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A new fast Level Set method

Ali Ganoun[1,2] *and* *Raphael Canals* [1]

[1]University of ORLEANS
Polytech Orleans
Laboratory of Electronics, Signals and Images (LESI)
12, rue de Blois, BP6744, 45067 Orléans
FRANCE

[2] University of GARYOUNIS
Faculty of Engineering
Electrical & Electronic Engineering Department
P O Box: 1308, Benghazi
LIBYA

E-mail: { Ali.Ganoun ; Raphael.Canals } @univ-orleans.fr

ABSTRACT

Level set methods have seen extremely expanded applications to track moving interfaces in a wide variety of problems over the past few years. Their central idea is to follow the evolution of a function whose zero level set always corresponds to the position of the propagating interface. The problem with the standard algorithm is that it is too slow for real time application: as a result, many fast methods have been proposed.

In this paper we introduce a new fast method to decrease the computational time of the standard algorithm. This new method is based on two principles. The first one uses at every iteration toward the final zero level set, uses the sign of the speed function that moves the propagating interface instead of using its value. The second one is to use a specific band near the zero level set instead of using all the level sets.

We demonstrate the new fast method by computing the solution of the level set in the image tracking problem.

1. INTRODUCTION

The standard level set method has been introduced by Osher and Sethian [1]. This method is based on the initial value partial differential level set equation which represents the evaluation of the implicit time-dependent function $\Phi(\gamma,t)$ for the closed surface γ [1]:

$$\Phi_t + F\ |\nabla\Phi| = 0 \tag{1}$$

where F is the speed function in the normal direction to the propagating interface. In the last equation, the closed surface γ – the propagating interface – is represented implicitly by the zero level set of the function $\Phi(\gamma,t)$, as opposed to the explicit methods where we track the propagating interface elements by discretization - Lagrangian formulation - since there are generally an infinite number of points on the propagating interfaces. The proposed equation solves the instability problems associated with the explicit methods. The level set equation also handles topological merging and splitting naturally, and works in any number of space dimensions without great modifications.

Since its introduction, the level set method has been used in a wide collection of problems involving moving interfaces, such as image enhancement and noise removal, shape detection and recognition. All these applications and others are results of the flexibility of the level set methods, and of the development of techniques used in the last few years with these methods. We refer the reader to [2], for some applications of the level set methods; we also refer the reader to [3], for a review of algorithm development techniques of the level set methods.

To track the evaluation of the propagating interface in the standard algorithm of the level set methods, we have to update and compute the evolution of all the level sets, not just the zero level set, which results in a computationally expensive technique. In order to use the level set approaches efficiently, many fast methods appear to decrease the computation cost of the standard algorithm. In this paper, we propose a new fast method called “Signed Function“. Very promising experiment results are provided by using this method with the image tracking problem.

The outline of this paper is as follows. Section 2 contains a review of the fast level set methods. In section 3, our proposed method is presented. In section 4, we give the detailed description of the experimental results. The conclusions are given in section 5.

2. FAST LEVEL SET METHODS

As a result of the computation cost of the standard level set method for propagating interfaces, other efficient methods have been proposed, such as the fast marching approach [2], and the narrow-band approach [2], [4]. The fast marching method assumes that the front is propagating normal to itself with speed that depends only on position and is always either positive or negative, which limits the applications of this approach. The second approach, the narrow-band one Fig.1, computes the evolution of the level sets only in a narrow band around the interface of interest; the quality of this approach depends on the width of the narrow band chosen. The problem of this approach is how to find the optimum band that balances between the time of updating the points in the narrow band and the time spent to update the position of the narrow band as the propagating interface moves

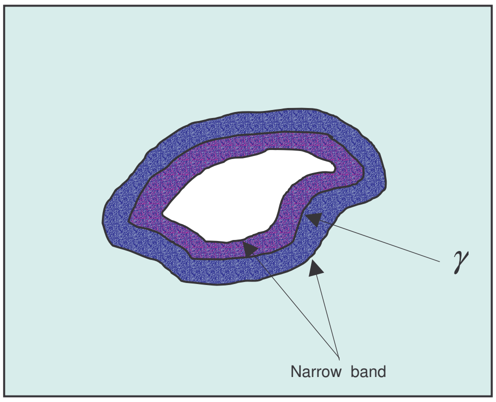

Fig.1. The narrow-band approach

and arrives to the edge of the narrow band. In general the narrow-band method is still too slow to be used in real time applications.

Extensions to the narrow-band approach for fast computation of level set equations have been proposed in [5], which uses a pyramidal/narrow-banding schemes. An other approach can be found in [6], where the authors have described a fast algorithm for level set-like tracking of moving interfaces. The algorithm relies on a heap sorted queue to schedule propagation events and a curvature measure that can be updated very efficiently.

