A Hybrid Snake for Selective Contour Detection

JUAN ZAPATA and RAMÓN RUIZ
Universidad Politécnica de Cartagena
Department of Electrónica,
Tecnología de Computadoras y Proyectos
Campus Muralla del Mar
Spain

Abstract: A hybrid snake algorithm is presented in this paper. The procedure is based on combining a dynamic balloon force, a GVF force and a traditional gradient force. The balloon force is modified in order to increase the capture range and convergence speed of active contour in a dynamic way. Our interest is to give the balloon force a bigger preponderance at the early of procedure and a smaller weight at the later stage. The superposition of effects get through the GVF force and the gradient force is ruled by a user parameter. Our GVF force is computed for a decreased number of iterations during the calculation process and so the diffusion field is located near edges only. In this manner, we can use this snake for segmentation of objects with strong edges inside or outside. The synthetic experiments and real-time face tracking application presented in this paper prove the feasibility of this hybrid snake.

Key–Words: Segmentation, object tracking, deformable models, active contours

1 Introduction

Active contours were first introduced by Kass et al. in 1988, with a model called snake [1], and since then many researchers have proposed various modifications of it, in order to apply it to edge detection, shape modelling and object tracking problems, under different constraints. The main problem with the original snake was its low capture range. This initialisation problem was solved by Cohen [2] by means of a balloon snake model. However, this model proposed a solution highly dependent on initial contour due to many local minimum. This local minimum can trap the evolution of snake toward the object boundary. A second problem was the difficulty of the snake in the fine adjust to the real boundary. Xu and Prince [3, 4] have proposed an gradient vector flow snake. They computed a diffusion of the vectors of gradient of an edge map of image instead of directly using image gradients. This GVF snake is able to track at concavity boundary. However it implies to have to compute the gradient vector field which can suppose an high computational load.

In this work we focus on the above mentioned problems. Using the snake, which is a linear and thus computationally inexpensive model, and first order statistics, we proposed an hybrid snake, which is an adaptive combination of the balloon model snake, GVF model snake and traditional snake. This hybrid model snake has a reduced diffusion vectorial field and so, a low computational load. So, gradient vector field is not extended over whole image although is extended over the feature of interest of image where it will be preponderant to the balloon model. The basic idea is to use a dynamic balloon model for a speed-up evolution and coarse adjust and the GVF model for a stop evolution and fine adjust. Other interest in our work is that our snake cannot be trapped in minima local. For it, our snake is able to pass through boundaries inside of objects and then stop on the target boundary. The superposition of effects from balloon model, GVF model and traditional snake is ruled by a user parameter which controls the trade-off between them. Special attention has been given to the accuracy of the proposed approach, resulting in efficient solutions to a variety of applications: synthetic images, cases involving different classes of objects and object movements in natural sequences, where the amount of noise is not known, backgrounds that are highly textured, and moving objects that get successively occluded.

This paper is organised as follows. First the mathematical foundation of active contour models is presented in the next section. In section 3 the different aspects of our hybrid snake are detailed. We present in section 4 some preliminary results of synthetic images and real images (face tracking). Finally, in the last section we propose several ways of research for future work.

2 Active Contour Models

Geometrically, a snake is a spline with a parametric representation $\mathbf{v}(s) = (x(s), y(s))$ embedded in the image plane $(x, y \in R)$, where x e y are the coordinate function and $s \in [0, 1]$ is the parametric domain.

Energetically, the active contour is subordinated to two energy functions that dictate the behaviour of the deformable model: an internal and an external energy. The technique refines an estimated initial contour by an energy minimisation procedure. The equation (1) can be viewed as a representation of the energy of the contour and the final shape corresponds to the minimum of this energy.

$$E^*_{snake} = \int_0^1 \left(E_{int}(\mathbf{v}(s)) + E_{ext}(\mathbf{v}(s))\right) ds \qquad (1)$$

The first term of the functional is the internal deformation energy. This internal energy (2) consists of the first and second derivatives of $\mathbf{v}(s)$ in relation to s and characterises the deformation of a stretchy, flexible contour. Two parametric functions, $\omega_1(s)$ and $\omega_2(s)$, dictate the simulated physical characteristics of tension and rigidity of the contour, respectively.

