be the transformation matrix that maps the four vertices of $Src$ to $Dst$, then

$M' = R \ast Sh$

(6)

The four vertices of $Src$ image are $\left(\frac{Cols}{2}, \frac{Rows}{2}\right)$, $\left(-\frac{Cols}{2}, \frac{Rows}{2}\right)$, $\left(\frac{Cols}{2}, -\frac{Rows}{2}\right)$, $\left(-\frac{Cols}{2}, -\frac{Rows}{2}\right)$. After geometric transformation, the four vertices are determined by $boundingRect$, and the $W, H$, which are the width and height of $Dst$, are obtained. Before the translation transformation $T$, the image needs to be moved to the center of $Dst$, and the translation matrix is $T2$:
The full affine transformation is:

\[ M = T \cdot T_2 \cdot R \cdot S_{h} \cdot S \cdot T_1 \]  
\[ Dst = M \cdot Src \]  

2.2. Artificial bee colony algorithm

The algorithm is composed of bee swarm and nectar source. The bee swarm consists of three parts: hiring bee, following bee and scout bee. The nectar source is composed of a group of ordinary nectar source and an optimal nectar source.

Employed bee: each employment associated with specific honey bees, carry corresponding sources of information, such as honey quality, honey distance, its in the maintenance of current sources of also random one dimensional parameters are random change, if the new bee absolute quality of modified (fitness) more than the current sources, use new bee instead of the current sources, or to the current number of sources of mining (trail) plus 1. It has a certain probability to transmit information to the following bees. After the nectar source is mined (the trail exceeds the threshold) and is abandoned, it turns into the scout bees. The calculation formula of probability \( r_{Fitness} \) of information transmission is as follows:

\[ r_{Fitness} = \frac{\text{fitness}_i}{\sum_{j=1}^{N} \text{fitness}_j} \]  

\( N \) is the number of nectar sources, equal to the number of hired bees.

Follow Bees: Get the information sent by hired bees and select the appropriate nectar source. The higher the relative quality of the nectar source (the greater the \( r_{Fitness} \) value), the more likely the following bees were to choose the nectar source. Follow the bee is completed, the choice will be randomly in the current sources of some parameters (e.g., sweetness, distance) on the random changes value (Formula 11 and Formula 12), and calculate the new sources of fitness (Formula 13), if more than the current sources, use new bee instead of the current sources, and guide the back with bee on the basis of the new bee to search again, or to increase the number of current sources of mining (trail), so that you can jump out into a local optimal solution;

\[ \text{Bee}[i].pr[r] = \text{Src}[i].pr[r] + \text{rand} \cdot (\text{Src}[i].pr[r] - \text{Src}[k].pr[r]) \]  
\[ r = \text{(int)} \cdot \text{random}(1, D) \]  
\[ \text{Src}.fitness = \begin{cases} \frac{1}{1 + f(x)} & f(x) \geq 0 \\ 1 + \text{abs}(f(x)) & f(x) < 0 \end{cases} \]
Of which \( i, k = 1, 2, \ldots, N, k \neq i \), \( \text{rand} \) is the random number on \([-1,1]\), and \( D \) is the parameter dimension. \( f(x) \) is the value of the objective function. When \( x_i \) is the optimal solution, the value of \( f(x_i) \) is the minimum and the value of fitness is the maximum.

Scout bees: They are hired bees that are transformed after the nectar source is abandoned. They randomly search for the nectar source. If the quality of the nectar source exceeds the threshold value, they are turned into hired bees again. Generally, the number is 5% to 20% of the colony.

Common nectar source: represents the possible solution vectors.

Best nectar source: record the optimal solution of the current iteration. In the initial stage, the bee colony needs to be initialized, which is mainly to initialize each dimensional parameter of the nectar source:

\[
\text{Src}[i].pr[j] = \text{random}\left(lb[j], ub[j]\right) \quad (14)
\]

\( i = 1, 2, \ldots, N \), \( LB[J] \) is the lower boundary of the \( j \)-th parameter, \( ub[j] \) is the upper boundary of the \( j \)-th parameter, \( j = 1, 2, \ldots, D \).

