Asian Journal of Information Technology 5 (12): 1441-1446, 2006

A Supervised Watershed Algorithm for Image Segmentation

[1]S. Kothainachiar and [2]R.S.D. Wahita Banu
[1,2]Department of Electronics and Communication Engineering,
Government College of Technology, Coimbatore, India 641013
[2]Allagapa Chettiyar College of Engg,
Karaikudi, India

Abstract: A Supervised Watershed Algorithm segments the image into as many regions as the number of markers, interactively placed by the user in the Region of Interest (ROI). Image Smoothing acts as the pre-processing step for segmentation. A non-linear Partial Differential Equation technique (PDE) or scale-space diffusion technique is used for image smoothing. This algorithm simplifies the problem of initialization as the image pixels are sorted previously according to difference between the maximum and minimum values in neighbors of the current pixel. This sorting makes an order of processing and ensures that the pixels around the edges have their processes postponed. The local seed points are automatically detected and labeled. To avoid over-segmentation problem, this algorithm merges the non-significant regions based on the markers. The user can repeat the process, until satisfactory results are obtained. Accurate segmentation results are obtained for gray scale images and color images by using this simple algorithm.

Key words: Image segmentation, markers, watershed, smoothing, performance evaluation

INTRODUCTION

The goal of the image segmentation process is to define areas within the image. Many image segmentation techniques have been developed. In Edge-based segmentation, image edges are detected and then linked into contours that represent the boundaries of image objects. In Clustering-based segmentation, image pixels are sorted in increasing order as a histogram according to their intensity values. In Region-based Segmentation, the goal is the detection of regions that satisfy a certain predefined homogeneity threshold. Two sub classes are Region Growing and Region Splitting/Merging. The watershed algorithm is based on region growing technique. The watershed algorithm can find contiguous edges in an image accurately but suffers from the over-segmentation problem.

The watershed segmentation algorithm is followed in this study, which consists of two steps[1]:

- Pre-processing is an essential step, in which specialized filters smooth the image, simplifying it for the subsequent segmentation step.
- Supervised segmentation allows the user to intervene directly in the segmentation process.

All image pixels are previously sorted according to the selected criterion. Then the Supervised Watershed Segmentation (SWS) is applied on the sorted pixels to segment the image into as many regions as the number of *markers* interactively placed by the user.

WATERSHED TRANSFORMATION

Definition: The algorithm by Vincent and Soille[2] is used in this study, which is a recursive simulation of the immersion process:

- All local minima are assigned a different label, which is propagated to all adjacent pixels at certain level h.
- All levels from the minimum to the maximum gray level are processed. At every level h:
  - Every pixel at a certain level with an already labeled neighbor receives its label. Labels are propagated from these to all pixels in that level.
  - Pixels having two or more neighbors with different labels are labeled as watershed points.
  - Remaining pixels are considered as new minima and are assigned a new label.

Over-segmentation: The over segmentation problem in the watershed transformation is mostly due to the noise and quantization error. To eliminate the effect of noise or quantization error on the final results, the watershed transformation is applied on the gradient of the original 2image.

Corresponding Author: S. Kothainachiar, Department of Electronics and Communication Engineering, Government College of Technology, Coimbatore, India 641013

IMAGE SMOOTHING

Image Smoothing is a pre-processing step. It can also be used as image de-noising. Here, smoothing through partial differential equation technique[3] and scale space technique[4] are used.

Edge preserving anisotropic filter using pde: Smoothing the image surface can be done by minimizing the energy functional or directly designing PDE's with specific regularization behaviors that evolve the noisy surface. Most of the non-significant image extrema (especially noise) can be effectively removed by treating the image I(x,y,z(t)) as a 3D surface and selectively deforming this surface based on the vertical projection of its mean curvature. The local surface deformation is computed from the local mean curvature k expressed by the following relation between the second derivatives of I:

$$K = \frac{I_{xx}(1+I_y^2) - 2I_xI_yI_{xy} + I_{yy}(1+I_x^2)}{2(1+I_x^2+I_y^2)^{3/2}} \quad (1)$$

To evolve the image I as a surface under this modified level set, curvature motion is equivalent to repeatedly iterate the following edge-preserving anisotropic filter:

$$I_{t+1} = I_t + K \quad (2)$$

Figure 1 shows the effect of smoothing on a standard image.