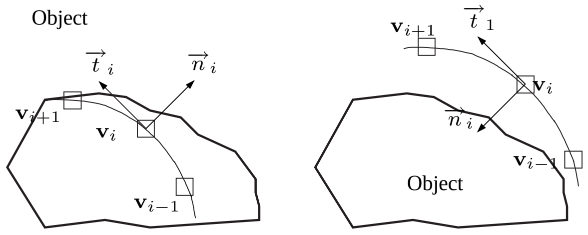
$$\begin{aligned} &\int_0^1 E_{int}(\mathbf{v}(s))\, ds = \\ &= \int_0^1 \omega_1(s) \left|\frac{\partial \mathbf{v}(s)}{\partial s}\right| + \omega_2(s) \left|\frac{\partial^2 \mathbf{v}(s)}{\partial s}\right|^2 ds \end{aligned} \qquad (2)$$

The second term, the external energy also termed the image energy, couples the snake to the image. Traditionally,

$$\int_0^1 E_{ext}(\mathbf{v}(s))\, ds = \int_0^1 P(\mathbf{v}(s)) + E_{con}(\mathbf{v}(s))\, ds \qquad (3)$$

where $P(\mathbf{v}(s))$ denotes a scalar potential function defined on the image plane. This scalar function can be designed so that local minima coincide with intensity extrema, edges or other image feature of interest. The second term of the equation (3), $E_{con}(\mathbf{v}(s))$, is the energy consequence of external constraints. These asserted constraints can benefit certain zones or local characteristics of the image. Therefore, during minimisation procedure the contour can be favoured to reach these zones. There are two key difficulties with the original technique. First, the procedure requires the initial contour to lie near the feature of interest and relies on an inherent force to move the contour towards the feature. Several methods have been proposed to address this problem [5] [6]. Cohen [2] proposed an inflating contour based on a balloon force. With this force, the initial contour do not need to be near the final contour towards where it should to converge. The basic idea is to increase the capture range of the external force fields and to guide the contour toward the desired boundary. The second problem is that active contours have difficulties in the fine adjust to the real boundaries. There is not a successfully solution for this problem, although pressure forces [2], control points [7], adaptive-domain [8] and the utilisation of solenoids fields [9] have been proposed by several researchers. This is due because a lot of this proposed methods solve the problem but they yield new difficulties. For example, pressure forces must be initialised to push out or push in, a condition that mandates careful initialisation. Xu and Prince [3, 10] proposed an gradient vector flow force computed as a diffusion of the gradient vectors of a gray-level or binary edge map derived from the image. This GVF force is able to move snakes into boundary concavities. However, this technique have a high computational cost, due to its iterative nature, which can turn it into a unacceptable solution for many applications.

In this work we propose a hybrid force term, which is an adaptive combination of forces, pressure force, GVF force and gradient force, that confronts both problems: initialisation and high computational load. A GVF force is used in order to reduce the sensitivity to initialisation, the new hybrid contour has no preference to expand or contract, other than to acquire its natural shape. The pressure force can be high because the contour will be not driven over the feature of interest due to gradient force is preponderant in that zone, and the snake is not trapped in the minima local yet. On the other hand, the active contour will be driven over local minima where the GVF force is not preponderant. To reduce the computational load, we suggest to compute the GVF field with a low number of iterations. So, GVF field is not extended over whole image although is extended over the feature of interest of image where is preponderant to the pressure force. The basic idea is to use the pressure force for a fast and coarse adjust and the GVF force and gradient force for a fine adjust. The superposition of effects is ruled by a user parameter which controls the trade-off between different forces. Now, we will introduce the mathematical foundation of snakes and develop the hybrid snake showing how it overcomes the main problems. Finally we apply the technique to synthetic image data and show its results for tracking of contours of head images.



(a) Inflation of *snake* (b) Contraction of *snake*

Figure 1: (a) Inflation (b) and contraction of the active contour is dependent of the direction of $\vec{n}_i$.

3 Hybrid Active Contour

In this section we detail the different aspects of our improved hybrid snake using a balloon snake, GVF snake and traditional snake.

