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Infrared and visual image registration based on mutual information with a combined particle swarm optimization – Powell search algorithm

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ABSTRACT

Infrared and visual image registration has widespread applications in the remote sensing and military fields. The use of mutual information has proved effective and successful in the infrared and visual image registration process. Optimization algorithms, such as particle swarm optimization (PSO) or the Powell search method, are often used to find the most appropriate registration parameters. The PSO algorithm has a high global search capacity and the search speed is fast initially, but the main weakness is its poor search performance in the later search stage. The Powell search method has a powerful local search capacity, but the search performance and time requirements are highly sensitive to the initial values. Therefore, in this study, we propose a novel hybrid algorithm, which combines the PSO algorithm and Powell search method. First, the PSO algorithm is used to obtain a registration parameter that is close to the global minimum. Using this result, the Powell search method aims to find a more precision registration parameter. Our experimental results demonstrate that the algorithm can correct the scale, rotation, and translation in an effective manner without requiring an additional optimization algorithm. Our method may be a good solution for registering the infrared and visible images, and it obtains better performance in terms of time and precision compared with traditional method.

1. Introduction

Infrared and visual image registration has widespread application in the remote sensing and military fields. Fusion images retain high resolution and texture information in the visual image, while they also emphasize the heat target in an infrared image. Image registration is an important task if we obtain images from different sensors before their fusion [1,3]. However, image registration is a difficult problem and many previous studies have attempted to address this issue.

The main objective of image registration is to find the optimal geometrical transformation parameters that maximize the similarity between the transformed template image and the reference image. Two main methods are used to find the optimal parameters: feature-based registration and area-based registration [2]. Registration is based on features such as search dots, lines, edge, curves, or regions in images, where these features are salient, stable, and distinct. In contrast to feature-based registration methods, area-based registration methods focus more specifically on the grayscale features of images. This type of method finds registration parameters using a specific similarity metric, e.g., a sequential similarity detection algorithm, cross-correlation [3], cross-power spectrum [4], or mutual information (MI) [5,6]. Irrespective of the method used, an optimization algorithm must be employed to calculate the registration parameter. Numerous optimization algorithms can be used such as the Powell search method [7], particle swarm optimization (PSO) [8], simulated annealing [9], ant colony optimization [10], and genetic algorithms [11].

Fig. 1 shows the process flow of the area-based registration method, which indicates that the optimization algorithm determines the precision, thus it is a key step in the process. The Powell search method is sensitive to the initial solution, where it requires less time to find the global optimal solution if the initial solution is close to the global optimal solution. By contrast, PSO is not sensitive to the initial solution and it has a high global search capacity. However, its convergence rate becomes slower as the number of iterations increases.

To address these problems, we proposed a novel hybrid algorithm, which combines the PSO algorithm and Powell search method. Our experimental results demonstrate that the proposed algorithm provides better performance.

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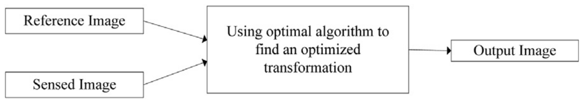

Fig. 1. Flowchart illustrating the area-based registration process.

2. Image registration

Image registration aims to obtain an optimized transformation from the sensed image to the reference image [1], which can be expressed as follows:

$$I_1(x, y) = g(I_2(f(x, y))), \quad (1)$$

where $I_1(x, y)$ is the reference image, $I_2(x, y)$ is the sensed image, f denotes a transformation, such as a translation, rotation, scaling, or affine transformation, and g is a grayscale interpolation method, such as bilinear, bicubic, or spline. In practical visual and infrared image fusion systems, the two optical systems are usually collinear with the same field of view and direction of movement. Thus, we can assume that translations and rotations are possible between the reference image and sensed image, which can be formulated as follows:

$$\begin{bmatrix} x' \\ y' \\ 1 \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta & \Delta x \\ \sin\theta & \cos\theta & \Delta y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}, \quad (2)$$

where θ is the angle of rotation, and Δx and Δy are the translations in the x-axis and y-axis, respectively.

