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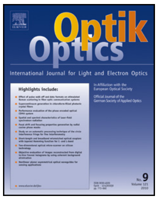

Regional information entropy Demons for infrared image nonrigid registration

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ABSTRACT

Infrared imaging fault detection which was treated as an ideal, noncontact, and nondestructive testing method was applied to the circuit board fault detection. Nonrigid deformation was existed between the fault circuit board infrared image and the well-performance circuit board infrared image. To solve this problem, a new Demons algorithm based on regional information entropy was proposed. The new method used regional information entropy instead of image's intensity to overcome the shortcomings of traditional Demons algorithm, which was sensitive to the intensity. The inertia parameter was introduced to improve the convergence performance, which was another improvement. In inertia parameter study, the value of inertia parameter was suitable at about 0.6. The simulated study and experiment of realistic infrared image study had shown that the proposed algorithm could match the images whose intensity has difference, while the original active Demons algorithm could not. The convergence performance with the inertia parameter had been improved about twice times in experiment.

1. Introduction

Infrared imaging fault detection is achieved by detecting infrared radiation, which is emitted by the object itself and reflecting the infrared emissivity of the surface and internal dissipation of the heat capacity, thereby the fault object is revealed has not been detected in the abnormal state. Infrared imaging fault detection which is treated as an ideal, noncontact, and nondestructive testing method is applied in circuit board fault detection [1–7]. The camera is fixed to the circuit board in practice. Different types of circuit board should have different fixed boxes, which limit the application of infrared imaging in detecting circuit board faults. So, nonfixed of collection infrared images will gradually become the mainstream. Nonfixed of collection infrared images can lead to rigid and nonrigid image transformation, which will bring some difficulties for image comparison, which because of the inconsistent parameter, such as camera position, camera angle, lens parameters, etc.

Image registration is a computational method to find the spatial relationship between two or more images. And it is the foundation and premise of image comparing in infrared imaging fault detection. Rigid registration could not meet the accuracy requirements because the circuit components become smaller and smaller, so nonrigid registration was researched in this paper. Nonrigid registration was widely applied in medical image analysis [8]. A lot of methods had been proposed for nonrigid registration, such as thin-plate splines [9], elastic model [10], optical flow [11], viscous fluid model [12], and so on. Demons algorithm proposed by Thirion was one of nonrigid registration algorithm based on optical flow [13]. Because of its linear computational complexity and ease of implementation, it was widely studied [14–18].

The basic hypothesis of the original Demons algorithm was that the intensity of image pixels keeps stability as image pixels moving. When the intensity of image pixels had changed, the original Demons algorithm could not match the images. To solve this problem, a new Demons algorithm based on regional information entropy was proposed and an inertia parameter was introduced to improve the speed of convergence. This approach will help to match the images that the intensity of image pixel has changed and improve convergence speed.

The remainder of this paper is organized as follows. Classical and active Demons are presented in Section 2. Improvement of Demons approach is developed in Section 3 and examination are taken in Section 4. Finally, Section 5 concludes the paper.

2. Classical and active Demons

Demons algorithm based on optical flow field is a nonrigid image registration algorithm [13]. It uses the gradient information of

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template image and the intensity difference between two images to deform the moving image. For a given point P, m is the intensity of moving image M; s is the intensity of reference image S. The displacement u for point P in M to match the corresponding point in S is calculated as follows:

$$u(p) = \frac{(m-s)\nabla s}{\left|\nabla s\right|^2 + (m-s)^2} \tag{1}$$

In Eq. (1) $u = (u_x, u_y)$, $\triangledown s$ is the gradient of template image at point P. Thirion's Demons algorithm only made use of the template image gradient, which may not be efficient. Wang et al. thought that the diffusion was bidirectional [14]. The force that allowed the moving object to diffuse into the corresponding reference object was called "passive" force f_s(Eq. 1) and the force that allowed the reference image to diffuse into the corresponding moving object was called "active" force f_m(Eq. 2). So, the total force was makeup of the passive force and the active force, calculated by Eq. 3.

$$f_m = -\frac{(s-m)\nabla m}{\left|\nabla m\right|^2 + (s-m)^2} \tag{2}$$

$$f = f_s + f_m = (m-s) \times \left(\frac{\nabla s}{\left|\nabla s\right|^2 + (m-s)^2} + \frac{\nabla m}{\left|\nabla m\right|^2 + (s-m)^2} \right) \tag{3}$$

