Model-Based Active Contour for Real Time Tracking

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Abstract

Real-time object tracking has become a very important task for a large number of computer vision and robotic applications. The tracking function must be robust, despite of the high complexity present in a given environment. Frequently, the object to be tracked is well known (humans, head, hands, traffic signs, etc.). Shape constraints can be introduced directly in energy formulation, or can be defined as deformable templates. Both of them have shown very good results in object segmentation, but sometimes they are so complex that real-time tracking computation is almost impossible. In this paper, we propose definitions of basics shape constraints for active contours to be used in real-time tracking. Constraints are easily incorporated and do not affect the complexity of the dynamic programming method used for solving it, thanks that they are applied locally. Our main interest is to improve the tracking robustness using these constraints, for robot navigation and human-robot interaction. An application for landmark tracking is presented: landmarks are quadrangular and planar objects (typically, posters).

Index Terms: *Model-based active contours, dynamic programming, robot navigation.*

1. Introduction: Active Contours Overview

Snakes or active contours [1] have been extensively used for object segmentation and tracking. This method is based on energy minimization along a curve, which is subject to internal and external forces; these forces are defined by the desired shape and image properties, respectively. Commonly, the curve is described by a set of control points; a continuous curve is interpolated from these control points, by quadratic or cubic B-Splines. The evolution of the curve is determined by the equation of movement, which could be resolved by variational methods.

Variational approaches have problems concerning optimality, numerical stability, convergence, and enforcement of hard constraints. Amini and al. [2] proposed to solve this variational problem by a dynamic programming method. The complexity for the dynamic programming method is $O(nm^{k+1})$, where n is the number of control points, m is the number of possible positions for a control point and k is the highest order differential for contour. One advantage of this method is that it can be accelerated applying it in a multi-scale space.

In order to reduce the space m, we can simplify the search by considering only straight lines perpendicular to the curve (figure 1). However, this restriction is not able to make a redistribution of control points; for some sequences, after some images, control points become arbitrarily grouped or separated in the curve. In order to solve this problem, a new sampling of the curve is needed to redistribute control points on it before processing the next image.

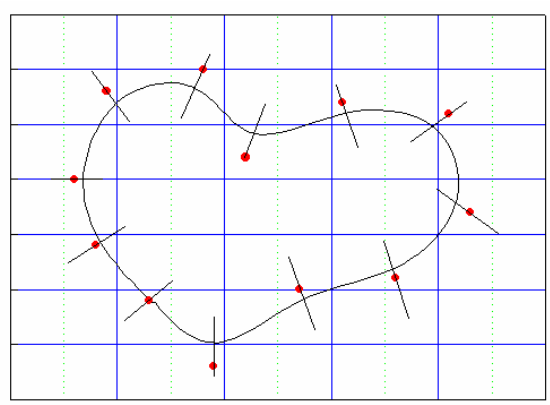

Figure 1. Search lines to find minimal energy

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For a good description of objects with corners or high curvature zones, the number of control points on these zones must be increased. However, if the point motions towards these high curvature zones are not restricted, the final curve can cross itself. In [3], it has been proposed to consider the active contour as a surface of an electrical charged conductor; these electrical charges generate a new internal force. As a result of these new repulsive forces, the control points are intrinsically redistributed along the curve with higher density in zones of high convex curvature.

When the object to be tracked has a structured shape, like a rectangle, a parametric shape-model can be defined (deformable template) which will be matched to an image, in a very similar way like snakes [4]. The characteristics for deformable templates are defined globally, so, the movement equation should be solved by variational methods. Condensation algorithm [5] has shown good results in tracking parameterized curves but as degrees of freedoms increase, real-time computation becomes very difficult.

Another way to introduce shape information in active contours is applying it constraints in order to deform it in a suitable way. Relationships between control points can be incorporated as energy terms and multiple control points can be introduced to describe vertices or discontinuities.

In this paper we present a simple way to introduce local restrictions in order to get model-based active contours for real-time tracking, without increasing the complexity much.

In section 2, we describe the classical energy formulation, taking into account the new internal force produced by electrical charges, required to maintain an optimal distribution of the control points along the contour. Section 3 describes local constraints for making deformable templates. Section 4 shows the definition of a poster template that is used for robot navigation. Experimental results are presented in section 5 and finally we give our conclusion.

