A Gradient Vector Flow Snake Model using Novel Coefficients Setting for Infrared Image Segmentation

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ABSTRACT: In this paper, a novel gradient vector flow snake model is proposed for infrared image segmentation. Our model has several advantages in terms of infrared image segmentation. Infrared images are characterized by high noise and low contrast. We propose a novel generalized gradient vector flow snake model combining the advantages of several snake models. And we also use a new type of coefficient setting to improve the capacity of protecting weak edges in infrared images during segmentation process. Experimental results and comparisons against other methods show that our proposed model performs much better in terms of infrared image segmentation than other snake models.

1 INTRODUCTION

Infrared radiation is an invisible type of electromagnetic wave, whose wavelength ranges between the radio wave and the visible light. Any object in the nature whose temperature is over absolute zero is able to radiate the infrared ray. Compared with the visible light, the infrared wave has some unique characteristics. For example, compared with the visible light, its heat effect is stronger, and it is more likely to be absorbed by the substance and less sensitive to the human eye.

The infrared images have the following features. (1) Most objects in the infrared images have weak edges. (2) Most of the infrared images have a high degree of heterogeneity. (3) The contrast of the infrared images is low. (4) The resolution of the infrared images is low.

Considering the features above, the traditional methods are ineffective in segmenting the infrared images. The active contour model has the following considerable advantages in terms of infrared image segmentation.

a. The object’s edges obtained by the model is smooth, and the model is very robust to edge clearance in the image.

b. The segmentation results represent the object’s edges with closed curves, thereby dispensing with the need to connect edges of the segmentation results. The closed contour is more conducive to object analysis and recognition.

c. The partial differential equation can be used to compute the relatively mature results via theoretical and numerical analysis. The model can also directly process the features of the to-be-segmented images.

Hence, the model is very robust and capable of yielding better segmentation results.

Currently, the active contour model has been widely used for segmentation of medical images [1-5]. This type of model has developed rapidly and its variants spring up in recent years. Due to the unique characteristics of the infrared images, the study on the use of active contour model for segmentation of infrared images is in the infancy. Generally, there is a lot of work to be done on the segmentation of infrared images using active contour model[6,7]. Existing study shows that the active contour provides a very promising approach for the segmentation of infrared images.

The active contour model can be classified into the parameter-based type [8-20] and the geometry-based type [21-25]. This paper focuses on the former type and proposes a novel model to segment infrared images more accurately. The proposed model has advantages in terms of weak edge protection and noise smoothing. Experiments are carried out to segment the real-world infrared images using the proposed model and other traditional active contour algorithms for the purpose of evaluating accuracy and other aspects of their performance. Finally, we draw a conclusion about this paper.

2 PROPOSED ALGORITHM

2.1 Improved version of the GVF model

The GGVF Snack model [10] enlarges the convergence range of the active contour, improves the LTI convergence performance and is more robust to the noise. Based on NGVF [13] which has higher
diffusion efficiency. NBGVF [14] provides a solution to the weak edge protection problem. Hence, this paper relies on the GVF external force model, and combines GGVF and NBGVF to propose a novel external force model.

The improved version of the external force is defined as a vector field, and it can be obtained by using the following energy functional:

$$E(V) = \iint g(x, y) (gs(x, y)V_{nn} + hs(x, y)V_{tt}) \, dx \, dy + h(x, y)(V - \nabla f) \, dx \, dy$$

$$g(|\nabla f|) = e^{-|\nabla f|/\kappa}$$

$$h(|\nabla f|) = 1 - e^{-|\nabla f|/\kappa}$$

$$hs(f) = \begin{cases} \left| |e| \right| \geq \pi \left( f^2 \right) + \frac{5f}{8\tau} + \frac{1}{2} (0 < |e| < \tau) \\ 0 (|e| = 0) \end{cases}$$

$$gs(f) = 1 - hs(f)$$

Where $V_{nn}$ and $V_{tt}$ denote the second-order derivative along the normal and tangent directions. $g(|\nabla f|)$ and $h(|\nabla f|)$ denote the coefficients of the smooth and data terms in Equation (1). As defined in GGVF, the value of K increases with the noise intensity in the image, but this may lead to the weak edge being over-smoothed. Unlike the coefficients of the normal and tangent diffusion operators in NBGVF, both of the coefficients directly depend on the intensity rather than the gradient of the edge graph, thereby greatly reducing the computational complexity.

