An Improved C-V Level Set Image Segmentation Model Based on Rapid Narrow-Band Method

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Abstract
In this paper, according to the traditional C-V level set model image segmentation of slow speed, low efficiency of initialization and weak ability to capture edge, puts forward a kind of improved C-V level set image segmentation model added edge information of image in model; in the numerical experiment, using narrow band method improved, thereby reducing the amount of computation, improve the efficiency of image segmentation. Experiments show that this algorithm is better than the traditional C-V model compared with the segmentation speed, and the algorithm has low complexity and high accuracy.
Key words: IMAGE SEGMENTATION, C-V MODEL, NARROW BAND.

1. Introduction

In the research and application of digital image processing, image segmentation is a very important problem. Image segmentation is to use the relevant methods to distinguish the image of target and background, in order to further research and analysis, in order to further study and analysis. It is widely used in industrial and agricultural production automation, character recognition, medical and remote sensing image analysis, fault treatment, etc. So far, the image segmentation algorithm is proposed in a variety of literature is varied, and the segmentation method based on the energy functional is a popular method of current research, the basic idea of this method is to express the target edge with continuous curve, and define an energy functional that the independent variable including edge curve, so the segmentation process change the minimum value for the process of solving the energy functional, in general can be realized by solving the corresponding Euler equation function, energy to achieve the most hours of the curve position is the outline of the target location. The segmentation method in general through the level set algorithm to achieve, the level set algorithm is the core process of 2D curves embedded in the image space to 3D surface as the zero level set. When the surface evolution, embedded into the zero level set curve in 3D surface is also changed, as long as the zero level set can be determined ultimately determine the mobile surface evolution results. C-V model of [1] is proposed by Chan and Vese in 2001, a regional level set method, evolution of its use of internal and external gray mean curve to promote the zero level set. The model of image gray uniform is very effective, and the segmentation is not affected by noise from [2]. But the model at each iteration to test the level set function is a signed distance function, which has a lot of calculation [3]; secondly, the C-V model without considering the image edge information, thus edge control ability is weak, is not conducive to split some weak edges or edge blur image [4]. Then many authors proposed some improved C-V model [5]. Document in the C-V model with an internal energy term to constrain the level set function close to a signed distance function, thus avoiding the re initialization procedure of the level set function, literature [6][7][8] joined the image edge information in the C-V model, improved image edge capture ability[9], literature iterative experiments using narrow band method, improve the segmentation efficiency. Based on the C-V model, this paper put forward an improved level set model, and in the numerical experiment, proposed an improved narrowband method.

2. The improved C-V model

2.1. C-V model

The energy functional of the C-V model is shown as follows:

$$E(c_1,c_2,C)=\alpha\int_{inside(C)}\left|u_0(x,y)-c_1\right|^2dxdy+\beta\int_{outside(C)}\left|u_0(x,y)-c_2\right|^2dxdy+\mu\cdot Length(C) \quad (1)$$

Where C said smooth closed contour curve, u_0 said the source image, c_1 is internal image grayscale mean of the evolution curve C, and c_2 is external image grayscale mean of the evolution curve C, under normal circumstances, $\alpha=\beta=1$, μ is a positive constant. The introduction of the level set function $\phi(x,y)$ to replace the evolution curve C, and regulations when the point (x,y) in the interior of the C, $\phi(x,y)>0$; when the point (x,y) outside of C; $\phi(x,y)<0$; when when the point (x,y) on C, $\phi(x,y)=0$. Thus the energy functional can be written as follows:

$$E(c_1,c_2,C)=\mu\int_\Omega\delta_\varepsilon(\phi(x,y))\left|\nabla\phi(x,y)\right|dxdy+\int_\Omega\left|u_0(x,y)-c_1\right|^2H_\varepsilon(\phi(x,y))dxdy+\int_\Omega\left|u_0(x,y)-c_2\right|^2(1-H_\varepsilon(\phi(x,y)))dxdy \quad (2)$$