The calculation steps of ABC are roughly as follows:

1. Initialize the bee colony and nectar source, so that the hired bee is associated with the nectar source;
2. Hire bees to find a better nectar source around the current nectar source or continue to mine the current nectar source;
3. Calculate the absolute mass (fitness) and relative mass (rFitness) of nectar source;
4. The hired bees transmit nectar source information to the following bees with a certain probability, and the following bees search for a better nectar source around the nectar source or mine the nectar source;
5. Record the best nectar source;
6. Sending reconnaissance bees to randomly search for new nectar sources when the nectar source is mined;
7. Record the best nectar source;
8. Repeat steps 7 until the maximum number of iterations is reached or the error is less than the threshold.

The self-organization of the colony depends on the positive feedback to the good nectar source and the negative feedback to the bad nectar source. High-quality nectar source will attract more bees to mine and search for the optimal around the current nectar source, while low-quality nectar source will be abandoned because the number of mining (trail) exceeds the threshold value of \( Th \).

3. Our Approach

As ABC is a general optimization algorithm, it needs to be optimized in different application scenarios to improve computational efficiency. In this paper, three links of ABC are optimized.

3.1. Probability of hiring bees to deliver messages

The probability calculation formula for hiring bees to send messages to the following bees is shown in Equation 10. Since the roulette model is adopted, the message can only be delivered successfully when \( r\text{Fitness} > \text{rand}(0, 1) \) is adopted, otherwise the cycle will continue until all the following bees are allocated. When a number of sources is large, each bee \( r\text{Fitness} \) smaller values, the relative quality value of the \( \text{rand}(0, 1) \) appear smaller than \( r\text{Fitness} \) decreases in the value of the probability that will cause the loss of the efficiency of the operation, for the purpose of this topic research object, this is a work force that is not acceptable waste, thus optimize the probability model of the message, at the same time, the swarm is scale ensure random disturbance, improve the efficiency of transfer information at the same time, probability calculation formula is rewritten as follows:

\[
r\text{Fitness} = \frac{\text{fitness}}{\text{fitness}_{\text{max}}} \times 0.9 + 0.1 \quad (15)
\]
Fitness\textsubscript{max} is the maximum of relative mass of all nectar sources in this iteration process. When the quality of a nectar source is poor, its relative mass is close to 0.1, and when the quality of a nectar source is high, its relative mass is close to 1, which meets the basic requirements of the original algorithm to ensure population diversity and improves the efficiency of the single iteration process.

3.2. Phased search process

In this paper, we need to optimize six parameters: the scaling S\textsubscript{x}, S\textsubscript{y} in the affine transformation, and translation Δ\textsubscript{x} in the x and y directions, the rotation Angle θ and the shear \textsubscript{dy} in the y direction. Considering the actual situation of the factory, the search range of the translation in the x and y directions is set as [-20,20], and the unit is pixel. The search interval of scaling in x and y directions is [0.7,1.3]; The rotation search interval is [-10,10], and the unit is degree. The shear search interval in Y direction is [-10,10], and the unit is degree.

When a single character is segmented by projection, a rectangular frame is formed with the upper, lower, and left boundaries of the character. If the defect is generated within the range of the rectangular frame, affine transformation is not required and the two images can be directly overlaid. Therefore, before initializing the random number of the bee colony and honey source, the current optimal solution is directly calculated by using the in-place value of each parameter and saved. Afterwards, the iterative process will attempt to update the optimal solution within a limited number of steps.