### 2.2 Numerical implementation

Now, the external force field can be obtained by minimizing Equation (1). The Euler-Lagrange equation of the energy functional can be written as:

$$g \cdot (gs \cdot V_{nn} + hs \cdot V_{tt}) + h \cdot (V - \nabla f) = 0$$

In order to obtain the vector field in Equation (6), we introduce the parameter $t$ and construct the following partial differential equation.

$$\frac{\partial V}{\partial t} = g \cdot (gs \cdot V_{nn} + hs \cdot V_{tt}) + h \cdot (V - \nabla f)$$

Moreover, as shown in Figure 1, the variation of the parameters in Equations (4) and (5) with the intensity of the edge graph takes the form of convex function. Compared with the parameters in NBGVF, the coefficients of the proposed model change gradually when the value of $f$ is high, and thus offer more protection to the weak edge in the infrared images. Hence, the proposed model is capable of segmenting the infrared images more accurately.
Meanwhile, the coefficients of the proposed model fluctuate violently when the value of f is low. As a result, contour divergence is more efficient at a long distance from the edge.

3 EXPERIMENTAL RESULTS AND ANALYSIS

In this section, the proposed GVF model will be compared with GVF [9], GGVF [10], NGVF [13], NBGVF [14] and CN-GGVF [18] across different images. First, we apply these methods to standard images, including the U-shaped image and the LTI image. All of these images are the traditional images used to evaluate the basic performance of various Snake models. Afterwards, we will evaluate the performance of the proposed model and other algorithms in terms of segmenting infrared images, such as the original infrared image and the infrared images corrupted with various types of noises. These segmentation results form the basis for detailed analysis and comparison. MATLAB R2014B is used as the development environment of the experiment programs in this paper. The computer configuration is Inter Core i5-4210M 2.6GHz CPU and 8G RAM. Subjective assessment has its limitations for the evaluation of segmentation performance. In our experiments, the segmentation results are evaluated using the following metrics: Precision, Recall and F1 measure [1]. Let $M_{seg}$ denote the actual segmentation results and $G_{seg}$ denote the segmentation baseline.

The metric Precision can be expressed as:

$$P = \frac{M_{seg} \cap G_{seg}}{M_{seg}} \quad (11)$$

Similarly, Recall can be defined as:

$$R = \frac{M_{seg} \cap G_{seg}}{G_{seg}} \quad (12)$$

F1 measure provides an evaluation metric that combines Precision with Recall. It is defined as:

$$F = \frac{2 \times P \times R}{P + R} \quad (13)$$

A high value for any of these three metrics means that the segmentation is accurate and the result approximates to the ground truth.

3.1 Catching range, convergence for convex and concave planes and insensitivity to initial contours

In this set of experiments, we use the U-shaped and square images to test the performance of the algorithms. The contour of the proposed algorithm evolves from a long distance away towards the target edge of the image. The parameter setting of the proposed method is $\{K, \tau\} = \{0.1, 1\}$ and the evolution is shown in Figs. 4 and 5. It can be seen that the final contour is well matched with the target edge. The results in Figure 2 (a) shows the large catching range of the proposed model. The results in Figure 2 (a) and (b) demonstrate the ability of the proposed method to obtain accurate segmentation results regardless of where the initial contour is placed and whether the contour is distant from the object or passes through the target edge.

Figure 3 demonstrates the ability of the proposed method to converge for convex and concave planes and obtain the U-shaped edge accurately through segmentation.
3.2 Segmentation results for infrared images

In this subsection, we will use the infrared images to evaluate the comprehensive performance of the proposed model. We captured the infrared images of the airplane, shop and tank using the infrared camera at a resolution of 640×480. After being preprocessed, the images are segmented using the proposed model and other traditional algorithms. The segmentation results are then compared.