Smoothing using scale-space anisotropic diffusion: The importance of multistage descriptions of images has been recognized from the early days computer vision. A clean formalism for this problem is idea scale-space filtering.

The anisotropic diffusion equation is given as

$$I^{t+1}_{i,j} = I^{t}_{i,j} + \lambda\,[c_N \,.\, \nabla_N I + c_S \,.\, \nabla_S I + c_E \,.\, \nabla_E I + c_W \,.\, \nabla_W I]^{t}_{i,j} \quad (3)$$

where 0≤ë≤1/4 for the numerical scheme to be stable, N, S, E, W are the mnemonic subscripts for North, South, East, West, the superscript and subscripts on the square bracket are applied to all the terms it encloses and the symbol indicates nearest-neighbor differences. At every iteration step, the conduction coefficient "c" is updated as a function of the brightness gradient g:

$$c^t_{Ni,j} = g(|\nabla_N I^t_{i,j}|) \qquad c^t_{Ei,j} = g(|\nabla_E I^t_{i,j}|)$$
$$c^t_{Si,j} = g(|\nabla_S I^t_{i,j}|) \qquad c^t_{Wi,j} = g(|\nabla_W I^t_{i,j}|) \quad (4)$$

Smoothing using this scale-space anisotropic diffusion is shown in Fig. 2.

Fig. 1: Image smoothing using PDE a): Original image b-c): smoothened image (40 and80 iteratins)

Fig. 2: Imaging smoothing using scale-space diffusion (a) Original image (b)-(c) Smoothing by two differnt functins for g in (4)

SUPERVISED WATERSHED ALGORITHM (SWS)

Sorting of image pixels: The image pixels are sorted out in a way such that the processing of image pixels around the edges is postponed to the last. Hence, all the image pixels around the edges have entered into the competition at the same time to conquer the edge pixels. Sorting the image pixels based on the z values in ascending order allows the region-growing process to automatically start from the minima of the sorted surface. The following relations can be used for sorting purpose:

- z is assigned the value of the image gray levels themselves.
- z is computed as the difference between a pixel and mean value in its neighbors N(p).
- z is computed as the difference between the maximum and the minimum values in *N(p)*.

Here, the third relation is chosen as the processing order. It is approximately equal to morphological gradient.

Markers: This algorithm segments the image into as many regions as the markers placed by the user. Thus, the region count can be interactively controlled by the user. The user can segment the particular region of interest by placing the marker on that region.

Watershed algorithm: Based on the user markers, the respective pixels get labeled (say, marker label). The new regions start growing around the sorted pixels with a new label (say, seed label). The steps involved in this algorithm are as follows: The original image is applied to the edge preserving anisotropic filter (or scale-space diffusion).

- By using the mouse, one marker per region is placed; labeling them from 1 to k. k is the total number of markers.
- Smoothened Image pixels are sorted in ascending order according to any one of the criteria listed earlier.
- For each pixel p extracted from the sorted list, the number of positive labeled neighbor pixels is counted. The three possible outcomes are:
    - There is no positive labeled pixel in N(p). The current pixel receives a new label and starts a new region. New regions receive labels starting from k+1. Labels from 1 to k are reserved for user placed markers. Labels starting from k+1 are reserved to seeds.
    - There is only one labeled pixel in N(p). The current pixel receives this label and is integrated into the corresponding neighbor region.
    - There are 2 or more positive labeled pixels in N(p). If neighbors have different markers labels (label = k), a border has been found. The current pixel is marked as an edge, say a -1 label. If 2 or more neighbors have different seed labels along with/without one marker label, all neighbors are merged to form a single region and the region is labeled with the smaller label in those neighbors and the current pixel is added to it.

The segmented image is drawn according to the newly assigned labels.

RESULTS

This section illustrates some practical results obtained with the SWS algorithm for different classes of images. In the original images, user selected *markers* are shown as small color boxes and the extracted edges are shown as red (or white or green) lines in segmented images. Fig. 3 and 4 show segmented output on gray scale images. Fig. 5 and 6 segmented output on color images. This SWS algorithm gives good segmentation results for noisy images (Fig. 7 and 8).