Where $H_\varepsilon(z)$ and $\delta_\varepsilon(z)$ are egularization forms of Heidegger's function and Dirac function,and $H(z)=\{\begin{matrix}1, z\geq 0\\ 0, z\leq 0\end{matrix}$, $\delta(z)=\frac{d}{dz}H(z)$, Ω represents the image domain. The energy function minimization problem can be achieved by solving the corresponding Euler equation of the energy functional, so as to get the following level set evolution equation:

$$\frac{\partial\phi}{\partial t}=\delta_\varepsilon(\phi)[\mu\cdot div(\frac{\nabla\phi}{|\nabla\phi|})-(u_0-c_1)^2+(u_0-c_2)^2] \quad (3)$$

Among them $\phi(0,x,y)=\phi_0(x,y) \quad in\,\Omega$.

Gray value in the formula and can be updated by the following ways in each iteration, respectively:

$$c_1(\phi)=\frac{\int_\Omega u_0(x,y)H_\varepsilon(\phi(x,y))dxdy}{\int_\Omega H_\varepsilon(\phi(x,y))dxdy} \quad (4)$$

$$c_2(\phi)=\frac{\int_\Omega u_0(x,y)(1-H_\varepsilon(\phi(x,y)))dxdy}{\int_\Omega (1-H_\varepsilon(\phi(x,y)))dxdy} \quad (5)$$

2.2. Improved C-V model

The C-V model is not sensitive to noise, and the model is very effective for the image of blur edge, and it also can process the image which contains inner contour. But the C-V model also has some shortcomings, first of all it need to use all of the information of the image in segmentation, so the complexity of the algorithm is high; secondly, C-V model has certain dependence on the setting of the initial contour, different initial contour often have different decomposition results; finally in the process of iteration it needs constantly to initialize level set function, then the amount of calculation is great. Based on this, this paper makes some improvements on the C-V model, adding the image edge information, and puts forward a fast algorithm based on template narrow band method. due to the traditional C - V model only considers the image area of the global information, without taking into account the edge of the image gradient information, thus the evolution of the level set speed and edge information detection will be affected, resulting in the evolution is often easily plunged into local minimum, so consider the introduction of edge detection function $g(|\nabla G_\sigma * u|)=\frac{a}{1+|\nabla G_\sigma * u|^2}$ to replace $\delta_\varepsilon(\phi)$, the parameter a is used to control the curve evolution speed, in the area of image grayscale change more gentle, a take larger value, so as to speed up the curve evolution; near the edge of the image, the image gray level change is bigger, the smaller a value accordingly, to guarantee the stability of the evolution of avoid falling into local minimum value. To get the improved C - V level set evolution equation as follows:

$$\frac{\partial\phi}{\partial t}=g(|\nabla G_\sigma * u|)[\mu\cdot div(\frac{\nabla\phi}{|\nabla\phi|})-\alpha(u_0-c_1)^2+\beta(u_0-c_2)^2] \quad (6)$$

3. Rapid narrow-band algorithm of level set model

3.1. Overview

In the use of level set models of image segmentation, we need to compute the distance of every moment all grid points within the scope of the whole image into the current contour curve, and then connect points which to the current contour curve distance is zero in turn to obtain a new evolution curve, so repeatedly until the end of segmentation. The calculation of the method is very large, and the complexity of the algorithm is high, when the number of discrete grid points of the image is N, the complexity of the algorithm is $O(N^3)$. In order to improve the segmentation speed and efficiency, literature[4] mention the narrow-band level set algorithm, in this method, distance calculation will be restricted to a narrow band which has the current evolution curve as the center, each time of the curve evolution ,only needs to calculate the distance the of points in the narrow band to the current evolution curve , when the curve evolution to the narrow boundary, and then with the current curve as the center to build new narrow-band, until the end of the segmentation, through the analysis and calculation , the complexity of the algorithm is only $O(KN_1{}^2)$(k is the narrow- band width , N_1 is grid points of image in the narrow-band).On the basis of this method, this paper puts forward a rapid level set narrow-band algorithm based on 3×3 template(Figure1), through the analysis and calculation, the complexity of the algorithm only is $O(KN_1)$,thus greatly improve the efficiency of segmentation.