2. Classical Energy formulation

The total energy for an active contour $\mathbf{v}$ described with a parametric representation $\mathbf{v} = (x(s),y(s))$ can be written as:

$$E_{tot}(\mathbf{v}) = \int E_{\text{int}}(\mathbf{v}(s)) + E_{ext}(\mathbf{v}(s))\,ds \tag{1}$$

where subscripts on E represent the internal and external energy terms.

Internal energy is commonly defined by:

$$E_{\text{int}}(\mathbf{v}) = \int_0^1 \omega_1(s)\mathbf{v}_s^2 + \omega_2(s)\mathbf{v}_{ss}^2\,ds \tag{2}$$

and external energy by:

$$E_{ext}(\mathbf{v}) = \int_0^1 P(\mathbf{v}(s))ds \tag{3}$$

where subscripts on $\mathbf{v}$ denote differentiation, ω_1(s) and ω_2(s) are weights given to the elasticity and the smoothness energies, and P is the image gradient intensity.
Considering the contour as the surface of an electric conductor has been proposed in [3], to introduce a constant electric charge Q. This charge is equally divided and distributed along the contour. A new force (repulsion) is then generated as a result of the electric charge density.

Taking into account this new repulsive force, the internal energy can be written as:

$$E_{\text{int}}(\mathbf{v}) = \int \omega_1(s)\mathbf{v}_s^2 + \omega_2(s)\mathbf{v}_{ss}^2 + k\frac{\sigma^2}{\mathbf{v}_s^2}\,ds \tag{4}$$

where k is a constant coefficient, and σ is the electrical charge density. $k\sigma^2$ can be seen as a coefficient, once the electric charge is given.

According to the Gauss law (5), once the equilibrium is reached, the electric flux through a closed surface is equal to the net charge enclosed by the surface, divided by the constant ε_0 (permitivity) and inside the conductor the electric field is exactly zero [6].

$$\oint \mathbf{E} \cdot dA = \frac{Q}{\varepsilon_0} \tag{5}$$

Furthermore, once the equilibrium is reached, the electric density will be higher in zones of high convex curvature (figure 2), and for an isolated electric conductor the distribution of charge density does not change, whatever its position in space will be. A very well known example is the lightning rods.

Consequently, the charged particles at the surface of our active contour will move under influence of forces generated only by the particles in their neighborhood. In other words, every span is only affected locally by the electric charge density. Movements of the object to be tracked should not have to affect the distribution of electric charges in the contour.

The redistribution of control points through this internal force can be used when the objects are unknown or when deformations need to push control points in some directions to maintain the contour shape.

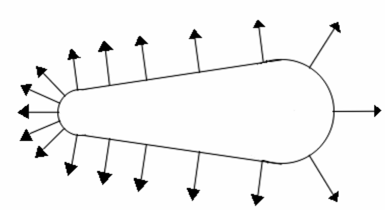
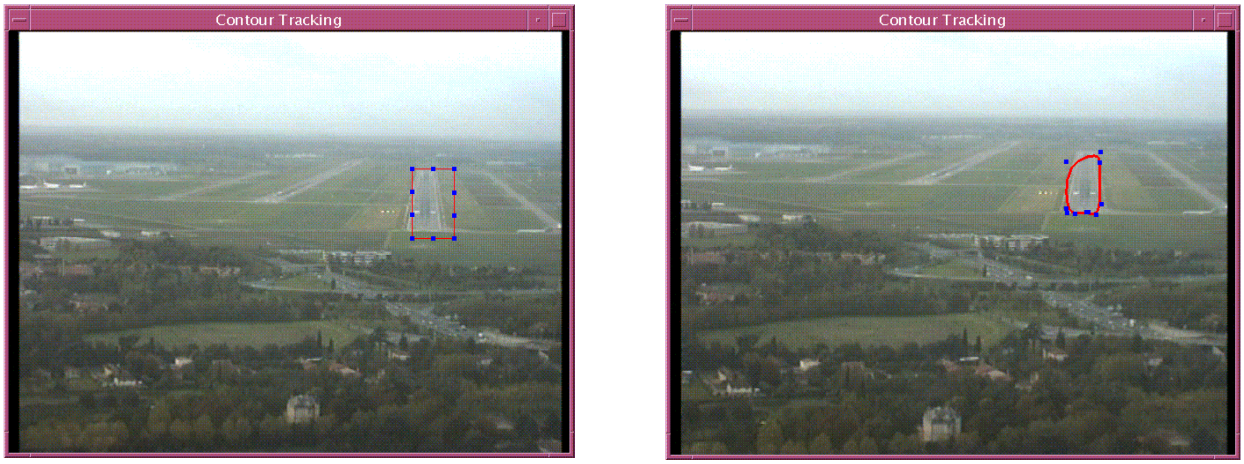