Because the premise of image registration is that the character has been successfully recognized, the structure of the character will not change greatly, and the values of affine transformation all float within a small range. In order to improve the identification efficiency, the parameter search range can be expanded to reach the upper and lower boundaries in stages. In the initial stage, searching within a smaller range is conducive to obtaining a more accurate optimal solution. Suppose that the search range is expanded once every iteration goes through \textit{perStage}=10 times, the range is increased by a single iteration \textit{amp}=0.2, \textit{d} is the cumulative increase range, and \textit{gen} is the current iteration number, then:

\[
d = \max\left(\text{int}\left(\frac{\text{gen}}{\text{perStage}} + 1\right) \ast \text{amp}, 1\right)
\]

Take the translation variable in the x direction as an example:

\[
\Delta x_i = \text{rand}(\text{lb}_x, \text{ub}_x) \ast d
\]

Take the x direction scaling variable as an example:

\[
S_{x_i} = \text{rand}\left(\left(\text{lb}_x - 1\right) \ast d + 1, (\text{ub}_x - 1) \ast d + 1\right)
\]

To sum up, the steps of stage search mode are as follows:

1. During the first iteration, each variable is kept in its original position and the graph to be measured and the template graph are directly superimposed;
2. Increase the search scope with a fixed amplitude every fixed cycle and continue to search;
3. Calculate the absolute mass (fitness) and relative mass (rFitness) of nectar source;
4. Execute global search when the upper and lower limits of the parameter range are reached;

3.3. Iteration termination condition

The original algorithm set the maximum number of iterations, \textit{maxCycle}, and the optimization was terminated when the swarm was updated to the \textit{maxCycle}. Because the bee colony algorithm is a heuristic non-deterministic algorithm, the speed of finding the optimal solution is different in each optimization, and setting a uniform number of iterations will cause a waste of resources.

The XOR image \textit{Dst} is obtained by the subtraction method, with the background set to 0 and the foreground set to 1, then the XOR pixel can be considered as the defect area. The number of all pixels in the statistical image with a gray value of 1 is \textit{N}, and the number of XOR pixels obtained by the
subimage method between a qualified image and the template image after registration is \( N=0 \). Therefore, the standard for evaluation of registration results is \( N=0 \). Considering that the original grayscale image has been processed by binarization, morphological processing and image normalization in the actual processing process, as well as the limitation of the pixel interpolation algorithm in the affine transformation process, the image to be registered and the template image cannot completely coincide, so it is necessary to clarify the termination conditions of iteration.

The optimal honey source increases the variable \( K \), which records the times of maintenance of the current optimal solution. If the current value is not updated after iteration of \( K_{\text{max}} \) times, the solution can be considered as the global optimal solution and the iteration is terminated.

\[
\text{TerminateCond} = (\text{gen} \geq \text{max Cycle}) || (K \geq K_{\text{max}})
\]  

4. Experimental Verification

In this paper, the number of nectar sources is set as 30, employing bees and following bees are each 30, the maximum number of iterations is 100, the maximum \( T_h \) of nectar source mining is 10, and the optimal maintenance threshold \( K_{\text{max}} \) is 20. The template image and the image to be detected are shown in Figure 4, and the calculation result of the optimal solution in the process of 100 iterations is shown in Figure 5. The image state obtained by the subtractive shadow method in the process of iteration is shown in Figure 6.

Experimental verification shows that among the 50 samples, characters generally meet the termination conditions of iteration in the first 70 times, and the time of a single iteration is about 1.6-1.7ms. Therefore, the registration of a single character can be completed in about 0.1s, which can basically meet the real-time requirements of the system.
5. Conclusions
This paper introduces the image registration algorithm based on gray information and feature-based registration. For a single binary character image with few feature points and no texture features, this paper adopts image registration based on affine transformation, and uses optimization algorithm to solve the six variables of image translation, scaling, rotation and Y direction clipping. This paper focuses on the analysis of artificial bee colony algorithm and optimization of the model and parameters for the application scenarios of this subject. The experimental verification shows that the improved artificial bee colony algorithm can obtain good image registration results in a relatively short time.

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