Fuzzy Logic Based Digital Image Edge Detection

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Abstract **-In this paper fuzzy based edge detection algorithm is developed. In the proposed algorithm, edginess at each pixel of a digital image is calculated using three (3) 3×3 linear spatial filters i.e. low-pass, high-pass and edge enhancement (Sobel) filters through spatial convolution process. Edge strength values derived from the three masks form three set of edges, utilized as fuzzy system inputs. Based on the Gaussian membership functions and fuzzy rules the fuzzy system decide whether a pixel in focus belong to an edge or non-edge. The final pixel classification of a given image is produced by generating output pixel value using Mamdani defuzzifier method. The robustness of the proposed method results for different captured images are compared to those obtained with Sobel and Prewitt operators. Experimental results show the ability and high performance of proposed algorithm.**

Keywords- Fuzzy Logic, Fuzzy inference system, Edge strength, Edge detection

I. INTRODUCTION

An edge is defined as an abrupt variation in pixel intensity within an image while the process of detecting outlines of an object and boundaries between objects and the background in the image is known as edge detection. Edge detection is a very important tool widely used in many computer vision and image processing applications. Earlier edge detection methods, such as Sobel, Prewitt, Kirsch and Robert are based on the calculation of the intensity gradient magnitude at each image pixel. In these algorithms, the gradient value is compared to the threshold value and a pixel location is classified as an edge if the value of the gradient is higher than a threshold. Gradient-based edge detectors have a major drawback of being very sensitive to noise.In order to counter noise problems Canny proposed an approach to edge detection in which the image is convolved with the first order derivatives of Gaussian filter for smoothing in the local gradient direction followed by edge detection and thresholding [Canny 1986]. Extensions of Canny edge detector can be found in [Laligant *et al*. 1994].

Edge detection represents an extremely important step facilitating higher-level image analysis and therefore remains an area of active research, with new approaches continually being developed. Recent examples include edge detectors using fuzzy logic, neural networks, or wavelets [Sun and Sclabassi 1995, Law *et al*. 1996, Bezdek *et al*. 1996, Wang *et al*. 2005]. Comparison of edge detection approaches and an assessment of their performance may be found in [Demigny et al. 1995, Ramesh and Haralick 1994].In this paper, fuzzy logic based approach to edge detection in digital images is proposed. Firstly, for each pixel in the input image edginess‘ measure is calculated using three 3 x 3 linear filters after which three fuzzy sets characterized by three (3) Gaussian membership functions associated to linguistic variable Low", Medium" and High" were created to represent each of the edge strengths. The second phase involves application of fuzzy inference rule to the three fuzzy sets to modify the membership values in such a way that the fuzzy system output ("edge") is high only for those pixels belonging to edges in the input image. The last step is final pixel classification as edge or non-edge using Mamdani defuzzification method.

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II. APPLICATION OF FUZZY LOGIC BASED EDGE DETECTION

Fuzzy logic represents a powerful approach to decision making [Zadeh 1965, Kaufmann 1975, Bezdek 1981]. Since the concept of fuzzy logic was formulated in 1965 by Zadeh, many researches have been carried out on its application in the various areas of digital image processing such as image quality assessment, edge detection, image segmentation, etc. Many techniques have been suggested by researchers in the past for fuzzy logic-based edge detection [Cheung and Chan 1995, Kuo, *et al*. 1997, El-Khamy *et al*. 2000]. In [Zhao, *et al*. 2001], Zhao, *et al*. proposed an edge detection technique based on probability partition of the image into 3-fuzzy partitions (regions) and the principle of maximum entropy for finding the parameters value that result in the best compact edge representation of images. In their proposed technique the necessary condition for the entropy function to reach its maximum is derived. Based on this condition an effective algorithm for three-level thresholding is obtained. Several approaches on fuzzy logic based edge detection have been reported based on fuzzy If-Then rules [Tao, *et al*. 1993, Li 1997]. In most of these methods, adjacent points of pixels are assumed in some classes and then fuzzy system inference are implemented using appropriate membership function, defined for each class [Mahani, *et al*. 2008]. In Liang, *et al*. [Liang, *et al*. 2003], adjacent points are assumed as 3×3 sets around the concerned point. By predefining membership function to detect edges. In these rules discontinuity in the color of different 3×3 sets, edges are extracted. It uses 5 fuzzy rules and predefined membership function to detect edges. In these rules discontinuity of adjacent point around the concerned point are investigated. If this difference is similar to one of predefined sets, the pixel is assumed as edge.A similar work is proposed by Mansoori, *et al*. [Mansoori, *et al*. 2006], wherein adjacent points of each pixel are grouped in six different set. Then by using of appropriate bell shape membership function, the value from zero to one is determined for each group. Based on the membership values, and fuzzy rules, decision about existing/not existing and direction of edge pixels are obtained.