3.1 Balloon Energy

Cohen [2] formulates the balloon model in the next form:

$$F = k_1 \vec{n}(s) - k \frac{\nabla P}{||\nabla P||} \tag{4}$$

where $\vec{n}(s)$, is a normal unitary vector to the curve at point $\mathbf{v}(s)$, k_1 is the force amplitude and k a scale factor, and P, is the image potential. The change of sign of k_1 or the orientation of the curve have an effect of deflation instead of inflation in the curve. In this way, $\vec{n_i}$ is a normal unitary vector to the tangent vector to the curve $\vec{t_i}$, and which direction is dependent of behaviour we are expecting in the active contour. If the vector $\vec{n_i}$ is pointing into the active contour, then the snake will be contracted. If it is pointing towards the exterior then the active contour will be inflated. This effect is illustrated in Fig. 1.

A desirable characteristic of this force is the adaptability, so the force is not acting when other external forces will be going to appear. This work proposes an adaptive balloon force which varies inversely proportional to evolution time of the snake. The adaptive balloon force is strong in the early stage of evolution and weak near the end of the evolution when GVF force and gradient force will be going to appear.

3.2 Gradient Vector Flow Energy

GVF force is a static external force and, in consequence, it does not change with time or depends on position of the snake itself. The main mathematical premise for this force comes from the Helmotz theorem, which states that the most general static vector field can be decomposed into two components: an irrotational component and a solenoidal component [10]. Then an external potential force generated from the variational formulation of a traditional snake must enter the force balance equation as a static irrotational field, since it is the gradient of a potential function. Therefore, a more general static field can be obtained by allowing the possibility that it comprises both irrotational component and solenoidal component. Prince and Xu [9] studied about this idea and designed a force obtained from sum of an independent solenoidal field and a traditional irrotational field.

To design a GVF snake the potential force is substituted for a new static external force field $F_{ext}^{(g)} = \mathbf{v}(x,y) = (u(x,y), v(x,y))$, named GVF, Gradient Vector Flow. Active contour based on GVF fields can be solved numerically by discretisation and iteration, in identical fashion to the traditional snake. Using the calculus of variations, it can be shown that the GVF field can be found by solving the following Euler equations:

$$\mu \nabla^2 u - (u - f_x)(f_x^2 + f_y^2) = 0 \tag{5}$$

$$\mu \nabla^2 v - (v - f_x)(f_y^2 + f_y^2) = 0 \tag{6}$$

where ∇^2 is the Laplacian operator. The authors pointed that any digital image gradient can be used to calculate f_x y f_y. It can be shown that a iterative solution is obtained to GVF:

$$\begin{aligned} u_{i,j}^{n+1} &= (1 - bi,j\Delta t)u_{i,j}^n + r(u_{i+1,j}^n + \\ &\quad + u_{i,j+1}^n + u_{i-1,j}^n + u_{i,j-1}^n - 4u_{i,j}^n) + c_{i,j}^1 \Delta t \\ v_{i,j}^{n+1} &= (1 - bi,j\Delta t)v_{i,j}^n + r(v_{i+1,j}^n + \\ &\quad + v_{i,j+1}^n + v_{i-1,j}^n + v_{i,j-1}^n - 4v_{i,j}^n) + c_{i,j}^2 \Delta t \end{aligned} \tag{7}$$

where:

$$r = \frac{\mu \Delta t}{\Delta x \Delta y} \tag{8}$$

The μ coefficient can be substituted for a variable weight function on the space, obtaining as result the following equation:

$$\mathbf{v}_t = \mu \nabla^2 \mathbf{v} - (\mathbf{v} - \nabla f)|\nabla f|^2 \tag{9}$$

In the last formulation, μ y $|\nabla f|^2$ can be substituted for a more general weighted function. Xu and Prince [9] proposed the following weighted functions:

$$\begin{aligned} g(|\nabla f|) &= e^{-(\frac{|\nabla f|}{K})^2} \\ h(|\nabla f|) &= 1 - g(|\nabla f|) \end{aligned} \tag{10}$$

The GVF field calculated by using in (10) is related to edge gradient. The K coefficient determines a commitment between the smoothness and consistence of the gradient.

3.3 Hybrid Energy

Although GVF force is a very interesting approach, it cannot solve the main problem in real time applications, the necessity of high speed calculus. So, we decided to decrease the iteration number in order to obtain a GVF field of reduced diffusion. This solution implies that capture range is reduced because it is not diffused in whole image. Therefore, we need of a pressure force in order to palliate the lack of GVF field and capture range.

