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A New Approach to Minimize the Energy of Deformable Contours

Eusebio de la Fuente, F.M.Trespaderne and J.R.Perán *
Instituto de Tecnologías Avanzadas de la Producción
University of Valladolid

Abstract

A new approach to solve the segmentation problem in noisy images with missing contours is presented using a deformable model. This model performs a radial search under a relaxation labeling procedure. The relaxation labelling, stated in terms of an optimization problem, is built with a concave criterion that always guarantees the global optimum. The algorithm is well suited for real-time applications due to the inherent local processing of an image near the snake elements. The algorithm has been applied to detect the boundaries of irregular pieces of meat in a production line of cooked ham.

1 Introduction

In order to automatize the manufacturing process of an industrial production line of cooked ham, boundaries of irregular meat pieces must be detected. The numerous specularities present in the scene and the photometric resemblance between fat surfaces of hams and the white table on which they lie make the segmentation process really intricate. Furthermore, shapes of fresh hams are irregular and different for each piece due to manual boning process and the soft nature of the meat. Classical edge detection techniques generate irregular and open contours often going inside the actual boundary of the ham mainly because of the low contrast between the table and the fat surfaces.

Active contours offer a reasonable approach to solving the boundary detection problem due to the presence of the edges depends not only on the gradient at specific points but also on their spatial distribution.

In this paper, we present a new deformable contour algorithm using a radial search and a relaxation labeling approach. The algorithm is applied to solve the segmentation problem of an intricate industrial application: the identification of irregular pieces of meat in a production line of cooked ham [1].

2 Active Contours

Active contours models was first proposed by Kass [3] and have been widely used in many applications in the past few years such as medical image processing, 3-D images, texture, ... This methodology is based upon the utilization of deformable contours which conform to various object shapes and motions.

*Address: E.T.S.Ingenieros Industriales, Paseo del Cauce s/n 47011 Valladolid, Spain. E-mail: eusfue@eis.uva.es

The basic active contour model, which is also commonly called a *snake*, can be thought of as an abstract elastic curve that, via minimization of an energy functional, deforms and adjusts its natural shape to match a specific contour, providing a continous boundary. The energy functional being minimized is a function of forces which are both internal or external to the snake. Internal forces act as a smoothness constraint, and external forces guide the active contour toward image features that are of interest.

To get a better grasp of this concept, we can think of an image as spatially varying potential field where, for example, bright areas represent high potential and dark areas low potential. A snake placed in such potential field will experience forces externally and will be pulled toward the lower potential (i.e. dark areas), where its energy will be at a local minimum.

3 Relaxation Labeling and Snakes

The structure of our active contour model includes (fig. 1):

- An initial central point C, where radial search converges.
- n radial search grid lines, with p evenly spaced points.
- Two borders, internal and external, that limit the search space. The area defined by these two borders is supposed to contain the final boundary. Close internal and external borders will reduce the computational cost.

The active contour is discretized in n radial points, each one on every radial line. These n points will constitute the n object boundary points $\mathcal{O} = \{o_1, o_2, \ldots, o_n\}$ considered in our labeling problem. The set of points along each radial line i will constitute the candidate labels $\mathcal{L}_i = \{l_1^i, l_2^i, \ldots, l_p^i\}$ for the final object boundary point o_i.

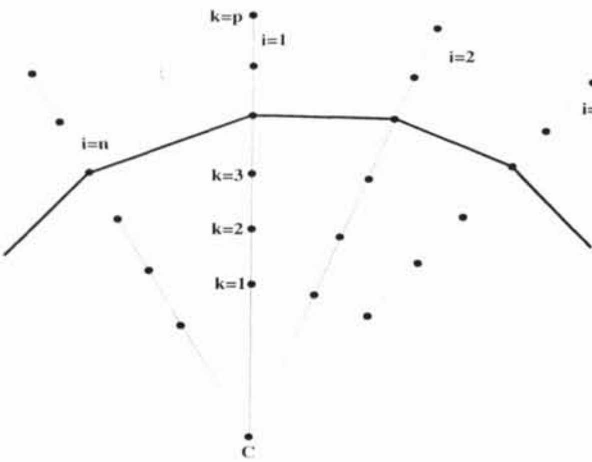

Figure 1: Structure of the active contour model. The area where active contour can evolve is reduced to the p points on every radial line.