III. Proposed Algorithm

In this paper, at first an input image is pre-process to accentuate or remove a band of spatial frequencies and to locate in an image where there is a sudden variation in the grey level of pixels. For each pixel in the image edge strength value is calculated with three (3) 3×3 linear spatial filters i.e. low-pass, high-pass and edge enhancement filters (Sobel) through spatial convolution process.In carrying out a 3×3 kernel convolution, nine convolution coefficients called the convolution mask are defined and labeled as seen below:

a	b	c
d	e	f
g	h	i

Every pixel in the input image is evaluated with its eight neighbors, using each of the three masks shown in Figure 1 to produce edge strength value. The equation used for the calculation of edginess values between the center pixel and the neighborhood pixels of the three (3) masks using spatial convolution process is given by:

$$\begin{aligned} O(x,y) = & aI(x-1,y-1) + bI(x-1,y) + cI(x-1,y+1) \\ & + dI(x,y-1) + eI(x,y) + fI(x,y+1) \\ & + gI(x+1,y-1) + hI(x+1,y) + iI(x+1,y+1) \end{aligned} \quad (1)$$

However, the result of convolution of the two Sobel kernels is combine thus, the approximate absolute gradient magnitude (edge strength) at each point is computed as:

$$O_g = |O_x| + |O_y| \quad (2)$$

The normalized edge strength is then defined as:

$$NO(x,y) = round\left[(O(x,y)/\max(O)) \times 100\right] \quad (3)$$

where $x = \{0,1,\ldots,M-1\}$ and $y = \{0,1,\ldots,N-1\}$ for an M-by-N image.

The edge strength values derived from the three (3) masks served as the inputs used in the construction of the fuzzy inference system based on which decision on pixel as belonging to an edge or not are made. Membership functions are defined for fuzzy system inputs. Many membership functions have been introduced in the literature.

In the proposed edge detection Gaussian membership functions are used. To apply these functions, each of the edge strength values of O_g, O_{Hp}, and O_{Lp} are mapped into fuzzy domain between 0 and 1, relative to the normalized gray levels between 0 and 100, using Gaussian membership functions given as

$$\mu_{mn} = G(x_{mn}) = e^{[-(x_{\max} - x_{mn})^2 / 2\sigma^2]} \quad (4)$$

where $G(x_{mn})$ is a Gaussian function, $x_{\max}$, x_{mn} are the maximum and $(m,n)th$ gray values respectively and σ is the standard deviation associated with the input variable.

$$h_{LP} = \begin{bmatrix} \frac{1}{9} & \frac{1}{9} & \frac{1}{9} \\ \frac{1}{9} & \frac{1}{9} & \frac{1}{9} \\ \frac{1}{9} & \frac{1}{9} & \frac{1}{9} \end{bmatrix}, \qquad h_{HP} = \begin{bmatrix} -1 & -1 & -1 \\ -1 & 9 & -1 \\ -1 & -1 & -1 \end{bmatrix}$$

$$h_x = \begin{bmatrix} -1 & 0 & +1 \\ -2 & 0 & +2 \\ -1 & 0 & +1 \end{bmatrix}, \qquad h_y = \begin{bmatrix} +1 & +2 & +1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}$$

Fig. 1: 3×3 kernels used for edge detection

Each of the mapped values are partition into three fuzzy regions Low", Medium", and High". The defined regions and membership functions are shown in Fig. 2. Fuzzy inference rules are applied to assign the three fuzzy sets characterized by membership functions μ_{Low}, μ_{Medium}, and μ_{High} to the output set. The rules, tabulated in Table 1 are defined in such a way that in the fuzzy inference system, output set $\mathrm{E_L}, \mathrm{E_M}$, and $\mathrm{E_H}$ correspond to pixels with low, medium and high probability value respectively. The output of the system P_{Final} representing the probability used for final pixel classification as edge or non-edge was computed using a singleton fuzzifier, Mamdani defuzzifier method given by;

$$p_{Final} = \frac{\sum_{\ell=1}^{M} \bar{y}^{\ell} \left(\prod_{i=1}^{n} \mu_{k_i^{\ell}}(\alpha_i)\right)}{\sum_{\ell=1}^{M} \left(\prod_{i=1}^{n} \mu_{k_i^{\ell}}(\alpha_i)\right)} \tag{5}$$

where α_i are the fuzzy sets associated with the antecedent part of the fuzzy rule base, $\bar{y}^{\ell}$ is the output class center and M is the number of fuzzy rules being considered.