![Image 4. Images used in the experiment, named as plane, ship and tank, from right to left.](image4)

![Image 5. Segmentation results of usual infrared images.](image5)

<table>
<thead>
<tr>
<th></th>
<th>GVF</th>
<th>GGVF</th>
<th>NGVF</th>
<th>NBGVF</th>
<th>CN-GGVF</th>
<th>proposed</th>
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<tbody>
<tr>
<td>planeN</td>
<td>0.9177</td>
<td>0.7606</td>
<td>0.8643</td>
<td>0.8705</td>
<td>0.7147</td>
<td>0.8861</td>
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<tr>
<td>Recall</td>
<td>0.9296</td>
<td>0.9899</td>
<td>0.9668</td>
<td>0.9859</td>
<td>0.996</td>
<td>0.9849</td>
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<tr>
<td>F1</td>
<td>0.9236</td>
<td>0.8603</td>
<td>0.9127</td>
<td>0.9246</td>
<td>0.8322</td>
<td>0.9329</td>
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<tr>
<td>shipN</td>
<td>0.9756</td>
<td>0.9097</td>
<td>0.9262</td>
<td>0.944</td>
<td>0.8767</td>
<td>0.9527</td>
</tr>
<tr>
<td>Recall</td>
<td>0.8284</td>
<td>0.9753</td>
<td>0.9045</td>
<td>0.8963</td>
<td>0.9733</td>
<td>0.9406</td>
</tr>
<tr>
<td>F1</td>
<td>0.896</td>
<td>0.9414</td>
<td>0.9152</td>
<td>0.9195</td>
<td>0.9225</td>
<td>0.9466</td>
</tr>
<tr>
<td>tankN</td>
<td>0.9381</td>
<td>0.8944</td>
<td>0.9145</td>
<td>0.9027</td>
<td>0.8607</td>
<td>0.8815</td>
</tr>
<tr>
<td>Recall</td>
<td>0.8529</td>
<td>0.9431</td>
<td>0.9196</td>
<td>0.8893</td>
<td>0.9518</td>
<td>0.9567</td>
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<tr>
<td>F1</td>
<td>0.8934</td>
<td>0.9181</td>
<td>0.9171</td>
<td>0.896</td>
<td>0.904</td>
<td>0.9176</td>
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</table>

In the experiment, the parameter setting of the proposed model is \( \{ K, \tau \} = \{ 0, 2, 1 \} \). The major influences that affect segmentation accuracy are the weak target edges and the interference from the edges of other objects near the target. Figure 4 shows the original infrared images used in the experiment and Figure 5 shows the segmentation results of various active contour models. The last column is the ground truth. From Figure 5, it can be seen intuitively that the propose model can segment the infrared images very accurately and is superior to other traditional models in terms of accuracy. As discussed at the beginning of this section, subjective evaluation has some limitations. Hence, we perform quantitative analysis of these results based on Equations (11), (12), (13).

The data in Table 1 intuitively reveals the advantages and disadvantages of the proposed method over other algorithms in terms of infrared image segmentation. Consider the metric of F1 which can reflect the segmentation performance overall. The value of this metric of the proposed method is higher than the other algorithms across the three images. This demonstrates the undisputed superiority of the proposed method.

4 CONCLUSIONS

The infrared image segmentation technology is of great significance to the real-world life and manufacturing. But many issues have yet to be addressed. The research on the use of active contour model for infrared image segmentation is in the infancy, but it has attracted a lot of attention. In this paper, we adapt the active contour model to the infrared images by improving NBGVF. A series of experiments have been performed to prove segmentation accuracy superiority of the proposed method over other algorithms (GVF, GGVF, NGVF, NBGVF, CN-GGVF). Meanwhile, it is proven that the proposed method can smooth noises while protecting weak edges in the infrared images. Hence, the proposed method is vastly superior to other algorithms.

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