Let $p(i,k)$ denote the *certainty* that label point l_k is assigned to object point o_i. Considering certainties as probability vectors, we can introduce the following constraint:

$$\sum_{k=1}^{p} p(i,k) = 1 \qquad \forall\, i \tag{1}$$

This constraint forces to find a label for every object point.

The active contour model is then described in terms of label point attributes and their vicinity relationships. *Proximity* has been used to relate a couple of label points. Two label points, $l_k^i \in$ and l_l^j are neighbours if they belong to two consecutive radial lines, so $|i-j|=1$ or $|i-j|=n-1$

4 Proposed Energy Functional

The snake model will evolve under the two deformational energies: the internal and external energies. The internal energy depends on the distance between neighbouring points meanwhile the external one depends on the gradient of the image.

4.1 Internal Energy

In our problem, there is a simple way to determine a relative measure of the distance $D(i,k;j,l)$ between two neighbour label points l_k^i and l_l^j:

$$D(i,k;j,l) = 1 - \frac{|k-l|}{max(k,l)} \qquad D \in [0,1]$$

$D(,:,)$ will take values near 1 if label points are close and will be almost null for distant label points.

4.2 External Energy

The gradient $G = |\nabla I|^2$ is obtained using an standard Sobel operator. Every label point has a normalized value of the gradient considering their sourrounding pixels,

$$G(i,k) = \frac{|\nabla I(i,k)|^2 - |\nabla I(i)|^2_{min}}{|\nabla I(i)|^2_{max} - |\nabla I(i)|^2_{min}} \qquad G \in [0,1]$$

where $|\nabla I(i)|^2_{max}$ and $|\nabla I(i)|^2_{min}$ are the maximum and minimum gradient magnitude of label points located on the i radial line, respectively.

5 Relaxation Labelling Procedure

An important element in relaxation labeling problems is the compatibility function [2], noted c(i,k;j,l). This function measures the compatibility of assigning label l_l to object o_j when neighbour label l_k is paired with object l_i. Note that compatibility function is only defined for neighbour labels. Our main contribution is to connect the compatibility function with the internal and external forces typically considered in active contour models. The external and internal forces are embodied with weights α and β in the compatibility coefficients :

$$c(i,k;j,l) = \alpha\, D(i,k;j,l) + \beta\, \frac{G(i,k)+G(j,l)}{2}$$

$$\alpha + \beta = 1 \qquad c() \in [0,1]$$

Now, we define a local measure of the energy of a labeling by:

$$\mathcal{C}_{ik} = \sum_{j=1}^{n}\sum_{l=1}^{m} c(i,k;j,l)\min\{p(i,k)\,,\,p(j,l)\} \tag{2}$$

$$c(i,k;j,l) > 0$$

A global measure of snake energy can be defined over the whole set of object-label pairings by arithmetic averaging:

$$\mathcal{C} = \sum_{i=1}^{n}\sum_{k=1}^{p} \mathcal{C}_{ik} \tag{3}$$

The criterium $\mathcal{C}$ is a concave function because it is the sum of positively weighted concave terms. Now, we can formulate the relaxation labeling in terms of a constrained concave nonlinear programming problem. Relaxation labeling procedure can be stated as finding a global maximum of the function $\mathcal{C}$, subject to the constraint (1):

$$\begin{array}{rl} \max & \sum_{i=1}^{n}\sum_{k=1}^{p} \mathcal{C}_{ik} \\ \text{suject to} & \sum_{k=1}^{p} p(i,k) = 1 \quad \forall\, i \end{array} \tag{4}$$

Provided that all functions are concave, a global optimum is guaranteed, irrespective of initial certainties values $p(.,.)$.

6 Experimental results

The algorithm is been used to identify irregular pieces of meat in an intermediate stage of cooking ham process [1]. In this case, the active contour can evolve on the whole surface of the image. The border of the image has been considered as the external border of the permitted area, and the center point C of the image, where the radial search converges, has been considered the internal border. The relaxation process guarantees in real-time a smooth final contour that maximizes the intesity gradient along it.

