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Edge Detection Techniques Beyond Classical Edge Detectors

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Abstract— Edge detection is a fundamental tool in image processing, machine and computer vision. Detection of edges is very important task for feature extraction, feature detection, object recognition, face recognition and many more practical applications. The field of research for edge detection is so rich, with a number of approaches and methodologies. This paper reviews different edge detection techniques such as classical edge detectors, Fuzzy Logic, Wavelet approach, Genetic Algorithm (GA), Neural Network (NN), Ant Colony Optimization (ACO) and some efficient hybrid combination of these approaches. The challenges in edge detection process are also discussed.

Key Words: ACO, Fuzzy logic, GA, NN, Wavelets.

I. INTRODUCTION

Edge detection is a fundamental tool for image segmentation. Detection of edges in an image is a very important step for the image understanding. Edge detection plays an important role in high-level processing tasks such as image segmentation and object recognition. An image is composed of various regions which are similar or different from each other based on various image characteristics like intensity, color, brightness etc. Edge represents a boundary between two regions which are homogeneous in some sense. Edges in an image are marked with discontinuity or significant variation in intensity or gray levels. In edge detection we try to identify and locate sharp discontinuities in an image. Boundaries in objects of the scene can be distinguished by the detection of edges. Edges in images are having some predefined shapes along but they can exist in form of curves also. The basic edge types which are generally found in images are step, ramp, line and roof.

This paper is organized as follows: In Section 2 various classical edge detectors are discussed. Section 3 presents different approaches for edge detection beyond classical operators. In Section 4 various challenges which are being faced in the process of edge detection are discussed followed by conclusion and future scope in Section 5.

II. CLASSICAL EDGE DETECTORS

The classical edge detectors are based on calculating first and second-order derivatives of the image [1-5]. Classical methods of edge detection engage convolving the image through an operator or mask, which is constructed to be perceptive to large gradients in the image. In uniform regions these masks return zero values. The classical operators are mainly grouped into some main categories like (i) Gradient based detectors: These operators are based on calculating the first order derivative of the image. These are Sobel, Roberts, Prewitt, Kirsch etc. (ii) Second order derivatives or zero-crossing detectors: Laplacian and LoG etc. (iii) Gaussian based detectors: Canny etc.

A. The Roberts detection

The Roberts edge detection (Lawrence Roberts, 1965) performs a 2-D spatial gradient calculation for images. The regions of high spatial frequency correspond to edges. The detection of edges oriented in the vertical 45° and 135° is done generally by this operator. Due to the relatively small size of kernels used in this operator, performance is susceptible to the presence of noise [1].

B. Sobel edge detection

Sobel introduced this method in 1970. This method depends on the Sobel approximation to the derivative. The points where the gradient is highest corresponds the edges. This method is more effective in detection of edges in the horizontal and vertical directions. Sobel takes less computation time compared to the Canny detector but the results of canny are more efficient. Sobel edge detection operator is combined with soft-threshold de-noising to improve the edge detection in images corrupted by White Gaussian noise [6].

C. Prewitt edge detection

Prewitt proposed the Prewitt edge detection in 1970. It estimates correctly the magnitude and orientation of an edge. It is limited to find edges in eight possible compass directions. Gradient calculation is done in the 3x3 neighborhood for eight directions. The convolution mask with largest module is selected.

The Prewitt operator performs well in the presence of Poisson noise whereas in case of noises like salt and pepper, speckle, the performance degrades [7].

D. Kirsch edge detection

In 1971 Kirsch introduced this method. In this method a single mask is rotated through 45° in eight different compass directions. Then each mask is convolved with the image and the maximum value so found gives the magnitude of edge. The simplicity of Kirsch implementation is attractive. This method is also susceptible to noise. The noise susceptibility can be removed if the image is filtered with Gaussian filter for image smoothing [8].

E. LoG edge detection

The Marr-Hildreth (1980) proposed the LoG operator for edge detection in images having fast and distinguishable variations in brightness. Laplacian operator is a second order derivative basically used for edge detection. The LoG of an image $f(x, y)$ is computed by first smoothing the image and then computing the Laplacian. The Laplacian function has an advantage that it can identify whether a pixel is on the dark or light side of an edge.