In this paper we present another approach which relies on using the sign of the speed function as an alternative of computing its value.

3. SIGNED FUNCTION METHOD

The signed function method is based on two key ideas. The first one is that we use, at any point and at each iteration toward the final zero level set, the sign of the speed function that moves the propagating interface to get the new value. The second one is to compute the evolution of the level sets only in a specific band near the zero level.

3.1 Sign of the Speed Function

In the standard algorithm, one approach to get the new zero level set is to use the iteration technique given as [2]:

$$\Phi^{n+1} = \Phi^n + \Delta t\,[\,F\ |\nabla\Phi|\,] \qquad (2)$$

where Δt is the temporal discretization step, and n the iteration number. The iteration phase starts after the initialization phase of the algorithm which consists in finding the initial zero level set Φ^0, and calculating the speed function that moves the interface to the new position.

In the initialization phase, we set the value of Φ^0 to +1 for the points corresponding to the interior of the closed interface γ, and set Φ^0 to -1 for the points corresponding to the exterior of the interface.

At the end of the iteration phase, when $t \to \infty$, the zero level set of the time-dependent function Φ – and therefore the new propagating interface γ – is given by the points where the value of $\Phi \geq 0$, which correspond to the new stable position of the propagating interface γ.

As the calculation cost of the algorithm depends largely on the time needed in the iteration phase, the proposed method tries to decrease the time of this phase. In the normal algorithm described above, the value of the speed function drives Φ^{n-1} toward the new value Φ^n, i.e. if the value of $\Phi^{n-1} \geq 0$ for a point at the exterior of the new interface, then at each iteration, the value of F decreases the value of Φ^{n-1} so that $\Phi^n \to -1$: in this case, the value of $F < 0$. In the other hand, if the value of $\Phi^{n-1} < 0$ for a point at the interior of the new interface, then at each iteration, the value of F increases the value of Φ^{n-1} so that $\Phi^n \to +1$, and in this case, $F \geq 0$.

The major idea of the proposed method is to use the sign of the speed function F, i.e. at each iteration and at any point, if the sign of F is positive, then instead of calculating the value of Φ^n that is moved toward +1, we simply change the value of Φ^n to +1, and if the sign of F is negative, instead of calculating Φ^n that moves toward -1, we change the value of Φ^n to -1.

3.1 Evolution in a Specific Band

The proposal in this approach is similar to the narrow-band method [2],[4], where we calculate the evolution of the level sets only in a specific range near the zero level set instead of computing the evolution of the level sets at all the level sets. In this section, we explain the difference with the narrow-band and the advantage of our approach.

The specific band approach is based on the assumption that we know the maximum range of motion from one frame to the next in the sequence. We use this practical assumption to reduce the computational cost. We calculate the maximum and the minimum points of the propagation interface in the horizontal and vertical directions. Then the specific band is simply calculated by adding / subtracting the rang δ from the minimum / maximum points, as shown in Fig.2, where δ is the maximum range of movement (known from the maximum range of motion). The choice of δ in this way is not the optimal one, as other more sophisticated techniques can be used, although of that, the advantage of this technique is the minimum cost of computation needed.

The evaluation of the level set is done only for the points inside the specific band which is usually very small compared to the overall space. We note that the main advantage of this approach is the minimum cost of computing the specific band compared to the cost of calculating the narrow-band.

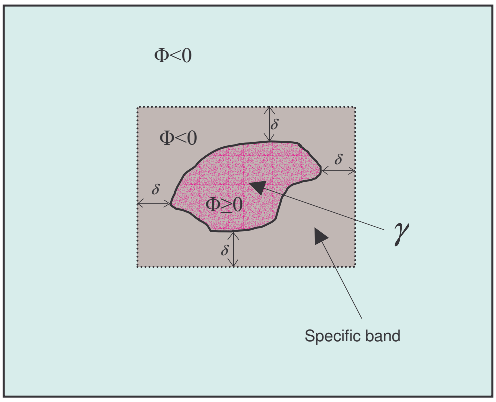

Fig.2. The specific band

4. EXPERIMENTAL RESULTS

To test the new fast method, we consider the case of using the level set method to the problem of object tracking as given in [7]. The problem of real time object tracking in an image sequence is the critical task in many image processing and computer vision applications such as object-based video database search, video surveillance, augmented reality, service robots, and many other applications. There are many different approaches developed to solve the problem of object tracking in successive images in the sequence, starting from the simple approaches of feature points which use the simple cross-correlation computations between successive images, and not ending with the approaches which are based on using both the boundary and the region of the object being tracked.