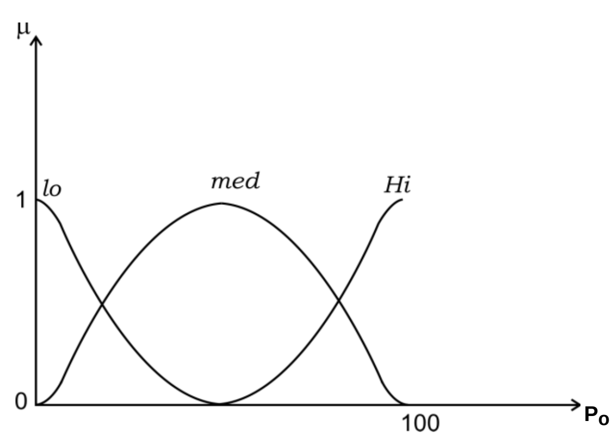

Fig. 2: Gaussian membership functions Low, Medium and High

Table 1

If $edginess_{Lp}$ is LO and $edginess_{So}$ is LO and $edginess_{Hp}$ is LO then p_{edge} is E_{L}

If $edginess_{Lp}$ is LO and $edginess_{So}$ is LO and $edginess_{Hp}$ is MD then p_{edge} is E_{L}

If $edginess_{Lp}$ is LO and $edginess_{So}$ is LO and $edginess_{Hp}$ is HI then p_{edge} is E_{L}

If $edginess_{Lp}$ is LO and $edginess_{So}$ is MD and $edginess_{Hp}$ is LO then p_{edge} is E_{L}

If $edginess_{Lp}$ is LO and $edginess_{So}$ is MD and $edginess_{Hp}$ is MD then p_{edge} is E_{L}

If $edginess_{Lp}$ is LO and $edginess_{So}$ is MD and $edginess_{Hp}$ is HI then p_{edge} is E_{M}

If $edginess_{Lp}$ is LO and $edginess_{So}$ is HI and $edginess_{Hp}$ is LO then p_{edge} is E_{L}

If $edginess_{Lp}$ is LO and $edginess_{So}$ is HI and $edginess_{Hp}$ is MD then p_{edge} is E_{H}

If $edginess_{Lp}$ is LO and $edginess_{So}$ is HI and $edginess_{Hp}$ is HI then p_{edge} is E_{H}

If $edginess_{Lp}$ is MD and $edginess_{So}$ is LO and $edginess_{Hp}$ is LO then p_{edge} is E_{L}

If $edginess_{Lp}$ is MD and $edginess_{So}$ is MD and $edginess_{Hp}$ is LO then p_{edge} is E_{L}

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If $edginess_{Lp}$ is HI and $edginess_{So}$ is LO and $edginess_{Hp}$ is HI then p_{edge} is E_{H}

If $edginess_{Lp}$ is HI and $edginess_{So}$ is MD and $edginess_{Hp}$ is HI then p_{edge} is E_{H}

If $edginess_{Lp}$ is HI and $edginess_{So}$ is HI and $edginess_{Hp}$ is HI then p_{edge} is E_{H}

IV. Experimental results

The proposed fuzzy edge detection method was simulated using MATLAB on different images, its performance are compared to that of the Sobel and Kirsch operators. Samples for a set of four test images are shown in Fig. 3(a). The edge detection based on Sobel and Kirsch operators using the image processing toolbox in MATLAB with threshold automatically estimated from image‘s binary value is illustrated in Fig. 3(b) and 3(c). The sample output of the proposed fuzzy technique is shown in Fig. 3(d). The resulting images generated by the fuzzy method seem to be much smoother with less noise and has an exhaustive set of fuzzy conditions which helps to provide an efficient edge representation for images with a very high efficiency than the conventional gradient-based methods (Sobel and Kirsch methods).