3.2. Rapid narrow-band algorithm of level set model

Given initial contour, with points on the curve as the center of 3×3 template ,and other points in the template that corresponds to points of image are marked as narrow-band points, let the template to traverse the entire curve to form a narrow band .This template selection can fully reflect search direction of the level set, because any point which is not on the zero level set in the narrow band and the point on the zero level set is on the line direction, this line is the contour curve of the zero level set(Figure 2), and the direction can be determined with the zero level set node and the 8 node in 3×3 template, by determine the search direction of the first step, it can easily control the search direction of the next step of the zero level set with the 8 nodes rather than all nodes in the template (Figure 3), thus greatly improve the speed of the algorithm. In Figure 2, the point $Q(x,y)$ is the node point in the zero level set, point $P(x,y)$ in the level set $\varphi = c$ is the shortest distance to the point $Q(x,y)$,here point 0 is the center point of the 3×3 template , adjacent to its eight node($V_1 - V_8$). In Figure 3 , V_1 and V_2 is the node in the template, point 0 is the node in the zero level set , Assumptions the level set function of V_1 and V_2 value ϕ_1 and ϕ_2 respectively, α_1 and α_2 is the parameter, and $\alpha_1 = \frac{\phi_2}{\phi_2 - \phi_1}$, $\alpha_2 = 1 - \alpha_1$, so $\alpha_1\phi_1 + \alpha_2\phi_2 = 0$ .Another advantage of this algorithm is no need to set the number of narrow-band reset, because every time the approximate solution process of neighborhood node contains the process of resetting the zero level set .

1.414	1	1.414
1	0	1
1.414	1	1.414

Figure 1. 3×3 Distance template

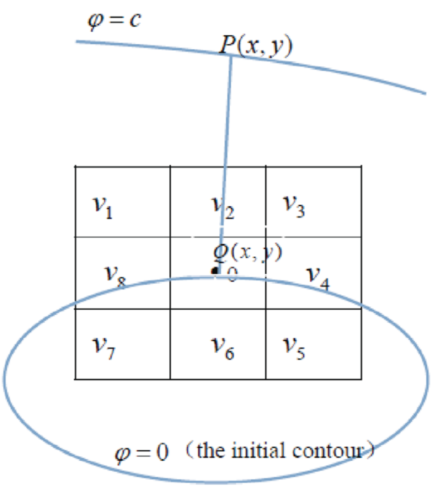

Figure 2. Diagram of narrow-band in the level set

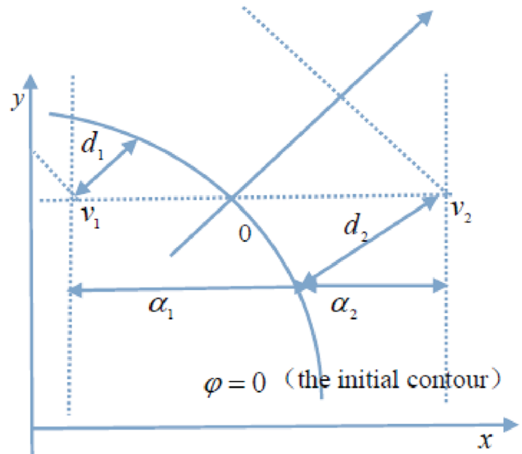

Figure 3. To determine the nodes of the zero level set

4. The numerical implementation of the model

The level set evolution equation can be using the finite difference method for numerical solution [7] ,the partial derivative in the all space domain can be solved with central difference, and the partial derivative all in all time can be solved with forward difference, specific said is as follows:

$\frac{\partial\phi}{\partial t} = \frac{\phi_{i,j}^{n+1} - \phi_{i,j}^{n}}{\Delta t}$, which Δt is the time step.