3. Improvement of Demons

3.1. Regional information entropy instead of intensity

The basic assumption of Demons is that the intensity of image pixel keeps stable, while image pixel moving. But to circuit infrared image, the intensity and gradient are changed as the object's temperature has changed, so the classical Demons algorithm could not match infrared images. The regional information entropy of the image reflects the distribution of regional intensity. The object's temperature has changed, while the distribution of object's intensity will keep stable. On the contrary, the regional information entropy of the object keeps stable. For a given point P, the regional information entropy of P is calculated by:

$$H(p) = \sum_{\Omega} -p(x)\log(p(x)) \tag{4}$$

In Eq. 4, $p(x)$ is the probability of intensity, Ω represents the regional areal. We use the regional information entropy instead of intensity. Calculating all the point's regional information entropy from moving image and reference image, the moving regional information entropy image EM and reference regional information entropy image ES are obtained. EM is thought as the moving image and ES as the reference image. The similar idea with active Demons, the displacement is calculated by:

$$u = (em - es) \times \left(\frac{\nabla es}{\left|\nabla es\right|^2 + (em-es)^2} + \frac{\nabla em}{\left|\nabla em\right|^2 + (es-em)^2} \right) \tag{5}$$

Algorithm 1: Active Demons added regional information.

```
- Calculating all the point's regional information of M and S, obtaining
  ES and EM.
- Calculating the gradient of ES $\triangledown es$
- Iterate until convergence:
    * Calculating the gradient of EM $\triangledown em$.
    * Calculating the displacement $v$ according to equitation 5.
    * Calculating the displacement $u = u + gauss^* v$.
    * Calculating the new EM depending on $u$.
- Calculating the moving image depending on $u$.
```

3.2. Addition inertia parameter

Inspired by Newton's inertia theorem, the displacement is regarded as speed. Because of the existence of inertia, the current speed will maintain and continue to the next time. At the same time, friction exists between the moving image and reference image. The speed will be slow down under the friction. We suppose that friction is proportional to the speed; the coefficient of friction was μ. So the friction was calculated by:

$$F = \mu v \tag{6}$$

The image movement should observe the conservation of momentum. We suppose that the quality of image is one and the original speed is v_0, so we can obtain the equation as:

$$v_0 = \int_0^t \mu v dt + v \tag{7}$$

Form Eq. 7, the speed at time t can be calculated.

$$v = e^{-\mu t} v_0 \tag{8}$$

We suppose that the time between nearby iterations is 1. From Eq.8, the speed is v_0 at the current iteration, next iteration the speed slow down to $e^{-\mu} v_0$. We use β instead of $e^{-\mu}$. So we can rewrite Eq. 8 as Eq. 9.

$$v = \beta v_0 \tag{9}$$

Algorithm 2: Algorithm 1 added inertia parameter

```
- Initialize $v_0 = 0$
- Calculating all the point's regional information of M and S, obtaining
  ES and EM.
- Calculating the gradient of ES $\triangledown es$
- Iterate until convergence:
    * Calculating the gradient of EM $\triangledown em$.
    * Calculating the displacement $v$ according to Eq. 5.
    * $v_0 = gauss^* v + \beta^* v_0$.
    * Calculating the displacement $u = u + v_0$.
    * Calculating the new moving information entropy image depending
      on $u$.
- Calculating the moving image depending on $u$.
```

3.3. Similarity evaluation

The similarity evaluation of the image does not have a uniform standard. We use three evaluation methods, which are commonly used: mean square differences (MSD), correlation coefficient (CC), and normalized mutual information (NMR). The formulas are as follows:

$$MSD = \frac{\sum (f(x) - m(x))^2}{N} \tag{10}$$

$$CC = \frac{\sum_i (S_i - \bar{S})(M_i - \bar{M})}{\sqrt{\sum_i (S_i - \bar{S})^2} \sqrt{\sum_i (M_i - \bar{M})^2}} \tag{11}$$

$$NMI = \frac{H_S + H_M}{H_{SM}} \tag{12}$$

In Eq. 10, $f(x)$ is the intensity of image f; $m(x)$ is the intensity of image m; N is the total number of pixels. In Eq. 11, S_i, T_i are the value of reference images and template's pixels, respectively; $\bar{S}$, $\bar{T}$ are the mean value of the reference image's pixels and the template image's pixels, respectively. In Eq. 12, H_S is the information entropy of the reference image; H_M is the information entropy of the moving