AREA BASED NOVEL APPROACH FOR FUZZY EDGE DETECTION

M. Hanmandlu
Dept. of Electrical Engineering, I.I.T. Delhi, India. {mhmandlu@ee.iitd.ac.in}
Rohan Raj Kalra
Dept. of Computer Science, S.I.T.M, Rewari, India. {rohankalra@hotmail.com}
Vamsi Krishna Madasu
School of Engineering Systems, Queensland University of Technology, Australia. {v.madasu@qut.edu.au}
Shantaram Vasikarla
School of IT, American InterContinental University, U.S.A. {svasikarla@la.aiuniv.edu}

ABSTRACT

This paper presents a novel approach for edge detection based on the Univalue Segment Assimilating Nucleus (USAN) area. The USAN area characterizes the structure of the edge present in the neighborhood of a pixel and can thus be considered as a unique feature of the pixel and is fuzzified. The Gaussian edge detector mask is then applied to the associated Gaussian membership function of the USAN area. A threshold is applied on the resultant gradient image to yield the binary image. The results of the proposed edge detector are compared with other well known edge detection techniques and it is found that the image obtained using the proposed approach is qualitatively the best.

Index Terms: *Edge detection, USAN area*

1. Introduction

Edge detection is extensively used in image processing applications to separate the object from the background in images. Using edges, significant amount of data can be reduced by filtering out the useless information while preserving the structural properties of an image.

A lot of research has been done in the field of image segmentation using edge detection. Some of the earliest operators to detect edges in an image were proposed by Sobel, Prewitt, Roberts, etc. These operators used local gradient methods to detect edges along a specified direction. The lack of noise control in these operators results in their poor performance on blurred or noisy images. Canny [1] proposed a method to counter noise problems, wherein the image is convolved with the first order derivative of the Gaussian filter for smoothing in the local gradient direction followed by thresholding to yield edges. Marr and Hildreth [2] proposed an algorithm that finds edges at the zero-crossings of the image Laplacian. Non-linear filtering techniques for edge detection also saw much advancement through the SUSAN method [3], which works by associating a small area of neighboring pixels with similar brightness to each center pixel. More recent techniques pose the edge detection as a fuzzy reasoning problem. Fuzzy logic used in [4] employs morphological edge extraction method. Ho *et al.* [5] have used both global and local image information for fuzzy categorization and classification based on edges. Tizhoosh in [9] has developed an approach for fast fuzzy edge detection. In [6] a fuzzy-based approach to edge detection uses both global and local image information. This work was based on our earlier work reported in [8]. We extend the approach in [6] by using the concept of SUSAN edge detector. Now as in [3] we calculate the USAN or similar brightness area around each pixel because area conveys more efficient information about the structure of the image. We use the Gaussian membership function to represent the USAN area of [3] in the fuzzy domain. Then these fuzzified values are in the range [0, 1] corresponding to the gray map in the range (0-255). Then we apply a local edge detector mask over the fuzzified values to get the gradient values which depict a thick edge map of the image. The next step is a simple thresholding on the gradient values to yield fine edges.

2. FUZZIFICATION

In this section, we will show the computation of USAN area so that it can be fuzzified for further processing to obtain the binary image.

2.1. Univalue Area Calculation

In this approach, a local region is defined around each pixel as this local area contains information about the structure of the image. Following SUSAN[3], we define a circular mask of radius 3.4 which leads to an area of 37 pixels on the basis of experiments. Here the central pixel is known as nucleus. The brightness of each pixel is compared with that of the nucleus of the mask. The area of the mask is constituted by the pixels having same brightness as the nucleus. This area of mask is known as the USAN (univalue segment assimilating nucleus). The most important property of

1-4244-0549-1/06/$20.00 ©2006 IEEE.