The problem of image tracking is formulated in [7], as a Bayesian estimation problem, with no motion model assumed nor any dense motion field computed. The solution of the Bayesian estimation problem is provided by a level set partial differential equation. We have implemented the algorithm given in [7], and tested the standard algorithm with and without the fast method and compared the results.

Fig.3 presents the first frame which is a 256x256 pixels gray-level image. There is one object in the image which is tracked. Fig.4 presents the next frame, in which the object has frame we found the same image after it's moved by 10 pixels in both x and y directions. We note also that there is a change in the form of the object from the first frame to the second.

We apply the tracking algorithm in order to track the object as it moves and changes its form. The result of tracking is shown in Fig.5 & Fig.6.

Fig.5 presents the iteration number and the propagating interface as it moves after each iteration by using the normal level set algorithm given in [7]. We note that the algorithm tracks the new form of the object, and for that it

Table 1. Number of Iterations and the time in seconds needed to track the object in Fig.3

	Standard Algorithm			
	Normal	**Specific band**	**Fast**	**Specific band + Fast**
N° of iteration	139	139	20	20
Time of iteration	413.3	22.4	13.8	0.86
Decrease in iteration	X	0 %	85.6%	**85.6%**
Decrease in iteration	X	94.5%	96.6%	**99.8%**

needs about 139 iterations and takes about 413 seconds on a 2GHz PC in Matlab, as shown in Table 1. If we use the band specific approach (δ = 12) with the standard algorithm, the algorithm needs also about 139, but it takes smaller time for that, about 22.4 seconds.

Fig.6 shows the tracking of the object by using our fast method implemented in the standard algorithm. As with the preceding cases, the algorithm track the objects as it moves and changes its form from the first frame to the second one. We can see the gain in the number of iterations and in the time needed to track the object. When we use the fast method with the standard algorithm, the algorithm needs 20 iterations, and makes the iterations in about 13.8 seconds. When we use both approaches - band specific and fast - with the standard algorithm, then it needs 20 iterations and 0.86 seconds, as shown in Table 1.

5. CONCLUSIONS

We have described in this paper a new fast method "Signed Function" for fast computation of the level set equation. The experiments indicate that this fast method produces a high percentage decrease (greater than 85%) in the number of iterations (and greater than 96% in the time) needed to compute the zero level set compared to the standard algorithm without any modifications. This result will be very helpful the real time applications which use the level set methods.

This technique can be improved by using the prediction technique to get the efficient specific band. Other improvement can also be with the efficient stopping criteria when the propagating curve arrives to the final position.

REFERENCES

[1] S. Osher, J. Sethian, "Fronts Propagating With Curvature Dependent Speed : Algorithms Based On Hamilton-Jacobi Formulations" *Jour. Computing Phys*. 79,12-49, 1988.
[2] J. Sethian, "Level Set Methods" Cambridge University Press, 1996.

[3] R. Fedkiw, G. Sapiro, C. Shu, "Shock Capturing, Level Sets, And Based Methods In Computer Vision And Image Processing: A Review Of Oher's Contributions" *Jour. Of Computational Physics* , 185 (2003) 309-341.
[4] D. Adalsteinsson, J. Sethian, "A Fast Level Set Method For Propagating Interfaces" *Jour. Computing Phys*., Vol. 118, pp. 269-277,1995.
[5] A. Mansouri, T. Chomaud, J. Konrad, "A Comparative Evaluation Of Algorithms For Fast Computation Of Level Set Pdes With Applications To Motion Segmentation" *In Proc. International Conf. On Image Processing*, ICIP-2001, Thessanloniki, Greece.
[6] B. Nilsson, A. Heyden, "A Fast Algorithm For Level Set-Like Active Contours" *Pattern Recognition Letters* 24 (2003) 1331-1337.
[7] A. Mansouri, "Region Tracking Via Level Set Pdes Without Motion Computation" *IEEE Trans. Pattern Analysis And Machine Intelligence* Vol. 24, No 7, July 2002.

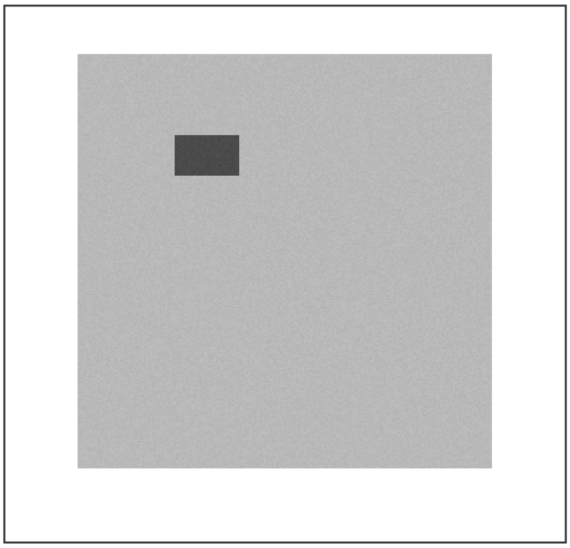

Fig.3 The first frame: there is one object in this frame to be tracked.