The curvature $div(\frac{\nabla\phi}{|\nabla\phi|})$ in the evolution equations can use second-order central difference to solve:

$$div(\frac{\nabla\phi}{|\nabla\phi|}) = \frac{\phi_{xx}\phi_y^2 - 2\phi_{xy}\phi_x\phi_y + \phi_{yy}\phi_x^2}{(\phi_x^2 + \phi_y^2)^{\frac{3}{2}}} \quad (7)$$

which $\phi_x, \phi_y, \phi_{xx}, \phi_{xy}, \phi_{yy}$ can be used as to the formula to calculate:

$$\phi_x = \frac{1}{2h}(\phi_{i+1,j} - \phi_{i-1,j}), \quad \phi_y = \frac{1}{2h}(\phi_{i,j+1} - \phi_{i,j-1}), \quad (8)$$

$$\phi_{xx} = \frac{1}{h^2}(\phi_{i+1,j} + \phi_{i-1,j} - 2\phi_{i,j}) \quad ,$$

$$\phi_{yy} = \frac{1}{h^2}(\phi_{i,j+1} + \phi_{i,j-1} - 2\phi_{i,j}) \quad , \quad (9)$$

$$\phi_{xy} = \frac{1}{h^2}(\phi_{i+1,j+1} - \phi_{i-1,j+1} - \phi_{i+1,j-1} + \phi_{i-1,j-1} \quad , \quad (10)$$

Which h is a discrete grid interval, c_1 and c_2 in the evolution equation can be solved according to the formula (2).The level set evolution termination criteria: when the absolute value of curve length change in a given number(n) of iterations has been less than a given threshold η , the level set evolution is terminated, in this experiment, fixed n= 8, η = 4.

The algorithm process is as follows:

input the original image u_0 .

(2) set the initial curve C in u_0 , and set the corresponding parameter values : the time step Δt , the grid interval h , and α, β, μ, a .

(3) use 3×3 template to set narrow-band and evolution of the level set function ϕ .

(4) extract the zero level set function from the level set function

(5) determine whether a level set evolution is terminated, if so, the end of the algorithm, or turn to the third step.

5 Experimental result and discussion

The following simulation experiments are conducted using Matlab7 programming, computer configuration used in the experiment for: Intel Core4 processor, 10 g of memory, Windows 7 operating system. The model parameter is set to: $\alpha = \beta = 1$, $\mu = 0.01 * 255^2$, time step $\Delta t = 0.1$, grid spacing $h = 1$, regularization parameters $\varepsilon = 1$, $\sigma = 2.0$, $a = 1$.

Experiment 1 is the traditional C-V model and the improved C - V model and the method of this paper (improved C - V model and the narrow band method) for photographic image segmentation experiments compared respectively. Figure 5 is experiment result with the traditional C - V model , figure 6 is experimental result with the improved C - V model ,Figure 7 is experimental result with the method of this paper, the traditional C - V model needs iteration 35 times, and takes 2.634s complete segmentation, the improved C - V mode needs iteration 27 times, takes 2.022s, and the method of this paper only needs 18 times, takes 1.037s. Experiment 2 is for a SAR satellite cloud image respectively, using the traditional model, the improved C - V model and the method of this paper segmentation. the traditional C -V model needs iteration 240 times, takes 8.524s (figure 9), the improved C - V model needs iterative 185 times, takes 6.022 s (figure 10), and the method of this paper only iterative 100 times, takes 4.426s (figure 11). The experimental results show that, the improved C-V model can capture the image edge information is more effective than the traditional C-V model, thus the segmentation efficiency is higher; and the narrow band method can reduce the complexity of algorithm, greatly improving the speed of image segmentation.