The LoG operator has a limitation that it has a large amount of multiplication operations, which makes it computationally difficult. By using look-up tables for the mask-coefficients can ease the task [9]. For multi-scale LoG operation the basic LoG filtering if combined with Gaussian approximation filter to produce efficient edge detection in real time [10].

F. Canny edge detection

This operator was given by John Canny in 1983. This method is very popular and its performance is still comparable to newer methods of edge detection. The performance of Canny operator is better compared to Roberts and Sobel in case of noisy images but the running time is more. Generally the edge detection operators including Canny also, suffer the problem of disjoint edges. Ya-Ping Wong et al. proposed an improved Canny method using Ant Colony Optimization to solve this problem [11]. Elitist ant strategy is used to find thin connected edges in this approach.

III. DIFFERENT EDGE DETECTION APPROACHES

A. Fuzzy based approach

The Fuzzy Logic was introduced by Sinha and Dougherty in 1990's in mathematical morphology. Fuzzy Logic is being used as a powerful tool for decision making [12]. In image processing the information about the image and its parameter are not very accurate, so the consideration of fuzzy nature of pixels, can ease certain image processing tasks.

The general fuzzy-based edge detection methods lack in some cases, as in these methods the global information of the image is neglected. In [13] Aijaz Ur Rahman Khan and Dr. Kavita Thakur presented a fuzzy inference based system based edge detection which uses a 2×2 window. This method produces better results compared to Sobel and Prewitt operators with reduced complexity.

In the edge-detection of blurry images, the gradient-based edge detectors like Sobel, Canny and other traditional fuzzy techniques do not produce convincing results. In [14] Jinbo Wu, Zhouping Yin and Youlun Xiong proposed a multi-level fuzzy edge detection method for blurry images. In this method first enhancement algorithm is used on the image and then a transform is used based on image threshold. Then edges are found using extremum of the gradient values. Results show better edge detection compared to other methods.

Sometimes the traditional fuzzy methods can't distinguish between noise and edge at the boundary. In [15] Om Prakash Verma et al. proposed a hybrid method to resolve this issue. Ant colony optimization is used along with fuzzy derivative technique. Fuzzy derivative is used to detect local variations caused by noise and ants are used to detect edges, resulting in efficient detection. In fuzzy based techniques there is an uncertainty in assignment of membership degree. This is known as hesitation degree, this a kind of problem in effective edge detection. Tamalika Chaira et al. [16] proposed an Attanassov's intuitionistic fuzzy set theory as a solution to this problem.

B. Wavelet approach

Wavelets are a class of functions obtained by scaling and moving the basic wavelet, whose average is zero. Wavelet transform-based approaches are being widely used in the domain of image processing, signal processing and other fields. In edge detection discrete wavelet transform, a special case of wavelet transform is very famous tool.

Basic wavelet $\Psi(x)$ can be defined as [17]:

$$\int_{-\infty}^{\infty} \Psi(x)dx = 0$$

In the frequency-domain, it is constrained by this inequation [17]:

$$C_{\Psi} = \int_{-\infty}^{\infty} \frac{|\Psi(\omega)|^2}{\omega} d\omega < \infty$$

Where $\Psi(\omega)$ is the Fourier transform of $\Psi(x)$

For a function $f(x)$, its wavelet transform can be obtained by the following equation [17]:

$$WT_f(a,b) = \int_{-\infty}^{\infty} f(x)\Psi_{a,b}(x)\,dx$$

Where $\Psi_{a,b}(x) = \frac{1}{\sqrt{a}} \Psi\left(\frac{x-b}{a}\right)$

Depending on discrete values of *a* and *b* this equation can correspond to the Discrete Wavelet Transform (DWT).

The wavelet-based edge detection techniques has an advantage over traditional methods, in their noise-rejection capability. Tao Yang, Guoxia Sun, Xiuman Duan proposed such a method [17]. A proper threshold is chosen after multiplying the DWT coefficients in the adjacent scale. If the multiplication product so obtained is large, it correspond to presence of edges otherwise noise.