We propose a hybrid energy term, which is an adaptive combination of both terms, balloon energy, GVF energy and traditional energy term. This balloon force is applied in an adaptive way. Our interest is to give the balloon force a bigger weight at the early of procedure than GVF and traditional force and a smaller weight at the later stage. The user parameter i, $i = c^n$, allows this behaviour if c has a range of values between 0 and 1 and n is the iteration number, so i is an exponentially decreasing function. In this way, the speed of convergence is increased and, at the early stage, the active contour can be strongly pushed toward the edges even if it starts far away with less chance of being over-pushed at the later stage. The GVF force and traditional force are combined as follows. The goal is to allow to snake pass through of minima local at the early stages of approach and stop it at the latter stages (on the target boundary); this means that at the early stages the gradient (traditional) force must be preponderant because the balloon force is strong in this stage and the snake is not trapped in weak gradients. At the latter stage, the gradient is step by step substituted for the GVF force (with a bigger weight than the gradient force due to the diffusion). Now, the balloon force is weak and is difficult for it to pass through of the edges. Anyway, if it happens, the gradient diffusion attract to the snake towards the real border in next iterations. The user parameter j, in similar manner to the user parameter j ($j = c^n$), allows tuning this behaviour. So, our hybrid energy is computed as follows:

$$E_{hyb} = jE_{grad} + (1 - j)E_{gvf} + iE_{ball} \qquad (11)$$

Normalised balloon, GVF and gradient forces are necessary in order to apply this hybrid term. In this way, all forces can be matched and compared in a quantitative level.

4 Results and Discussions

An experiment was designed in order to investigate the performance of our segmentation method and

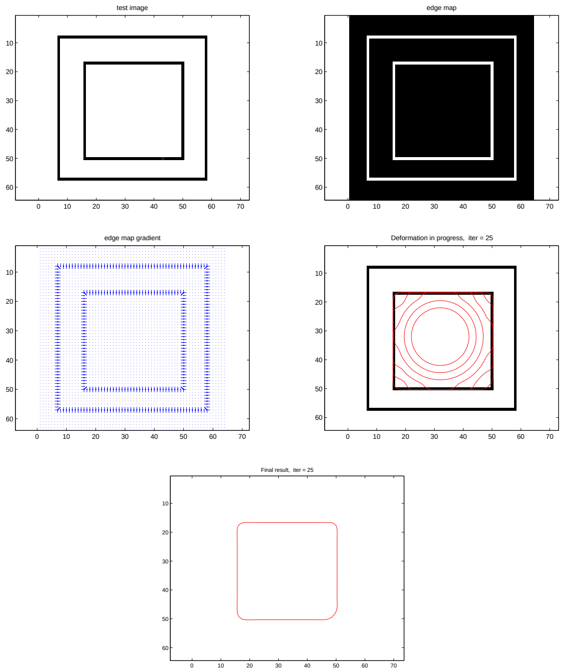


Figure 2: Traditional snake: From left to right and from above to down, original synthetic image, edge map, edge map gradient, snake in progress and final snake

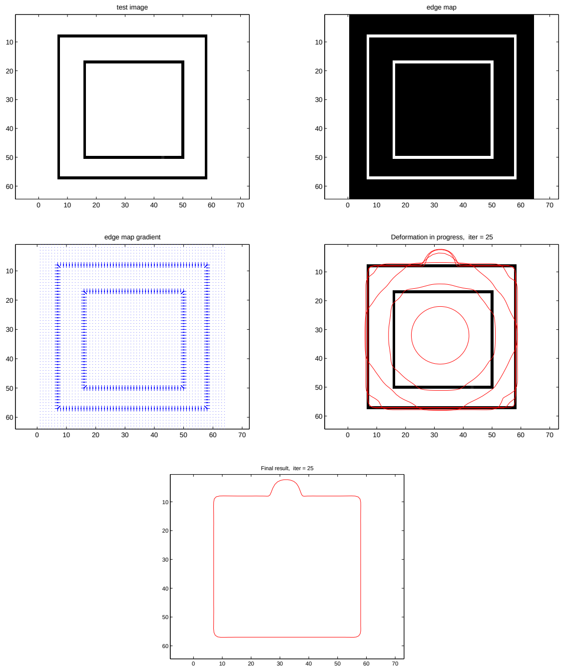


Figure 3: Adaptive Balloon snake: from left to right and from above to down, original synthetic image, edge map, edge map gradient, snake in progress, final snake