Figure 4. The original image

Figure 5. The segmentation result with the traditional C-V model

Figure 6. The segmentation result with the improved C-V model

Figure 7. The segmentation result with the method of this paper

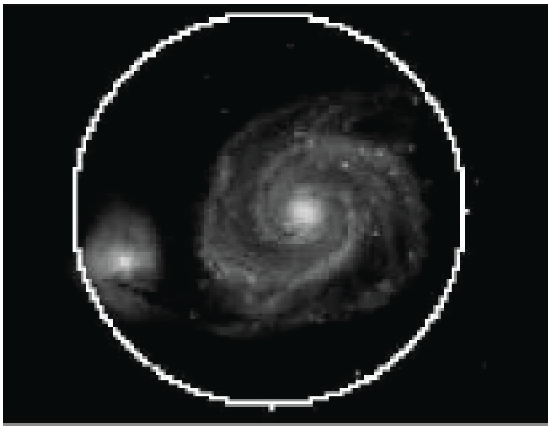

Figure 8. The original image and the initial contour

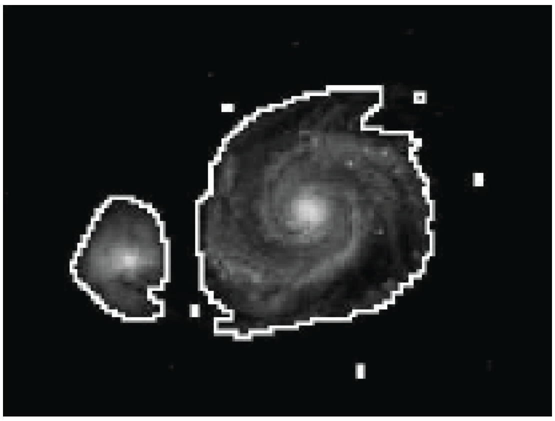

Figure 9. The segmentation results with the traditional C-V model

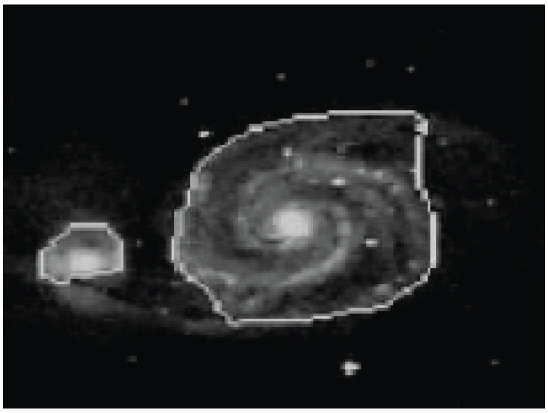

Figure 10. The segmentation results with the improved C-V mode

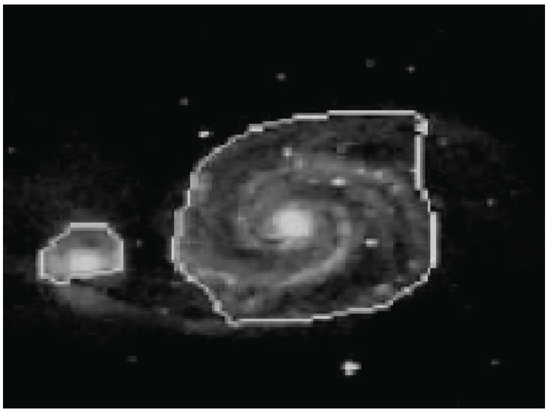

Figure 11. The segmentation results with the method of this paper

6. Conclusion

In this paper, on the basis of the traditional C-V model in image segmentation considering only the global information of the image, it propose an improved model which is joined the image edge gradient information, and proposes a rapid narrow-band method based on 3×3 template in the numerical implementation, through numerical experiment, the method of this paper has good stability than the traditional C - V model , and it has the stronger ability to capture the edge and the faster speed of segmentation and the lower algorithm complexity, but the edge detection function is introduced in this paper is only related to the gradient information of the image, which has nothing to do with the prior image information, thereby affecting the efficiency of image segmentation, this is the direction of next research.

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