Figure 2. Electric charges distribution in a charged conductor



(a) (b)

Figure 3. Detection of a structured object: (a) initial snake, (b) final result.

To allow the redistribution of control points along the curve, instead of restricting the search to straight lines perpendicular to the curve (see Figure 1), the dynamic programming is applied to a square multi-scale neighborhood.

This general approach can be extended with parametric models in order to detect more structured objects [8]. This method has been used to track a landing strip during a landing task on an aircraft (see Figure 3). Such an object is a planar rectangle, the image projection must be a trapezoid, and it could be interesting to apply constraints so that the curve shape remains as close as possible to a trapezoid. Then, the general approach becomes so complex that real-time tracking is almost impossible. Instead of making very complex parametric models we have defined simple local constraints.

3. Definition of model-based active contours

Taking into account that a contour **v** is defined by a B-spline computed from an ordered set of control points; a deformable template is described using two local constraints:

a) A mixed sequence of single and multiple control points, and
b) shape relationships between control points and segments on the curve.

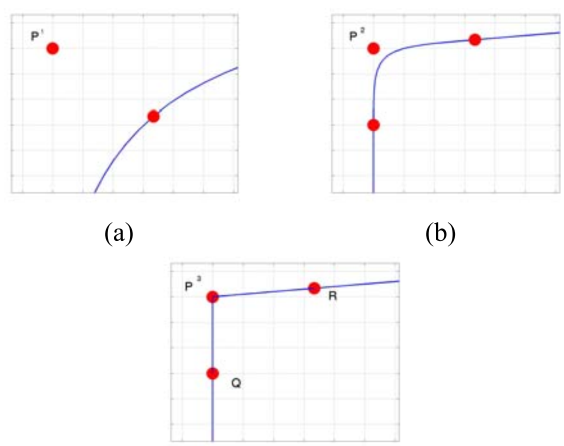
Once a template is defined, a new term for shape constraints is included in the total energy as written in (6).

$$E_{tot}(\mathbf{v}) = \int E_{\text{int}}(\mathbf{v}(s)) + E_{ext}(\mathbf{v}(s)) + E_{cons}(\mathbf{v}(s))\,ds \qquad (6)$$

The constraints in the term E_{cons} can be expressed, for example, as a distance between local models and new positions of the contour, as we will describe later.

A very important aspect of multiple control points to be taken into account is that, a control point of multiplicity k will generate new k-1 segments in the curve. Moreover, multiple control points are reflected as corners or discontinuities in the curve. In Figure 4, three cubic B-Spline curves with a point **P** of multiplicity 1, 2 and 3, respectively, are shown. We can see in figure 4c that a triple control point in a cubic B-Spline generates a discontinuity on the curve.