Wavelet based edge detection can even be implemented in nano-scale edge detection with improved results compared to other methods**.** Wei Sun, Jose A. Romagnoli, Joseph W. Tringe proposed a wavelet based edge detection approach for scanning electron microscopy images [18]. In this approach the characteristics of the image like the superimposed edge search region and of the threshold value are based on wavelet decomposition.

In images having non-uniform illumination wavelet based edge detection produces efficient results. Wanpeng Cao et al. [19] proposed a new edge detection technique which utilizes wavelet based fuzzy enhancement algorithm for edge detection in case of images with non-uniform or weak illumination.

Haar Wavelet is an effective method which is also used to detect edges for both grayscale and colour images. Zhongliang Fu, Chunya Tong, Huang Yan and Zhou Fan proposed an 8-input/8-output architecture based on Gabor wavelet [20]. This method utilizes the advantages of Otsu threshloding to make the process of edge detection faster and effective. The results are comparable to Canny detector.

In case of synthetic aperture radar (SAR) images, prior to edge-detection, edge enhancement is needed. Wavelet transform can fulfill this requirement too in such a way which leads to efficient edge detection [21].

Due to the multi-scale feature and localization characteristic of Wavelet transform, edge detection can be implemented in different scales. Li Wan-She et al. presented the utility of wavelet transform comparing their noise immunity superior to LoG and Canny operators [22].

C. Genetic Algorithm approach

Genetic Algorithm (GA) is a heuristic-based search algorithm which is being widely used for optimization and search problems. Process like inheritance, mutation, selection, and crossover are the basis of Genetic Algorithm. Here chromosomes population is used in the search process using a fitness function, as a candidate solution, which is updated time to time.

S. M. Bhandrkar et al. presented a G.A. based method for edge detection [23]. Here the process of edge detection is formulated as one of choosing a minimum cost edge configuration. 2D chromosomes are used for edge configurations. The adaptation of mutation and crossover rates leads to a rapid convergence. This approach produces efficient results with satisfactory convergence rate and noise immunity.

The classical edge detectors when combined with G.A., can enhance their effectiveness in edge detection. Zhang et al. proposed combination of Sobel detector and G.A. for edge detection [24]. The results found are better compared to Otsu threshloding based method.

Genetic Algorithm can be used to increase the processing speed of search algorithms. Zavad Rahebi et al. proposed Ant Colony Optimization based on G.A.[25]. In this method initially a series of answers formed by artificial ants is considered then G.A. is used to generate the next population. The use of G.A. in this method results in efficient edge detection with increase in speed and answer's optimum.

Guo Yutang and Liu Lulu presented a new approach to enhance the convergence rate of the G.A. based on edge detection [26]. In this approach they have used the theory of good point set for redesigning the crossover operation. The image is filtered to remove the non-edge pixels prior to edge detection. This approach increases the convergence rate along with efficient edge detection results and noise-immunity.

Implementing G.A. in traditional methods can enhance their effectiveness. Sheta et al. proposed the implementation of G.A. in traditional edge detection methods [27]. The results show that this approach produces better results compared to K-means clustering and methods base on global threshold.

D. Neural network

Artificial Neural networks are inspired from biological nervous system of human brain. These networks are adaptive systems as their basic elements called neurons have an intelligent learning mechanism. These networks are being employed in various systems of information and processing, to achieve faster and efficient results.

Neural network-based edge detection is more effective in images in which there exists vagueness in the quality of image. Like satellite images are vague in nature due to the atmospheric turbulence and poor resolution of sensors. In such cases neural based approaches prove to be superior to the traditional methods. Wang Jianlai, Yang Chunling, Sun Chao proposed a cellular neural network along with Particle Swarm Optimization (PSO), for satellite image edge detection [28]. This method outperforms Sobel and LoG based methods.

