Active Contours, Gvf and Balloon Model

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Abstract: --
One of the substantial techniques in the field of digital image processing is image segmentation. It is excessively used in the field of medicine provides visual means for identification, inspection and tracking of diseases for surgical planning and simulation. Active contours or a snake is an image segmentation technique which is widely used for boundary detection. They are regarded as promising and vigorously researched model-based approach to computer assisted medical image analysis. However, its utility is limited due some problems caused in the traditional methods, i.e. Poor convergence of concavities and small capture range. This paper shows the application a new model for active contours, which comprises of the Balloon Model and the GVF model. This model helps in improving the detection quality of closed edges, thereby resolving the limitations of the traditional snake model.

Index Terms —Active contour models, balloon model, edge detection, gradient vector flow

1. Introduction

Segmentation is the process of splitting the image into several parts like objects (also called foreground or background. Active contours [1] or snakes provide an effective way of segmentation [2] of curves defined within the image domain that can move under the influence of external and internal forces. These forces are defined such that the snake will shrink wrap to an object boundary. This method is widely used in many applications, including motion tracking, edge detection and segmentation.

There are two types of active contour models in literature today: - *parametric active contours and geometric active contours* [3][4]. Our main focus here is on parametric contours. Parametric active contours synthesize parametric curves within an image domain and allow them to move towards desired features, usually edges. Typically the curves are drawn towards the edges by potential forces, which are defined to be the negative gradient of a potential function. Additional forces like the potential forces and pressure forces together comprise the external forces. There are also internal forces designed to hold the curve together (elastic forces) and to keep it from bending too much (bending forces).

There are two main difficulties we face during the parametric active contour algorithm. First, the active contours have difficulties progressing into boundary concavities. The second problem is that the initial contour must in general, be close to the true boundary or else it will predict an incorrect result. Most of the methods that are proposed to solve the above problems are ineffective in solving both issues and end up creating more difficulties.

In this paper we present two distinct models to help resolve the problems mentioned above. Firstly, the *balloon model* or the expanding snake model helps resolve the problem of small capture range. When the approximate boundary of an object is unknown the traditional model fails to provide accurate results, in such situations using the balloon model shows robustness. Secondly, the *gradient vector flow* (GVF) model[5] which forces active contours into concave regions. GVF is computed as a diffusion of the gradient vectors of a gray-level or binary edge map derived from the image. Since the external forces cannot be written as the negative gradient of a potential function, GVF snake is different from all other snake models used before.

The major advantages of using these models over the traditional model are that it can be initialized far from the boundary since it has a large capture range. And unlike pressure forces, it does not require prior knowledge about when to shrink or expand towards the boundary.

2. Literature survey

A. *Parametric snake model*

The contour [1] is defined in the (x, y) plane of an image as a parametric curve

$$\mathbf{v}(s) = (x(s), y(s))$$

Contour is said to possess energy (E_{snake}) which is defined as the sum of the three energy terms.

$$E_{snake} = E_{internal} + E_{external} + E_{constraint}$$

The energy terms are defined cleverly in a way such that the final position of the contour will have a minimum energy (E_{min}) Therefore our problem of detecting objects reduces to an energy minimization problem.

Internal Energy (E_{int}) depends on the intrinsic properties of the curve and is the sum of elastic energy and bending energy.

Elastic Energy ($E_{elastic}$) of the curve is treated as an elastic rubber band possessing elastic potential energy. It discourages stretching by introducing tension.

$$E_{elastic} = \frac{1}{2}\int_s \alpha(s)\,|v_s|^2\, ds \qquad\qquad v_s = \frac{dv(s)}{ds}$$

Weight α(s) allows us to control elastic energy along different parts of the contour. Considered to be constant α for many applications.

Bending Energy ($E_{bending}$): The snake is also considered to behave like a thin metal strip giving rise to bending energy. It is defined as sum of squared curvature of the contour.

β(s) plays a similar role to **α(s).** Bending energy is minimum for a circle.
Total internal energy of the snake can be defined as:-

$$E_{\text{int}} = E_{elastic} + E_{bending} = \int_s \frac{1}{2}(\alpha\,|v_s|^2 + \beta\,|v_{ss}|^2)ds$$

$$E_{bending} = \frac{1}{2}\int_s \beta(s)\,|v_{ss}|^2\, ds$$

External energy (E_{ext}) of the contour is derived from the image so that it takes on its smaller values at the function of interest such as boundaries. Define a function $E_{image}(x,y)$ so that it takes on its smaller values at the features of interest, such as boundaries.