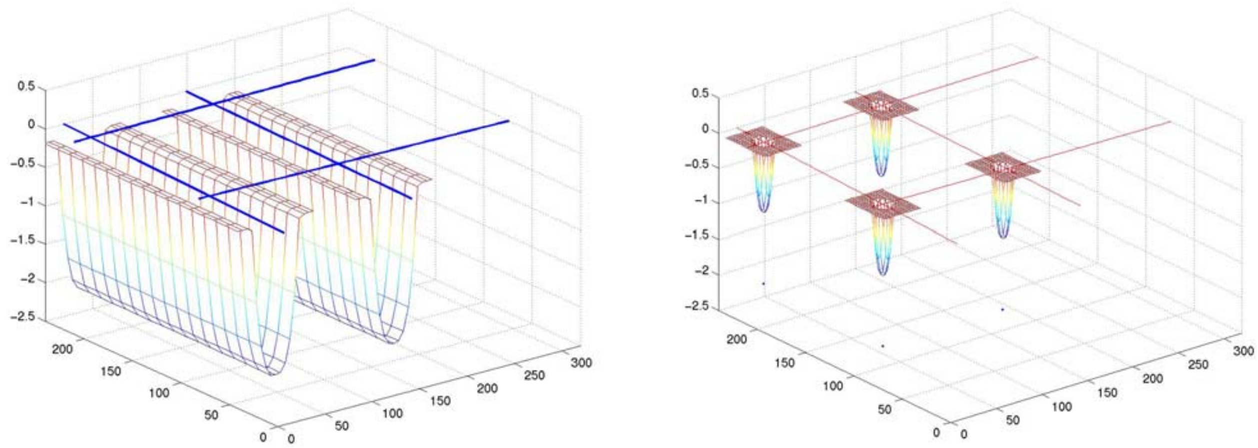
Be **P** a control point of multiplicity k = 3, like the one described in figure 4c. When this point is moved, the position of the points **Q** and **R** are strongly affected, and consequently the associated segments. Therefore, the energy terms are also affected, for the segments of curve that contain these three points in it (as a beginning or end of a segment). So, in order to avoid too many propagations, between each span involved in the movement of a multiple control point, the calculation of energy for all these segments could be processed together, without affecting the complexity of the dynamic programming.



(a) (b)

(c)

Figure 4. Cubic B-Spline curves with a multiple control point P.



(a) (b)

Figure 5. Potential zones of search for: (a) straight lines, and (b) crossing of straight lines

In general, for a control point of multiplicity k, we can evaluate together the energy of the k-1 spans directly involved, as described in (7):

$$E_{\mathbf{P}mult} = \sum_{i}^{i+k-1} E(v_i(s)) \qquad (7)$$

where i is the first span which contains a multiple control point, and $E(\mathbf{v}_i)$ is the energy for the i^{th} span.

As an example, for a control point of multiplicity $k = 3$, as the one shown in figure 4c, and using geometrical properties in the triangle ***PQR***, we can define the shape relationships and therefore the constraint energy as:

$$E_{\mathbf{P}cons} = c_c \left| QR^2 - \left(QP^2 + PR^2\right) \right| \qquad (8)$$

where c_c is a coefficient and QR, QP, PR, are the distances between points. Then, we get an energy constraint term, which privileges rectangles triangles.
Accordingly to this approach, the minimization of the total energy for the k-1 segments around a multiple point, allows to impose a corner or discontinuities in a contour, which can be modeled without difficulty.

Another type of shape constraints can be easily included, using the potential zones of search for the position of a control point, with respect to its position in the contour model. For example, let us consider an initial snake where a subset of control points have been characterized to remain aligned (every side of the rectangle on figure 3a); then for this subset of control points a potential can be applied to each of these points, as a measure of the distance between the current position and the distance to a straight line, which has been previously estimated.

The equation 9 shows an example of an energy term for this kind of potential zones of search:

$$E_{\mathbf{P}cons} = c_L \left| C_i C_j - P_k \right|^{\eta} \qquad (9)$$

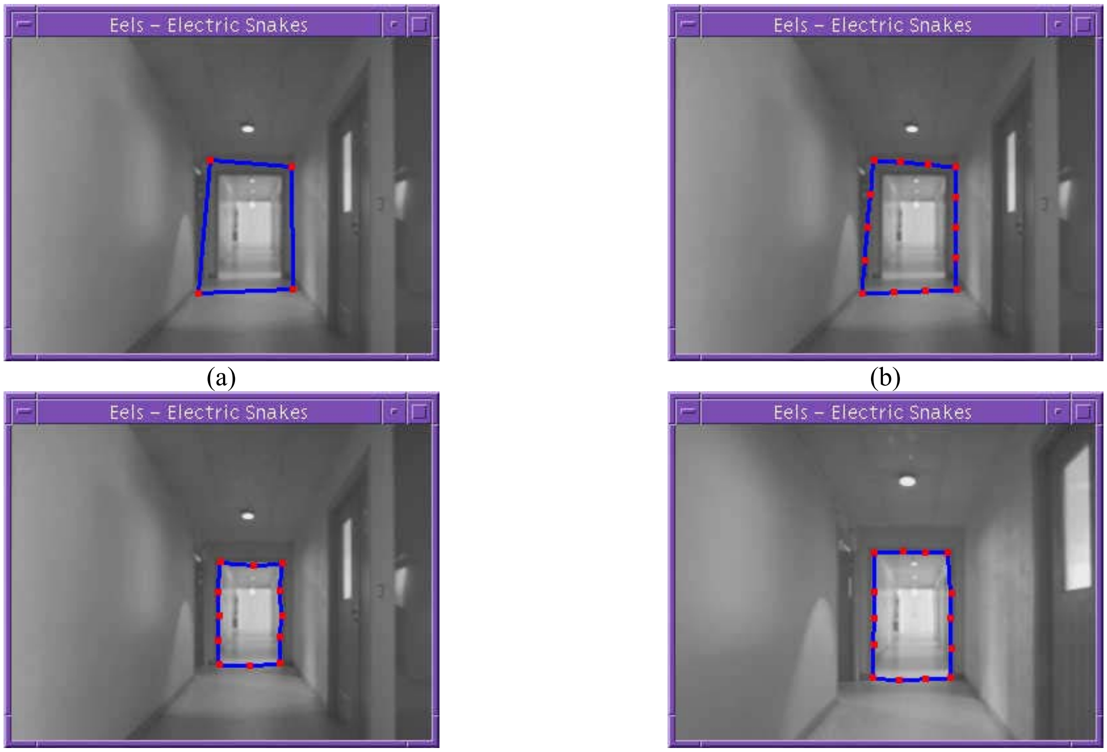
where C_iC_j is a straight line defined by the control points P_i and P_j, such as they are multiple control points or corners, and P_k is a control point between them ($i < k < j$). c_L is a constant to weight this potential and η gives the form of the potential, normally equal to 2 or 3.

The potential zones of search for control points defining a straight line segment, is presented on figure 5a; this energy to be minimized is computed as a distance to this same straight line on the previous snake, taking into account the possible variations of its slope.

Another kind of potential zones of search could be defined, as the distance between the cross of two straight lines and a multiple control point (figure 5b).

Models generated in this way (a sequence of single and multiple control points and shape relationships) do not affect dynamic programming a lot, because these constraints are calculated locally. The required computations are very simple, and the required data are the same as the ones also used for the estimation of the other energy terms. An example of deformable template is given in the next section.

Depending on the nature and the position of a segment or group of segment in the template, other external potentials can be included to take into account different image properties. For example, an external force could attract a multiple control point towards an interest point detected by a corner detector applied locally (Harris detector [9]). It is well known that the corner detectors are not very accurate; so the detected corners add forces that are not privileged with respect to the other ones.



(a) (b) (c) (d)

Figure 6. Corridor segmentation

4. Poster templates

We are interested in robotics applications. Our first example consists in tracking quadrangular patterns in corridors: doors used for the navigation task and posters, which will be used later for robot localization in human environments.

Our template is made of a sequence of control points, where four of them have multiplicity 3 (discontinuities for cubic B-Splines). The number of control points between corners is defined in the initialization process, taking into account the distance between them.

Locally, single control points are restricted to move under a potential search zone as the one defined previously (figure 5a). Multiple points or corners are also restricted to move in a determined distance of the crossing of straight lines, which defines each corner (figure 5b). Initialization process could be made automatically by a hard image processing method. The initial potential search zones are calculated during this step process for the initial snake.

Later, these zones are computed again when once the equilibrium is reached after tracking the object on every image of the sequence.

5. Results

In following figures, we show the results for a rectangular model-based active contour that is fitted to a doorframe (fig. 6) and a poster (fig. 7). In the initialisation process (fig. 6a), four points are given by another image processing method. These four points define the initial model, and automatically the initial distribution of other control points on the rectangle sides (fig 6b), as well the potential search zones are computed from this initial model. Figures 6c and 6d show segmentation of the doorframe for two different positions of our robot in the corridor.