In medical images using traditional edge detection approaches the quality of detected edges is not very much acceptable. Medical images have very fine details in them, so in such cases using neural networks for edge detection can ease the process, because of the learning ability of neurons. Dingran Lu et al. proposed neural network based edge detection for medical images [29]. Using the adaptive learning and non-linear mapping properties of neural networks along with fuzzy sets for training phase produces efficient edge detection for bladder cancer diagnosis.

The classical edge detectors like Sobel, Roberts and Canny have high computational time. In images like satellite and obstacle detection due to large amount of information to be processed, these detectors are replaced with neural networks and other optimization based methods. Hezekiah Babatunde, Olusegun Folorunso1 and Adio Akinwale proposed Cellular Neural Networks (CNN) for edge detection [30]. This CNN is based on differential equations. Results prove this method is more efficient for edge detection compared to classical edge detectors.

The robustness of neural network based methods towards the effect of noise present in the images is more compared to traditional methods. Guo Jing et al. proposed a feed forward neural network based edge detection for plant root images [31]. This network is a three layer network with back propagation for training. The results prove the efficiency and noise-robustness of this method.

Advanced Wavelet neural networks (WNN) are very efficient in their adaptive learning virtue along with good localization characteristics. Cia and Nian proposed a WNN for edge detection [32]. The Image features are extracted from local statistics of the image. This information is fed to the input of WNN. This method produces optimized results.

E. Ant Colony Optimization (ACO) based techniques for edge detection

Ant colony optimization is a very efficient algorithm inspired from basic ant colony systems. It is based on the heuristic search approach by which ants find their food following shortest path. They use pheromone to follow each other and find an optimum path for search. M. Dorigo first proposed this ant colony approach to travelling salesman problem approach [33]. It is being implemented in various fields including image processing. In edge detection ACO is very efficient technique due to its robust and parallel computation.

Yanfang Che and Yong Pu proposed an efficient edge detection method using Ant Colony search [34]. In this method the ants use the heuristic information for searching the edges. This method produces very fine and connected edges. The noise sensitivity is also very less.

The traditional edge detectors are unable to distinguish between edge pixels and non-edge pixels. But using ACO for edge detection, the search space for edge detection can be minimized. O.P. Verma et al. proposed such a method which uses ACO and adaptive threshloding [35]. Adaptive threshloding is used to find edge map. Then ants are placed on this map for edge detection. This approach produces efficient edge detection in less computational time compared to traditional edge detectors.

The hybrid combination of ACO and other methods like G.A. and neural network etc. can perform very superior detection of edges. Javed Rahebi et al. proposed a combination of G.A. and ACO for edge detection [25]. This hybrid approach produces better edges compared to classical methods.

When the images are filtered by classical filters like Sobel filter, some discontinuities appear. ACO can provide solution to such problems. O.P. Verma, M. Hanmadlu et al. proposed such a solution in which fuzzy derivative technique is used with ACO [36]. This method produces efficient edge detection and also sort out the Problem with Sobel Filter.

IV. CHALLENGES IN EDGE DETECTION PROCESS

By analyzing the available literature for edge detection we have found that edge detection task depends on the characteristic of the image and the efficiency of different techniques vary in different cases. The main challenges we have come to know for different detection techniques can be summarized as:

i. Uneven lighting conditions
ii. Moving or dynamic background
iii. Presence of noise
iv. False edge detection
v. Shifted or dislocated edges.
vi. Undesired Intensity variation
vii. Presence of clutters
viii. Overlapping objects in images.

V. CONCLUSIONS AND FUTURE SCOPE

Edge detection is a vast field of research in image processing. The classical edge detectors like Sobel, Prewitt, Canny etc. are still attractive for researchers because their performance can be enhanced using improvisation of some sort or other. Other techniques like wavelet, fuzzy, neural and G.A. are more effective compared to Classical edge detectors in most cases. In this survey it is found that the optimization techniques and the hybrid combination of different classical methods are more efficient compared to traditional methods. Use of ACO for edge detection proves this fact that optimization techniques have far potential in them for edge detection.

It is a challenge for future researchers to find new optimization methods, improvisation of existing techniques and innovative algorithms for edge detection. The richness of the research-field for edge detection will definitely attract the future researchers.

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