USAN area is that it falls to half as the edge is approached. The area around each pixel is computed from:

$$c_{m,n} = e^{-\left(\frac{I(r)-I(r_0)}{t}\right)^8} \quad (1)$$

where, t is the threshold of the brightness gradient and is set to 20. In (1) r is the intensity value ranging from 1 to 256, and r_0 is the intensity value at the nucleus. The value of $c_{m,n}$ is the area of the mask at location (m, n) in the image X. The Eqn. (1) is adapted from [3] where the power is 6. But this value is found not suitable for fuzzification; hence we have arrived at 8.

2.2. Histogram based Fuzzy Membership Function

The membership function gives the degree by which a particular property, for e.g., intensity is associated with a pixel. Here, we use a Gaussian membership function that contains only one parameter fuzzifier f_h, given by:

$$\mu(m,n) = G(c_{m,n}) = e^{-(c_{\max}-c_{m,n})^2/2f_h^2} \quad (2)$$

where, m = $1,2\ldots M$; n = $1,2\ldots N$, c_{max} is the maximum area around any pixel. Here c_{max} = 37; (because we are using a circular mask of 37 pixels), $c_{m,n}$ is the area value at (m,n)[th] location.

A fuzzy histogram is used to obtain the frequency of occurrence of membership function of the area in the fuzzy image X. Thus we get

$$X = U\{\mu(k), p(k)\} \quad (3)$$

where, $\mu(k)$ is the membership of each pixel with an associated USAN area and $p(k)$ is the frequency of occurrence of this area in an image X.
Thus a normalized probability function is derived so as to satisfy the condition:

$$\sum_{k=1}^{37} p(k) = 1 \quad (4)$$

Use of k[th] area in (2) leads to

$$\mu(k) = e^{-(c_{\max}-k)^2 / 2f_h^2} \quad (5)$$

where, k varies between 1 and 37 (c_{max}), and fuzzifier f_h can be determined from [8]:

$$f_h^2 = \frac{\sum_{k=0}^{c_{\max}-1}(c_{\max}-k)^4 p(k)}{\sum_{k=0}^{c_{\max}-1}(c_{\max}-k)^2 p(k)} \quad (6)$$

The entropy function using (5) is given by

$$E(\mu) = -\{\mu(k)\ln\mu(k) + (1-\mu(k))\ln(1-\mu(k))\} \quad (7)$$

We can optimize E with respect to f_h for an improved image before attempting edge detection.

3. LOCAL EDGE DETECTOR

An area based edge detector is defined in [6] as:

$$\eta(m,n) = e^{\sum_i\sum_j \frac{[\mu(m+i,n+j)-\mu(m,n)]^\alpha}{2(f_h)^\beta}} \quad (8)$$

where i , j = [-(w-1)/2 , (w-1)/2] , and size of the edge detector mask is w×w.

The two parameters, α and β are the design parameters. The mask is a generalized Gaussian function. For example α = β = 2 would yield a normal Gaussian mask. The use of USAN area membership function helps find edge pixels that can be easily localized. These are further accentuated by applying the edge operator in (8) as gives the edge map of the image. This is not the case with the most of primitive edge operators like Sobel, Prewit etc. except the Canny edge detector that has been constructed imposing the localization constraint.

3.1 Entropy Optimization of parameters α and β

As the final edge output depends heavily on two parameters, α and β; the optimization of these parameters is required. Taking into consideration that the edge mask is applied locally and doesn't involve the entire image the entropy function is computed from

$$E(\eta(m,n)) = -\left[\eta(m,n)\ln\eta(m,n) + (1-\eta(m,n))\ln(1-\eta(m,n))\right] \quad (9)$$

The derivatives of E w.r.t. α and β are obtained as:

$$\frac{\partial E}{\partial\alpha} = \frac{\partial E}{\partial\eta(m,n)}\cdot\frac{\partial\eta(m,n)}{\partial\alpha} = \frac{\eta\sum_i\sum_j K^\alpha \ln K}{2(f_h)^\beta}\ln\left\{\frac{\eta}{1-\eta}\right\} \quad (10)$$