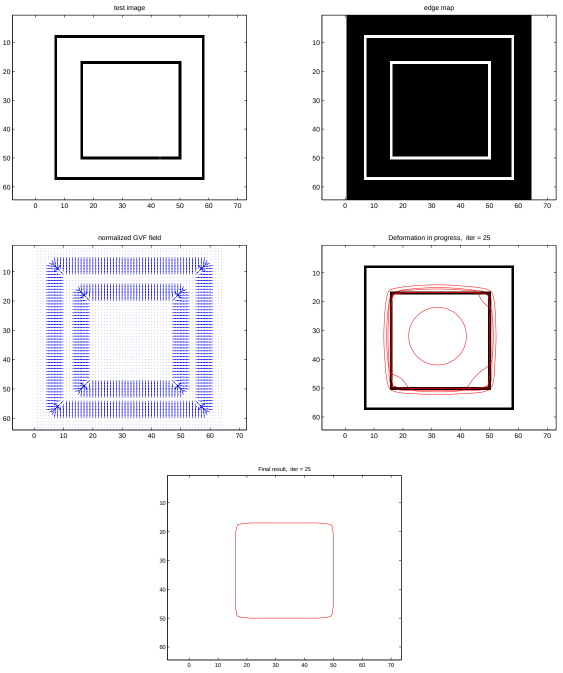


Figure 4: GVF snake: From left to right and from above to down, original synthetic image, edge map, reduced diffusion GVF (5 iterations), snake in progress and final snake

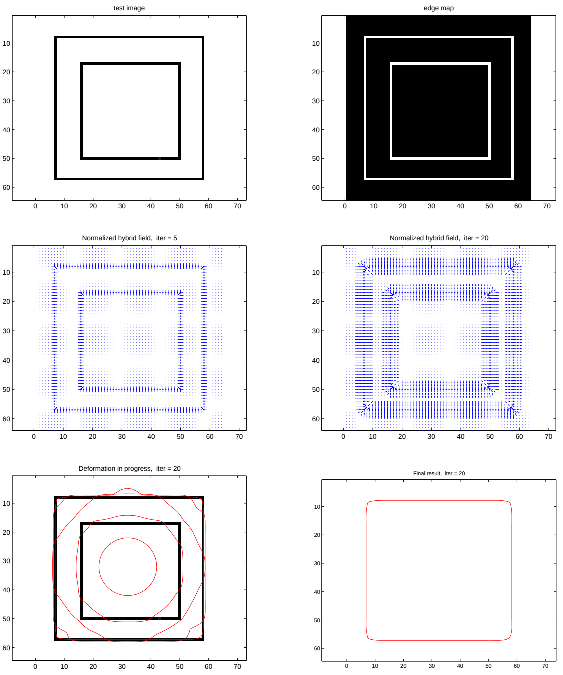


Figure 5: Hybrid snake: From left to right and from above to down, original synthetic image, edge map, hybrid force field (5 iterations), hybrid force field (20 iterations) snake in progress and final snake

compare it with original balloon, GVF and traditional snake. During the experiment the snake modified the implicated forces but the value of physical parameters and the initial position was unaltered. Fig. 2 to 5 shows this experiment. Fig. 2 shows a traditional snake and its behaviour. This snake is not able to pass through the first local minima. Fig. 3 shows a adaptive balloon snake (combining adaptive balloon force and gradient force), the snake is able to pass through the first minima local but it is not able to fit the second minima local although the balloon force is very weak in this end stage. Fig. 4 shows a GVF force with an adaptive balloon force, in this case although the GVF is a reduced diffusion field (only 5 iterations) the snake is not able to pass through the first local minima. At last, Fig. 5 shows our hybrid snake, at the early stage the hybrid force field is composed by the gradient field and adaptive balloon force thus it is able to pass through the first edge but at latter stage the balloon force and gradient fields is very reduced and the GVF field is preponderant and the snake is trapped by the external GVF field. For all examples, the snake's initialisation is not centered simetrically inside the synthetic image, in the same way the different edges are not symmetric. In all cases, $\alpha = 0.05$, where alpha is the elasticity parameter, $\beta = 0.3$, where beta is the rigidity parameter and $\gamma = 1$, where gamma is the viscosity parameter. Based on the figures and above parameter values, two main points can be drawn as to the performance comparison. One point is that in terms of subjective criteria the traditional and GVF snake's capture range is far from enough to locate the target boundary (external edge). The second point is that, according to quantitative analysis, our approach resulted more preferable results than the original GVF snake in any case due to its low computational load.