V. Conclusion

In this paper, effective fuzzy logic based edge detection has been presented. This technique uses the edge strength information derived using three (3) masks to avoid detection of spurious edges corresponding to noise, which is often the case with conventional gradient-based techniques. The three edge strength values used as fuzzy system inputs were fuzzified using Gaussian membership functions. Fuzzy if-then rules are applied to modify the membership to one of low, medium, or high classes. Finally, Mamdani defuzzifier method is applied to produce the final edge image.Through the simulation results, it is shown that the proposed algorithm is far less computationally expensive, its application on the image improve the quality of edges as much as possible compared to the Sobel and Kirsch methods.This algorithm is suitable for applications in various areas of digital image processing such as face recognition, fingerprint identification, remote sensing and medical imaging where boundaries of specific regions need to be determined for further image analysis.

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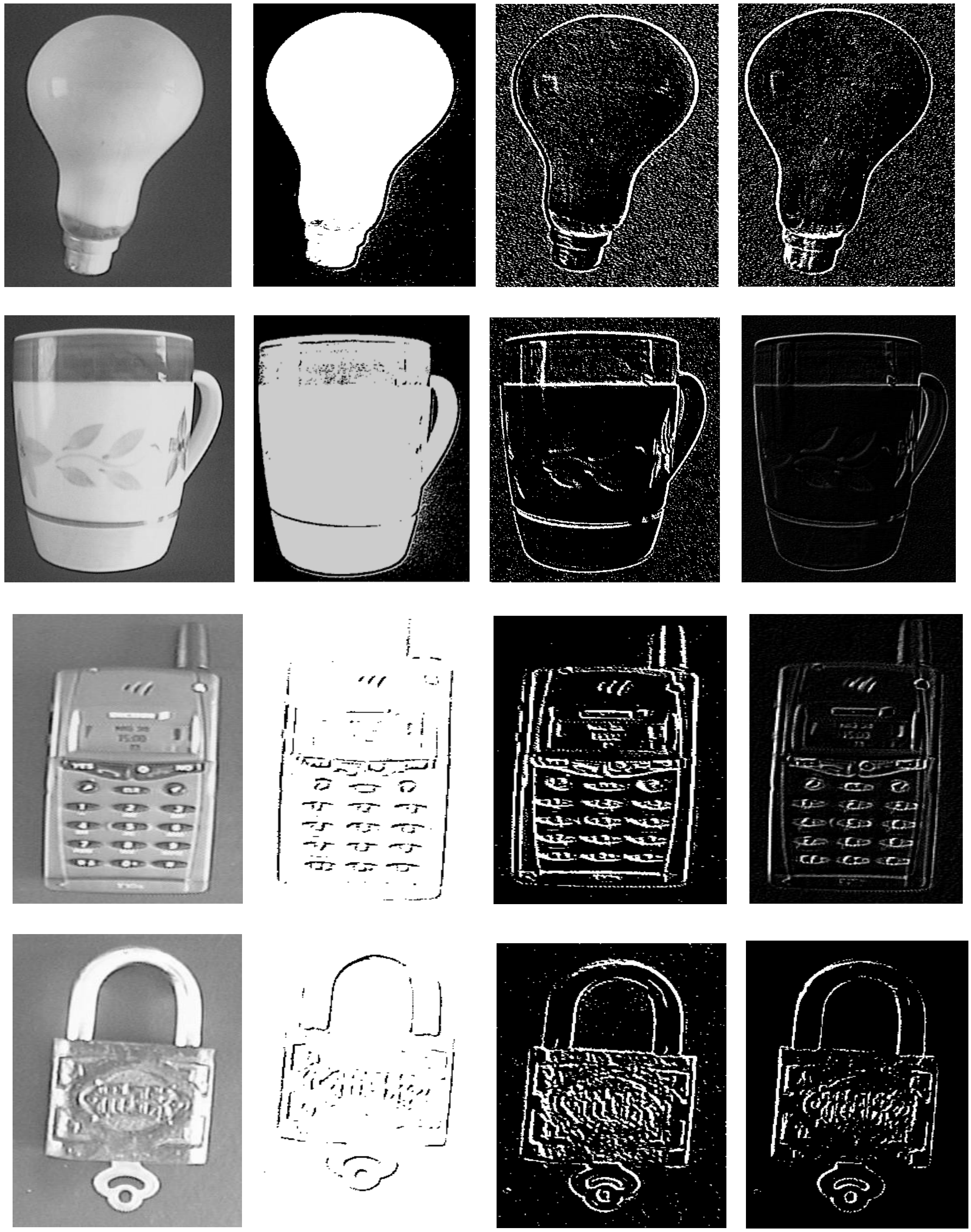

(a) (b) (c) (d)

Fig. 3 (a) Original images, (b) Sobel operator results, (c) Kirsch operator results, (d) Proposed fuzzy edge detection algorithm results

VII. References

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