Key rests on defining $E_{image}(x,y)$.

$$E_{ext} = \int_s E_{image}(v(s))ds$$

Energy and force equations: The problem currently on hand is to find a contour v(s) that minimize the energy functional

$$E_{snake} = \int_s \frac{1}{2}(\alpha(s)\,|v_s|^2 + \beta(s)\,|v_{ss}|^2) + E_{image}(v(s))ds$$

Using variational calculus and by applying Euler-Lagrange differential equation we get following equation

$$\alpha v_{ss} - \beta v_{ssss} - \nabla E_{image} = 0$$

Equation can be interpreted as a force balance equation.

$$\mathrm{F}_{\text{int}} + \mathrm{F}_{\text{image}} = 0 \qquad\qquad F_{ext} = -\nabla E_{image}$$

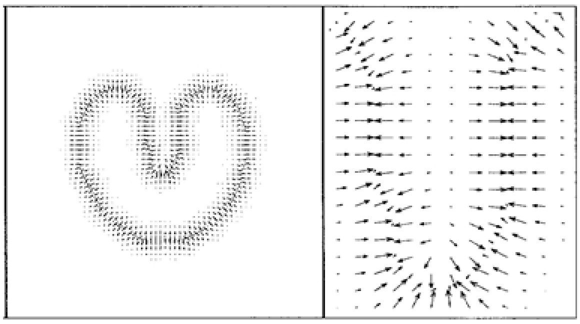
Each term corresponds to a force produced by the respective energy terms. The internal force F_{int} discourages stretching and bending while the external potential force F_{image} pulls the snake toward the desired image edges.
Solving the Euler equation:-
Consider the snake to also be a function of time i.e. $v_t(s,t)$

$$\alpha v_{ss}(s,t) - \beta v_{ssss}(s,t) - \nabla E_{image} = v_t(s,t)$$

$$v_t(s,t) = \frac{\partial v(s,t)}{\partial t}$$

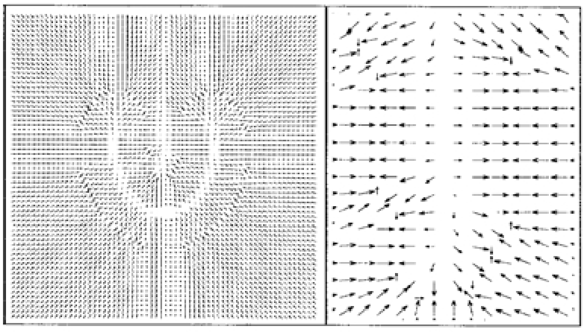
If RHS=0 we have reached the solution. On every iteration update control point only if new position has a lower external energy. Snakes are very sensitive to a false local minimum which leads to wrong convergence.

B. Weakness of Traditional Snakes



(a) (b)

Fig. 1 (a) traditional potential forces and (b) close-up



(a) (b)

Fig. 2 (a) traditional distance forces and (b) close-up

An example of behavior of traditional snake is shown in fig. 3(b) and fig. 4(b). In fig. 4(b) we can see that it has boundary concavity on the side are left vacant. This snake formulation is a result of Euler's equation and we can see that it remains split across the concave region.
The reason for the poor convergence of this snake as seen in fig. 1(b) is because the forces point horizontally in opposite direction. Another weakness of the traditional snake model is that it has a limited capture range; this can be explained in fig. 1(b). The magnitudes of the external forces die out quite rapidly away from the object boundary. The boundary localization will become less accurate and distinct.
External forces are a negative gradient of a potential function that is computed using Euclidean distance map. These forces are referred to as distance potential forces so as to distinguish them from traditional potential forces The distance potential forces shown in fig. 2(a) have vectors with large magnitudes away from the object, explaining why the capture range is large for external force model. In fig.2 (b) the traditional potential forces are horizontally in opposite direction, which pulls the snake apart and not downward into the boundary concavity.Hence the problem of convergence is not solved by distance potential forces

3. Balloon Model

The snake model originally introduced by Kass has been further developed by modified in recent years. The balloon model or the expanding snake mode [6] is one of the examples of this. Unlike, the traditional snake that shrinks wraps to the image boundary, this snake model expands outwards.
This model is based on an additional inflation force applied to give stable results. A snake which is not close to contours is not attracted by them. The curve behaves like a balloon which is inflated. When it passes by edges, will not be trapped by spurious edges and only is stopped when the edge is strong. The initial guess of the curve not necessarily is close to the desired solution. Pressure force is added to the internal and external forces.

The expansive behavior is achieved by modifying the values of f_x; f_y as followed,

$$f_x(x,y) = k_1 n(s) - k\frac{\nabla P_x}{||\nabla P_x||}$$
$$f_y(x,y) = k_1 n(s) - k\frac{\nabla P_y}{||\nabla P_y||}$$

where n(s) is the unit principal normal vector to the curve at point v(s), and k_1 is the amplitude of this force. k_1 and k are chosen such that they are of the same order, which is smaller than a pixel size and k is slightly larger than k_1 so an edge point can stop the Inflation force. The curve then expands and it is attracted and stopped by edges as before. The smoothing effect with the help of the inflation force then removes the discontinuity and the curve then passes through the edge.

4. Gradient Vector Flow Snake

The overall approach is to use the force balance condition as a starting point to design the snake. This parametric curve thus formed is called GVF snake.