Fig. 3a: Finger X-ray image with 11 marks b) Segmented image

Fig. 4: a) Face of Ape image with 7 markers b) Segmented image

Fig. 5: a) Pepper image with 24 markers b) Segmented image

Fig. 6: a) Bear image with 4 markers b) Segmented image

Fig. 7: a) Noisy bird image with 2 markers b) Segmented images

Fig. 8: a) Noisy ring image with 2 markers b) Segmented image

Fig. 9: (a) Segmented brain tumor image using automatic watershed algorithm (b) Segmented brain tumor image using supervised watershed algorithm

The number of regions in each image is exactly matched with the number of markers placed on the original image. Thus, this SWS algorithm avoids the over-segmentation problem.

PERFORMANCE EVALUATION

Borsotti's evaluation function q: Borsotti[5] introduced a quantitative evaluation function for segmentation algorithms. His proposed evaluation function Q is given as:

$$Q(I) = \frac{\sqrt{N}}{1000 * S_I} \sum_{j=1}^{N} \left[\frac{e_j^2}{1 + \log_{10} S_j} + \left(\frac{N(S_j)}{(S_j)} \right)^2 \right] \quad (5)$$

Here, e_j^2 is the squared color error of region j. The segmentations that result in small values for evaluation function are considered more favorable (i.e., better segmentation) than those with high values. Table 1 gives the comparison result between raw watershed algorithm and SWS algorithm. Due to over-segmentation, the evaluation values for raw watershed algorithm are higher than those of SW2S algorithm.

Table 1: Performance measure of raw watershed method vs SWS method

	Measure			
Seg Alg	Finger	Hematite	spine	Texture(with noise)
RW	6.1209	2.5707	4.2853	16.4051
IWS	0.1585	0.2548	0.1852	0.2983

Table 2: Performance measure of SWS methods using differnt gradient and smoothing approaches

	Measure,Q		
Gray-scale Images	1*	2*	3*
Finger	0.1538	0.1585	0.1572
Texture (with noise)	0.2967	0.2983	0.2977
Face	0.5337	0.4689	0.5096
Coins	0.0666	0.0667	0.0669
Bird	0.1146	0.0903	0.0909
Brain Tumor-1	0.4439	0.4619	0.4762
Brain Tumor-2	0.2482	0.2581	0.2490
Hematite	0.2822	0.2548	0.2268
Spine	0.1852	0.1852	0.1854

The gradient image required for SWS method can be obtained from either morphological operator or from the difference in two extreme of neighbors. Table 2 gives the performance values of same SWS methods using different gradient images and different smoothing methods.

- SWS Algorithm using Morphological Gradient and PDE Smoothing

- SWS Algorithm using Gradient (from difference in extremes of neighbors) and PDE Smoothing
- SWS Algorithm using Gradient (from difference in extremes of neighbors) and Scale-Space Anisotropic Smoothing

Figure 9 gives the comparison between this algorithm and automatic marker controlled watershed segmentation. Using this SWS algorithm, the required regions of the image can be segmented by placing the user marker on those regions.

CONCLUSION

Various smoothing methods and gradient methods have been employed with the segmentation algorithm and their performance measures were tabulated. This algorithm can also be used to segment the noisy images. Accurate results can be achieved for gray and color images using this simple method. This algorithm can be practiced in various applications. So, this can be further extended to specific field of interest like object segregation in medical images. This work is well suited for medical images, satellite images and other images, where the Region of Interest (ROI) plays a vital role in image segmentation.

REFERENCES

1. De Andrade, M.C., 2004. An Interactive Algorithm for Image Smoothing and Segmentation, Electronic Letters on Computer Vision and Image Analysis Published by Computer Vision Center/Universitat Autonoma de Barcelona, Barcelona, Spain, 4: 32-48.
2. Vincent, L. and P. Soille, 1991. Watersheds in Digital Space: An Efficient Algorithm based on Immersion Simulations, IEEE Transaction on Pattern Recognition and Machine Intelligence, 6: 583-598.
3. Yezzi, A., 1998. Modified Curvature Motion for Image Smoothing and Enhancment, IEEE Transavtion on Image Processing, 3: 345-352.
4. Yezzi, A., 1998. Modified Curvature Motion for Image Smoothing and Enhancement, IEEE Transaction on Image Processing, 3: 345-352.
5. Perona, P. and J. Malik, 1990. Scale-Space and Edge Detection Using Anisotropic Diffusion, IEEE Transaction on Pattern Analysis and Machine Intelligence, 12: 7-629.