Available online at www.sciencedirect.com
ScienceDirect
Pattern Recognition Letters 28 (2007) 58–63
Pattern Recognition Letters
www.elsevier.com/locate/patrec

NGVF: An improved external force field for active contour model

Ning Jifeng [a,b,*], Wu Chengke [a], Liu Shigang [a], Yang Shuqin [b]

[a] Xidian University, National key laboratory of ISN, No. 2 South TaiBai Road, Xi'an, Shaanxi 710071, China
[b] Northwest A&F University, 3 Taicheng Road, Yangling, Shaanxi 712100, China

Received 8 July 2005; received in revised form 26 April 2006
Available online 23 August 2006

Communicated by H.H.S. Ip

Abstract

An improved external force field for active contour model, called as NGVF, is presented in this paper. Based on analyzing the diffusion process of the GVF and three interpolation functions, it is found that the generation of GVF contains diffusions in two orthogonal directions along the edge of image, one is the tangent direction and the other is the normal direction. Moreover, the diffusion in the normal direction plays the key role on the diffusion of GVF, while the diffusion in the tangent direction has little effect. So the GVF in the normal direction (NGVF) is taken as a new force field to study. Experiment results with several test images reveal that, compared with GVF, NGVF can enter into long, thin indention and has faster convergence speed towards the concavity and bigger time step.

Keywords: Active contour model; Gradient vector flow; GVF in the normal direction; Image interpolation

1. Introduction

The variational method has been a research focus of image processing in recent years (Kass et al., 1988; Osher and Sethian, 1988; Yuen et al., 1998; Jain et al., 1998; Caselles et al., 1998; Zhong et al., 2000; Chan and Vese, 2001; Wang and Chou, 2004). Notably, active contours, known as "snakes", have been widely studied and applied. And their applications mainly include edge detection, segmentation of objects, shape modeling and motion tracking. Active contours were first introduced in 1988 by Kass et al. (1988). They are closed curves or surfaces represented by parametric equation. An energy function is associated with these curves, which convert the problem of finding objects into the process of energy minimizing. Affected by both internal force and external force, the parametric curves move to the direction of minimum energy. The internal force is decided by the curves themselves, and the external force is decided by the image, so the external force is also called "image force". The traditional force field has small capture range, and is sensitive to the initial snake curve. In order to enable the curves to converge the edge of objects rapidly, many improved models of image force field were put forwarded. Cohen (1991) presented the balloon model, which enlarge the capture range of snakes, but could not enter into the concavities of the objects' edge. Additionally, external forces defined as the negative gradient of a Euclidean distance map were widely used (Cohen and Cohen, 1993).

Xu and Prince (1997, 1998) proposed a new external force model, known as GVF, which uses a spatial diffusion of the gradient of an edge map of the image to create a dynamic force field. It solves the problem of small capture range of traditional snakes' model, and can go into the concavities of the objects' edge in principle.

There are two different implement methods of active contour model, namely parametric active contours and geometric active contours (or geodesic active contours) (Malladi et al., 1995; Caselles et al., 1997). Parametric active contours use a parametric representation of the curves, and geometric active contours utilize level set

* Corresponding author. Fax: +86 29 8823 2281.
E-mail address: jf_ning@sina.com (N. Jifeng).

0167-8655/$ - see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.patrec.2006.06.014

methods for its implementation (Osher and Sethian, 1988). In general, parametric snakes have the advantage over geometric snakes in convergence speed. The virtue of geometric active contours is that, during evolution process, the application of level set methods makes the splitting or merging of the curves treated automatically, whereas parametric methods have difficulty in handling these situations (Sumengen, 2004).

In recent years, some relations between these two models have been researched (Xu et al., 2000; Paragios et al., 2004). In (Paragios et al., 2004), GVF was integrated into the geodesic active contour, which improved the segmentation effects of geometric snakes. Therefore, constructing a good external force field would be of benefit to the segmentation performance of parametric snakes and geometric snakes.

In this paper, we discuss at length the diffusion process of GVF force field and propose an improved external force field called as NGVF. There has close relationship between NGVF and GVF. However, compared with GVF, NGVF has some better performances than GVF in many cases.

The rest of paper are organized as follows: In Section 2, we introduce briefly active contour and GVF model, in Section 3, further discussion on GVF and proposed new model is explained in detail. While, some experiment results appear in Section 4. Conclusions of this paper are presented in Section 5 and the acknowledgement.