In the case of the poster tracking, an average of 16 images (320x240 pixels) per second are processed, in a Pentium II platform, under linux. Figure 7 shows some images of a poster tracking sequence, where it is possible to see that the distribution of control points in different frames on the sequence are: a) regular and b) independent of the object size.

The internal energy coefficients used were $\omega_1 = 0.05$, $\omega_2 = 0.2$, which give more rigidity to the segments in the model. The charge electric q was equal to 50.0, and the gradient of the image was multiplied by $c = 17.0$. For the potential zones of search we had used $\eta = 3$, and all other weights constants were equal to 1.

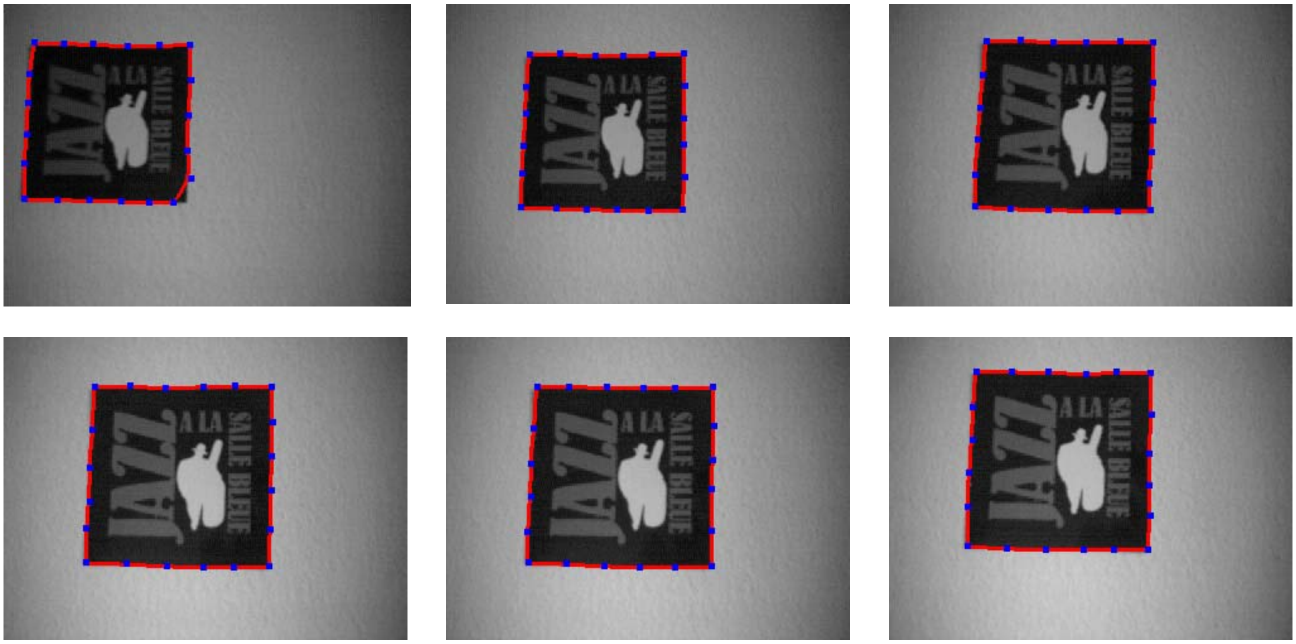


Figure 7. Poster tracking sequence

6. Conclusions

This paper has described a model-based active contour formalism suitable to detect and track structured objects. New forces are added to describe two local constraints: the colinearity of some points and the definition of vertices, or discontinuities on the contour. This formalism has been used to detect and track a landing strip during the landing execution by an airplane or posters during the navigation of a mobile robot in a built environment. Some other constraints could be added to describe other shapes –ellipses-, required to track spherical or cylindrical objects.

In our current work, more global constraints are taken into account, for example to express parallelism or convergence of segments on the contour. As long as locality is preserved, dynamic programming remains very efficient to minimize the energy along the contour; with more global relationships between control points, the complexity is higher and real time tracking becomes a challenge.

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