3. Image registration based on MI

3.1. MI theory

The definition of the MI for the reference image I_1 and sensed image I_2 combines the marginal and joint entropies of the images in the following manner:

$$\mathrm{MI} = H(I_1) + H(I_2) - H(I_1, I_2), \quad (3)$$

where $H(I_1)$ and $H(I_2)$ denote the entropy values of I_1 and I_2, respectively. $H(I_1, I_2)$ is the entropy of the joint probability distribution of the image intensities.

$$H(I_1) = -\sum_i p_1(i)\log_2 p_1(i) \quad (4)$$

$$H(I_2) = -\sum_i p_2(i)\log_2 p_2(i) \quad (5)$$

$$H(I_1, I_2) = -\sum_{i,j} p_{12}(i, j)\log_2 p_{12}(i, j) \quad (6)$$

p_1 and p_2 are probability densities, and p_{12} is the joint probability density.

MI considers the statistical intensity of the images, but also their joint probability distribution. Thus, the MI value will ensure that the maximum value is obtained when the two images are matched, as shown in Figs. 2 and 3.

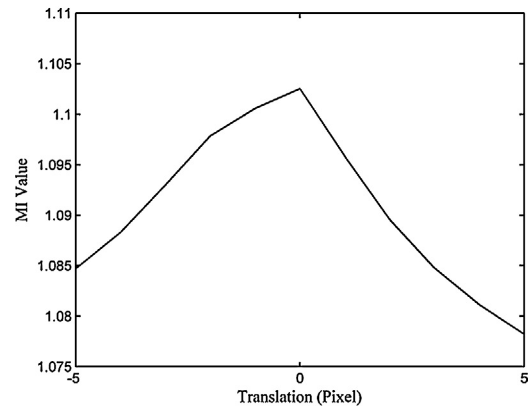

Fig. 2. Relationship between the rotation angle and MI value.

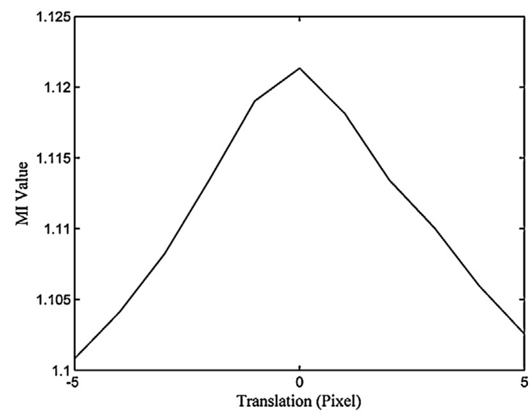

Fig. 3. Relationship between the translation and MI value.

3.2. PSO

PSO was proposed by Kennedy and Eberhart in 1995 [8]. Suppose there are M particles in the D-dimension. Particle i's position is $\vec{x}_i = (x_{i1}, x_{i2}, \ldots, x_{iD})$ and its velocity is $\vec{v}_i = (v_{i1}, v_{i2}, \ldots, v_{iD})$. Each particle remembers its best position $\vec{p}_i = (p_{i1}, p_{i2}, \ldots, p_{iD})$ during the iterative process. The global best position $\vec{p}_g = (p_{g1}, p_{g2}, \ldots, p_{gD})$ is also maintained. At each iteration, the position and velocity are updated according to the follow equations,

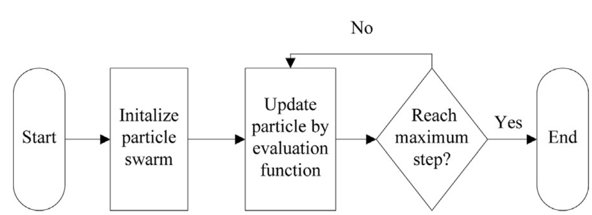

Fig. 4. Flowchart of the PSO algorithm.

$$V_i = \omega V_i - c_1 r_1 (P_i - X_i) + c_2 r_2 (P_g - X_i) \quad (7)$$

$$X_i = X_i + V_i, \quad (8)$$

where r_1 and r_2 are random numbers that are distributed uniformly in [0,1], c_1 and c_2 are cognitive and social parameters, and ω is an inertia weight, which acts as a memory of the previous velocities. Fig. 4 shows a flowchart of the PSO algorithm.

3.3. Powell search method

The Powell search method was proposed by Powell in 1962 [7] and it is an extension of the basic pattern search method. After several improvements, the current process employed by the Powell search method is as follows.