$$\frac{\partial E}{\partial\beta} = \frac{\partial E}{\partial\eta(m,n)}\cdot\frac{\partial\eta(m,n)}{\partial\beta} = \frac{\eta\ln f_h\sum_i\sum_j K^\alpha}{2(f_h)^\beta}\ln\left\{\frac{\eta}{1-\eta}\right\} \quad (11)$$

where, $K = [\mu(m+i,n+j) - \mu(m,n)]$

The above derivatives are used in the learning of the parameters, α and β recursively by the gradient descent technique. The learning laws are as follows:

$$\alpha_{new} = \alpha_{old} - \varepsilon_\alpha \frac{\partial E}{\partial\alpha} \quad (12)$$

$$\beta_{new} = \beta_{old} - \varepsilon_\beta \frac{\partial E}{\partial\beta} \quad (13)$$

where, ε_α and ε_β are the learning factors chosen in the range [0, 1] corresponding to α and β respectively. If α and β diverge or converge too quickly the value of ε_α and ε_β have to be altered respectively to ensure convergence.

3.3. Image thresholding

After edge image based on USAN areas is generated, the next task is to binarize the image according to a certain threshold. An optimum threshold is determined experimentally as:

$$c_{th}(m,n) = \begin{cases} 1, & \lambda \geq 0.911 \\ 0, & \lambda < 0.911 \end{cases} \tag{14}$$

4. PROPOSED ALGORITHM

The steps of the area based fuzzy edge detector algorithm are as follows:

1. Calculate the area *(c)* around each pixel in the image.
2. Calculate the value of parameter f_h.
3. Fuzzify the area using Gaussian membership function.
4. Optimize α and β iteratively until they converge.
5. Apply the local fuzzy edge detector function $\eta(m, n)$.
6. Apply the selected threshold on the thick edge map from Step 5.
7. Stop

5. RESULTS AND DISCUSSIONS

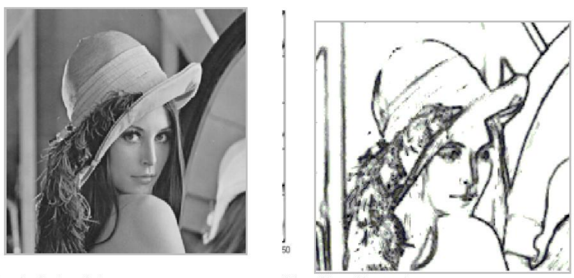
The fuzzy edge detector is implemented on the standard 256×256 pixel gray level test images, i.e., Lena, Barbara and Cameraman images. Prior to the application of this algorithm no preprocessing was done on these images. As this algorithm has three phases: fuzzification using the Gaussian function, local edge detection using the proposed Gaussian type edge masks and thresholding, we will present results at each of these three phases. After applying the edge mask, we will get an edge map of the image which is then refined by the thresholding operation. Here the Lena image is used for visual analysis. We haven't attempted quantitative analysis as it requires an additional processing such as edge linking and edge sorting as per their lengths. The technique yielding the large number of longest edge segments is considered the best. However, this criterion doesn't work for textured image such as Lena. The quantitative analysis is not explored here.

5.1 Experimental Results

The original and gradient images of Lena are shown in Fig.1. As can be seen in the gradient image the structure of the image is retained but the edges are very thick. Then thresholding is done to binarize the image and to obtain almost one pixel-thick edges. The result of thresholding is shown in Fig. 2.

In all the test images, the original shape is retained with a good balance of detail and speckle-textured edges. For comparison purposes, we have applied the Canny edge detector and scale space Gaussian gradient diffusion operator [7] on the test images. Results are as shown in Fig. 3 whereas in Fig. 4 we have applied the SUSAN method on test images. It appears that Fig. 3 and Fig. 4 have much difference in the appearance of the Lena image.