This deformable method is particularly well suited to solve the segmentation problem of these noisy images with missing contours such as those between fat surfaces and the white table. Furthermore, the inherent local processing of the image near the snake elements makes the algorithm specially suited for real-time applications.

7 Conclusions

There may be a number of problems associated with the classical theory of snakes such as initialization and multiple minima. The boundary detection algorithm we present does not need an initial estimation of the boundary but only an internal point and an area where the snake can evolve. Moreover, the boundary detection problem has been posed as an optimization problem that seeks the contour that maximizes a global functional using a modified relaxation labeling. This process, stated in terms of an optimization problem, has been built with a concave criterion that always guarantees the global optimum.

References

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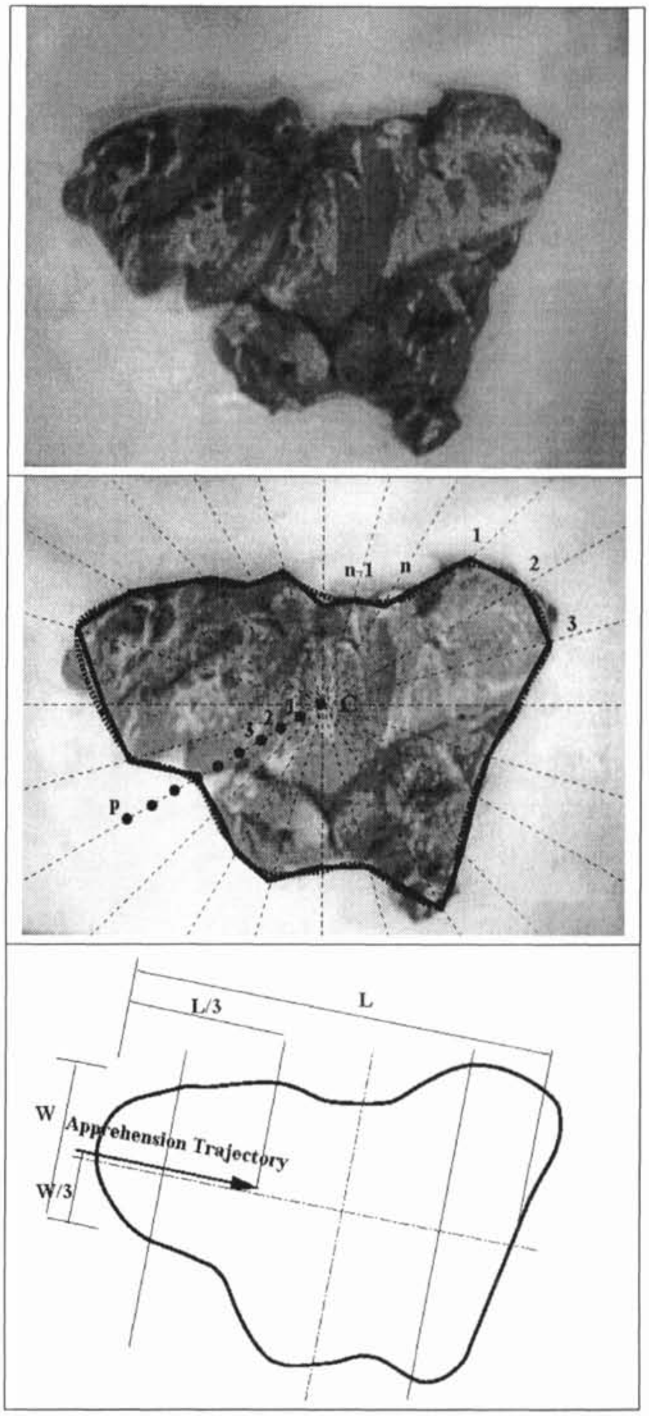

Figure 2: The active contour model applied to the identification of irregular pieces of meat. a)Original image. Classical techniques fail in the edge detection task due to the low contrast between the white table and the fat surfaces. b)Structure of the active contour model. The border of the image has been considered as the external border of the permitted area, and the center point C of the image, where the radial search converges, has been considered the internal border.c)The measurement of some contour parameters makes it possible to identify the piece in order to grasp it [1]