Gradient Vector Flow:- The GVF field is defined to be a vector field **:-** V(x,y) = $(u(x,y), v(x,y))$

Force equation of GVF snake is, $\alpha v_{ss} - \beta v_{ssss} + V = 0$

V(x,y) is defined such that it minimizes the energy functional,

$$E = \iint \mu(u_x^2 + u_y^2 + v_x^2 + v_y^2) + |\nabla f|^2 |V - \nabla f|^2 \, dxdy$$

f(x,y) is the edge map of the image.
GVF field can be obtained by solving following equations

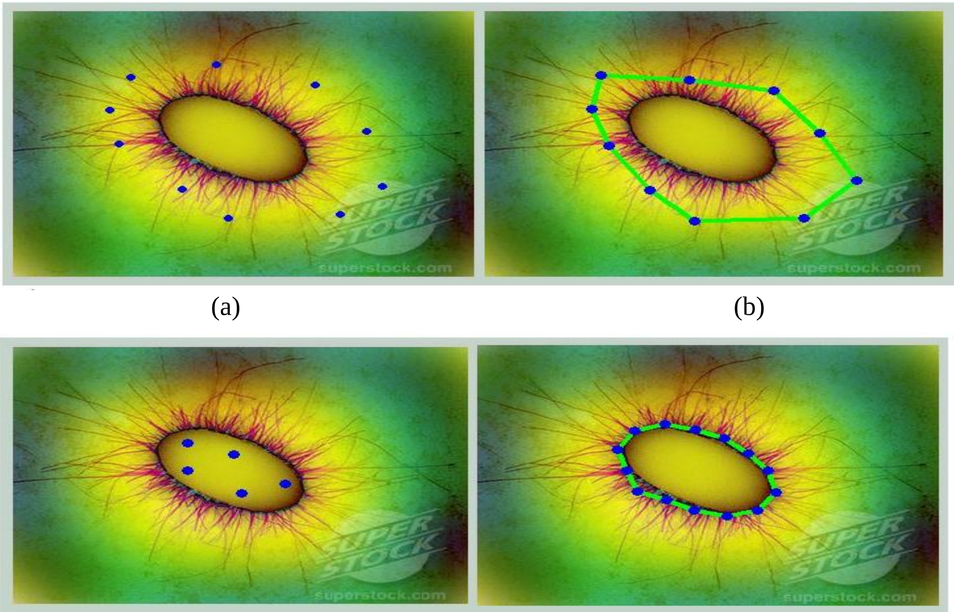
$$\mu\nabla^2 u - (u - f_x)(f_x^2 + f_y^2) = 0$$

$$\mu\nabla^2 v - (v - f_y)(f_x^2 + f_y^2) = 0$$

∇^2 Is the Laplacian operator.
The above equations are solved iteratively using time derivative of u and v. These equations provide further intuition behind the GVF formulation. We note that in the homogenous region the second term in both regions is zero because the gradient of f(x, y) is zero.

4. Results and Discussion

The Expanding snake model increases the capture range of an active contour. After its application we can see that the snake can move towards object boundary (fig. 4(b)) whereas in the case of the traditional snakes, they had a smaller capture range (fig. 3(b)).

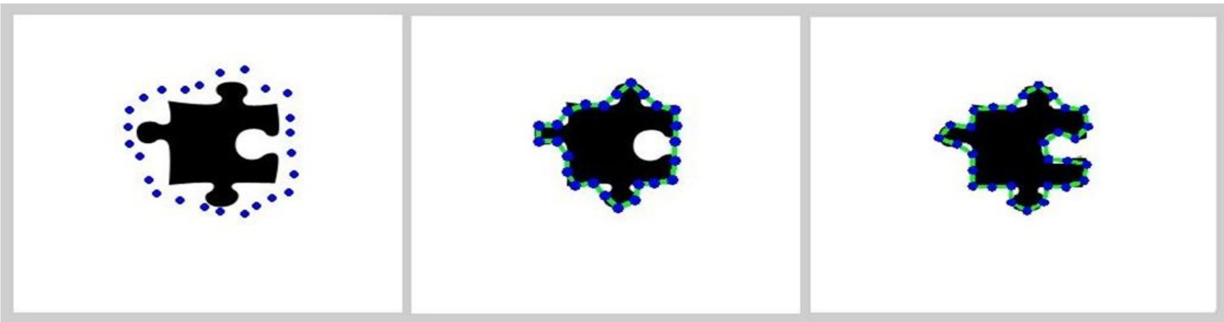


(a) (b)

(c) (d)

Fig3.(a) snake boundary using traditional snake , (b) small capture range of traditional snake, (c) snake boundary using balloon model and (d) problem of the small capture range resolved

The application of the GVF snake model shows that the snakes can move into boundary concavities (fig. 4(c)) as compared to the traditional snake model (fig. 4(b)).



(a) (b) (c)

Fig4.(a) Convergence of a snake using, (b)traditional snakes and (c)using GVF snake

5. Conclusion

We have presented a model of deformation which can successfully deal with two of the major problems that are encountered in the traditional snake model thereby making it more efficient. Firstly, the Balloon Model which enables us to give an initial guess of the curve which in turn helps us to deal with the problem of small capture range. . Secondly, the application of the Gradient Vector Flow (GVF) model which successfully allows convergence to boundary concavities. This model provides a collective way of treating visual problems that were till now treated differently. We can also conclude that although the GVF snake model and the Balloon Model are both slower than the traditional snake model in the iteration process they provide us with much more accurate.

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