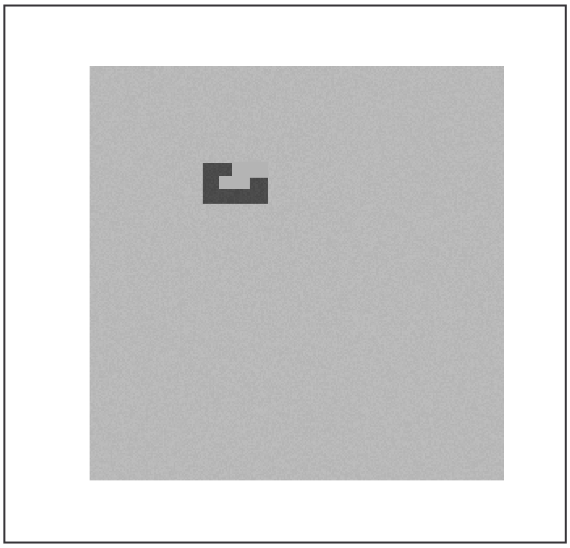

Fig.4 The second frame: the same object shown in the first frame with the changes in the position and in the form.

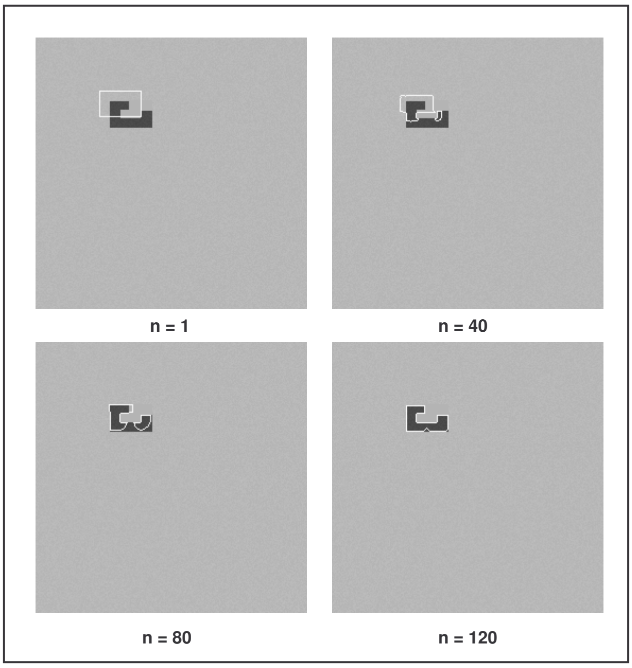

Fig.5 The zero level set of the object as it moves with the increase of the iteration number to track the new position and the change of the form of the object, by using the normal tracking algorithm.

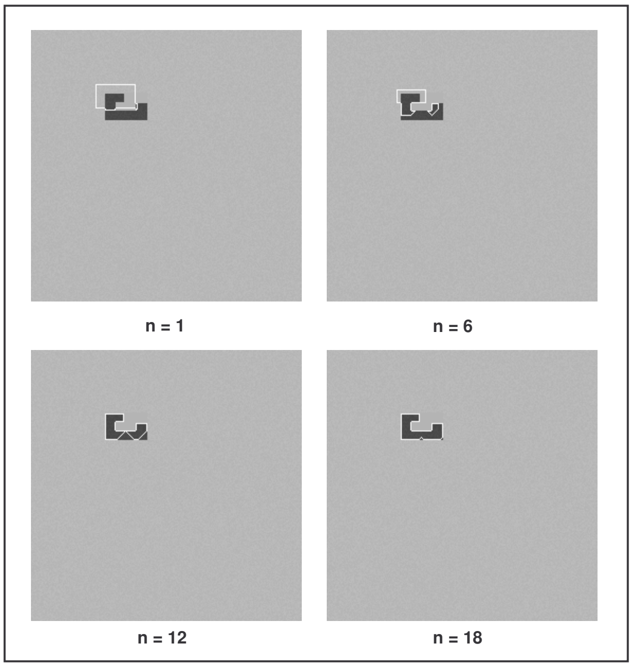

Fig.6 The zero level set of the object as it moves with the increase of the iteration number to track the new position and the change of the form of the object, by using our fast method with the standard algorithm.