2. Active contour model

2.1. Snakes

In 2D, snakes are a curve $c(s) = (x(s), y(s), s \in [0,1])$ that moves through the spatial domain of an image to minimize the energy functional:

$$E_{\text{snakes}} = \int_0^1 \frac{1}{2}[\alpha|c'(s)|^2 + \beta|c''(s)|^2] + E_{\text{ext}}(c(s))\,\mathrm{d}s \tag{1}$$

where α and β are weighting parameters that control the snake's tension and rigidity, respectively, and the two parameters of $c'(s)$ and $c''(s)$ denote the first and second derivatives of $c(s)$ with respect to s. The external energy function E_{ext} is derived from the image, and it takes on its smaller values at the features of interest, such as boundaries.

In (1), a snake that minimizes E must satisfy the Euler equation

$$\alpha c''(s) - \beta c''''(s) - \nabla E_{\text{ext}} = 0 \tag{2}$$

This can be viewed as a force balance equation

$$F_{\text{int}} + F_{\text{ext}} = 0 \tag{3}$$

where $F_{\text{int}} = \alpha c''(s) - \beta c''''(s)$ and $F_{\text{ext}} = -\nabla E_{\text{ext}}$.

2.2. GVF (Gradient Vector Flow)

Xu and Prince (1997, 1998) proposed an external force field, known as GVF, which has large capture range. GVF is the vector field $V(x,y) = [u(x,y), v(x,y)]$, which minimizes the energy functional:

$$Q = \iint \mu(u_x^2 + u_y^2 + v_x^2 + v_y^2) + |\nabla f|^2 |V - \nabla f|^2\,\mathrm{d}x\,\mathrm{d}y \tag{4}$$

where f is edge map of original image and μ is weighting parameters.

Using the calculus of variations, it can be shown that the GVF field can be found by solving the following Euler equations:

$$\begin{aligned}&\mu\nabla^2 u - (u - f_x)(f_x^2 + f_y^2) = 0,\\ &\mu\nabla^2 v - (v - f_y)(f_x^2 + f_y^2) = 0\end{aligned} \tag{5}$$

where ∇^2 is the Laplacian operator.

GVF is a dynamic force field, which diffuses along the directions of x and y of image gradient simultaneously, and could preserve the image's edge information well after numerous iterations. GVF has favorable convergence and could enter into the concavities of the objects' edge in principle, so it has been one of the models which are used most wildly. However, the diffusion speed of the edge information of GVF is low and so only through more iteration numbers can the force field go into the concavities of the objects' edge.

3. Discussion of problem and proposed model

3.1. Discussion of gradient vector flow

In Eq. (5), ∇u, ∇v are diffusion terms, and $(u - f_x)(f_x^2 + f_y^2)$, $(v - f_y)(f_x^2 + f_y^2)$ are data attraction terms. It is well known that Laplacian operator has very strong isotropic smoothing properties and does not preserve edges, whereas $(u - f_x)(f_x^2 + f_y^2)$ and $(v - f_y)(f_x^2 + f_y^2)$ could preserve the edge map, μ is a weight or regularization parameter adjusting between the first terms and the second terms. So the outcomes of Eq. (5) are equivalent to a progressive construction of the GVF starting from the object boundaries and moving towards the flat background.

The above analyses show that the diffusion of GVF force field depends virtually on Laplacian terms, while data attraction terms only preserve the edge map, which is to say that the properties of GVF have close relationship with Laplacian terms. Accordingly, if Laplacian terms in Eq. (5) could be replaced with other better diffusion operator, the property of GVF force field would be improved.

Therefore, we emphasize on analyzing the Laplacian terms next.

In (Aubert and Pierre, 2002), Laplacian terms are decomposed using the local image structures, that is, the tangent and normal directions to the isophote lines (Fig. 1).

Further, we rewrite Laplacian terms as

$$\nabla^2 f = f_{TT} + f_{NN} \tag{6}$$

$$f_{TT} = \frac{1}{|\nabla f|^2}(f_x^2 f_{yy} + f_y^2 f_{xx} - 2 f_x f_y f_{xy}) \tag{7}$$

$$f_{NN} = \frac{1}{|\nabla f|^2}(f_x^2 f_{xx} + f_y^2 f_{yy} + 2 f_x f_y f_{xy}) \tag{8}$$