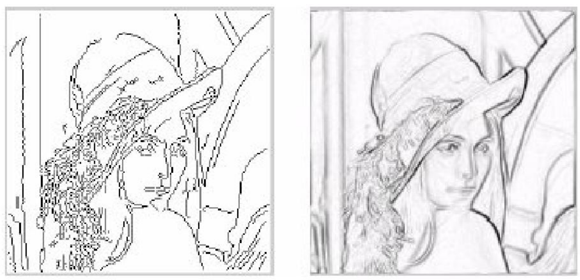
Canny yields unnecessary edges thus cluttering the main shape details whereas the proposed area based edge detector drops some edges and enhances the important edges that contribute to the main shape. The Gaussian gradient diffusion operator causes blurred edges, and mainly accentuates only the strong edges but most valuable details of the face are lost. SUSAN edge detector causes the problem of step edges. This distinctive feature of the proposed area based edge detector is ideal for face recognition applications.



(a) Original image (b) Gradient image

Fig.1 Edge Detection using fuzzification

Fig. 2 Thresholded Image



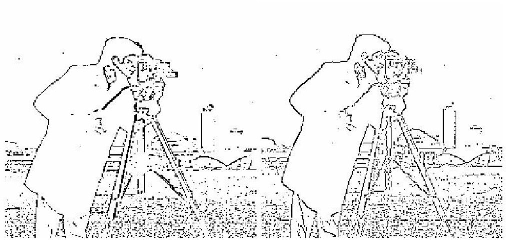
(a) Canny Edge operator (b) Gradient diffusion operator

Fig. 3 Comparative Output

(a) Original image (b) SUSAN Edge Detection

Fig.4 SUSAN Output

(a) Original image (b) Fuzzified image



(c) Thresholded Image (d) SUSAN Edge Detection

Fig. 5 Results on Cameraman

(a) Original image (b) Fuzzified Image

(c) Thresholded Image (d) SUSAN Edge Detection

Fig. 6 Results on Barbara

6. Conclusions

The area based fuzzy edge detector presented in this paper uses the area concept in [3]. The area is fuzzified using the Gaussian membership function. The local edge detection operator is applied using parameters α and β which are optimized using the entropy optimization method to obtain the gradient image which is the edge map of the image. Then, a thresholding level is selected to obtain the fine edge image. Results show that this edge detector is immensely suitable for applications such as face recognition and fingerprint identification as it does not distort the shape of the image and is able to retain all the important edges unlike other edge detectors. However, in this work it remains to undertake quantitative analysis to judge the performance of various edge detectors. Appropriate fuzzification function and thresholding selection are important for the success of the proposed edge detection algorithm.

Acknowledgement

The authors gratefully acknowledge the support of LASTEC, Defense Research and Development Organization Delhi (DRDO) under the Contract number: 5/ST/04-051.

7. References

[1] J.F. Canny, "A computational approach to edge detection", *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 8(6), 1986, 679-698.

[2] D. Marr, and E.C. Hildreth, "Theory of edge detection", *Proc. of the Royal Society of London*, b207, 1980, 187-217.

[3] S.M. Smith, and J.M. Brady, "SUSAN – A new approach to low level image processing", *International Journal of Computer Vision*, 23(1), 1997, 45-78.

[4] I. Bloch, "Fuzzy sets in image processing", *ACM Symposium on Allied Computing, 1994*.

[5] K.H.L. Ho, and N. Ohnishi, "FEDGE – Fuzzy edge detection by fuzzy categorization and classification of edges", *Fuzzy Logic in Artificial Intelligence*, Springer, IJCAI'95 Workshop, Montreal, Canada, 1188:182-196.

[6] M. Hanmandlu, J. See, and S. Vasikarla, "Fuzzy edge detector using entropy opimization", *Proc. International Conference on Information Technology: Coding and Computing,* 2004, 665-670.

[7] B.M. ter Haar Romeny, *Front-End Vision and Multi-Scale Image Analysis*, Kluwer Academic Publishers, 2002.

[8] M. Hanmandlu, M., D. Jha, M., and R. Sharma, "Color image enhancement using fuzzification", *Pattern Recognition Letters* 24(1-3), 2003, 81-87.

[9] H.R.Tizhoosh, "Fast fuzzy edge detection", *Proc. Annual Meeting of the North American Fuzzy Information Processing Society*, 2002, 231-242.