At last, in validating the performance of the proposed method, we used our algorithm for tracking a head in movement. In Fig. 6 we show the tracking of a head in movement with occlusions of short duration. Our snake is able to pass through a first wall of edges due to a strong adaptive balloon force and a weak traditional gradient but at latter stage is trapped for a hard GVF.

5 Conclusions

In this paper we have presented a modified snake model assisted by a hybrid force. The internal energy of the proposed snake model is given in terms of two well known geometric characteristics, i.e the first derivative (tension) and the second derivative (rigidity) functions, whereas the proposed external energy is given in terms of a hybrid energy which combine

Figure 6: Sample images of database (occlusion)

image gradient vector field force with an adaptive balloon force and GVF force. The last object's position provides the snake initialisation for the next iteration. In this way, we constrain the final contour problem in a small frame region, and we follow a force-based approach to approximate the snake's energy minimisation procedure. The indicative experimental results we present illustrate the proposed method's success (see Fig. 6). The core component of the system is based on a modified snake algorithm that involves low computational cost. Experimental results demonstrated the robust of the system.

There are still rooms to improve the proposed approach. In particular, our future research will be focused on addressing the following issues. Firstly, we are currently investigating the relation between weights and parameters, in order to establish a reliable relation between them. Also, the implementation of an ”intelligent” adaptive balloon force, i.e. a balloon force which is able to know if it must use an inflation o deflection force. The balloon force is designed like an adaptive force, it acquires a proportional value depending of the stage into the procedure. A bigger importance is given at the early stage and this importance decreases at the latter stage. This process is ruled by user parameters i and j. The GVF is not developed fully because it does not add utile information to segment or to track an object. For example, in a sequence (see Fig. 6), the time lapsed between frames is very short for a head in movement, and the target will be located in a very close position. So, the active contour can be extracted of a frame and this is used like seed contour for the next frame. This seed frame is always located in a narrow zone with reduced diffusion gradient vector field.

References:

[1] M. Kass, A. Witkin, and D. Terzopoulos, “Snakes: Active Contour Models,” *International Journal of Computer Vision*, vol. 1, no. 4, pp. 321–331, Jan. 1988.

[2] L. Cohen, “On Active Contour Models and Balloons,” *Computer Vision, Graphics and Image Proccessing*, vol. 53, no. 2, pp. 211–218, Mar. 1991.

[3] C. Xu and J. Prince, “Gradient Vector Flow: A New External Force for Snakes,” in *IEEE Proc. Conf. on Comp. Vis. Patt. Recog. (CVPR)*, 1997, pp. 66–71.

[4] ——, “A Generalized Gradient Vector Flow for Active Contour Models,” in *1997 Conf. Info. Sci. Syst., Johns Hopkins University*, Mar. 1997, pp. 885–890.

[5] B. Leroy, I. Herlin, and L. D. Cohen, “Multi-resolution Algortihms for Active Contour Model,” in *12th International Conference on Analysis and Optimization of System*, 1996, pp. 58–65.

[6] L. Cohen and I. Cohen, “Finite-Element Methods for Active Contour Models and Balloons for 2-D and 3-D Images,” *IEEE Trans. Pattern Analysis and Machine Intelligence*, vol. 15, no. 11, pp. 1131–1147, Nov. 1993.

[7] C. Davatzikos and J. L. Prince, “An Active Contour Model for Mapping the Cortex,” *IEEE Trans. on Medical Imaging*, vol. 14, no. 1, pp. 65–80, Mar. 1995.

[8] ——, “Convexity Analysis of Active Contour Models,” in *Proc. Conf. on Info. Sci. and Sys.*, 1994, pp. 581–587.

[9] J. Prince and C. Xu, “A New External Force Model for Snakes,” in *1996 Image and Multidimensional Signal Processing Workshop*, 1996, pp. 30–31.

[10] C. Xu and J. Prince, “Snakes, Shapes, and Gradient Vector Flow,” *IEEE Transactions on Image Processing*, pp. 359–369, 1998, mar.