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Gaussian Mixture Model for Edge Detection Techniques

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Abstract—**Edges can be defined as the rigid significant change of image intensity pixels usually appears at the boundary between different regions, edges can modeled according to the image intensity profiles and amplitude changes, such as; Step, Ramp, Ridge /Line, and Roof Edges. Edge detection plays an efficient role in digital image processing and practical aspects of various life fields. Image edge detection frequently minimizes the amount of data and gets rid of worthless information and preserves the essential image characteristics. Edge detection techniques can be grouped into two main categories, Gradient and Laplacian edge detection techniques. Gaussian Mixture Model (GMM) lately applied for edge detection purposes. GMM considered as an unsupervised classifier that required a probability density functions (pdf) of the given data to be calculated at the training step. In the related works, we considered researches that deal with Gaussian model only since it is our concern in this work to focus on its main characteristics and properties effects. In this paper, we discussed and analyzed various concepts related to edges, various edge detection techniques, and ultimately introduced a comparison between these techniques.**

***Index Terms*— Digital image processing, Edge detection, Gradient methods, Laplacian methods, Gaussian Mixture Model.**

I. Introduction

Generally in digital image processing, the image consists of discontinuity and similarity characteristics; the discontinuities define the significant variation in pixel intensity that addresses the boundaries of the objects in an image which form the edges [1][2]. Edges represent the boundaries that identify objects in an image, which utilized in segmentation process and object recognition [3]. Edge detection considered as the fundamental step in many fields such as digital image processing and computer vision [1]; it refers to the method of locating the sharp discontinuities in an image [4].

The traditional techniques of edge detection are represented by convolving the image with a 2-D filter to construct sensitive gradients to certain types of edges and return zero in the uniform regions of the image [4].

A lot of edge detection operators are available and the selection of the proper edge detection operator depends mainly on edge's structure and orientation, and environment's noise [4]. The main objective of edge detection methods is to extract the effective features such as curves, lines, etc. and role characteristics such as amplitude, position, and direction and ignore unnecessary data [1][5]. The essential problems that might face any edge detector include; the noise, lightning conditions, areas with similar intensity, the selection of proper edge detector relies on quality of the detector to overcome these problems [1]. Image segmentation is the process of partitioning an image into a number of regions that share same color or texture from the background [1][3]. Both the segmentation and edge detection methods required careful selection of thresholding value which considered as a criterion for the detection process [6]. Edge detection approaches are frequently utilized in image segmentation for advance applications in more sophisticated fields such as applying Fuzzy [7], Genetic Algorithm [8] and Neural Network [7].

In this paper we analyzed and compared some edge detection techniques, since the aim of this work is not to focus on the most recent techniques and to provide a succinct comparison of the essential edge detection techniques.

II. Edge Definition

Edges can be defined as the significant change of image intensity pixels usually appears at the boundary between different regions [9], sometimes there is a small sudden change in image intensity but it is not an edge, it is a noise in

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the image which is a local intensity change but not a significant [6]. A lot of pixels in the image might have a nonzero gradient value but not all these pixels represent an edge, frequently, thresholding represents the judgment in this case.

The essential problem that arises in the edges is the appearance of the false edge, generating thin or thick lines, and missing true edges, all these problems are caused by the noise in the image [4].

There are a lot of reasons that effects on pixel intensity, some of these events are; different physical changes, geometric events, such as objects and surface boundaries, and Non-geometric events such as shadows [9].

III. Modeling Edge Discontinuity

Edges usually related with the model according to the image intensity profiles or the image first derivative. Edges can represent various shapes according to the amplitude changes as follows [6][1]:

- Step edge: Image intensity suddenly changes from one value on one discontinuity side to a different value on the other side.
- Ramp edge: Image intensity change not in instantaneous and appears over a finite distance, then the step become a ramp edge.
- Ridge /Line edge: Image intensity abruptly changes value and then returns to the starting value within some short distance.
- Roof Edge: the line edge considered as a roof edge when image intensity changes not in spontaneous manner and arise over a finite distance normally created by surfaces connectivity.

However, step and line edges are rarely seen in real images this back to the smoothing or low-frequency components generated in most sensing devices, step edges become ramp edges and line edges become roof edges when image intensity changes not instantaneous over a limited distance, Figure 1 demonstrates the profiles of edge discontinuity.

IV. Edge Detection Using Derivatives

In Calculus, the variance of continuous functions is described using derivatives [9]. An image is represented by a 2D function, and the representation of edges is described using derivatives, however, to detect the pixels that lie on an edge area, different edge detection techniques can be grouped into two main categories: [9][10]:

The Gradient method: Finds the edges by searching for the local maximum and minimum in the first derivative, such as Prewitt, Sobel, etc.

The Laplacian method: Finds the edges by searches for zero crossing in the second derivative of the image, such as Laplacian, Gaussian, etc.

Figure 2 shows the representation of the edges detected as the gradient of the signal described by the first derivative of t;

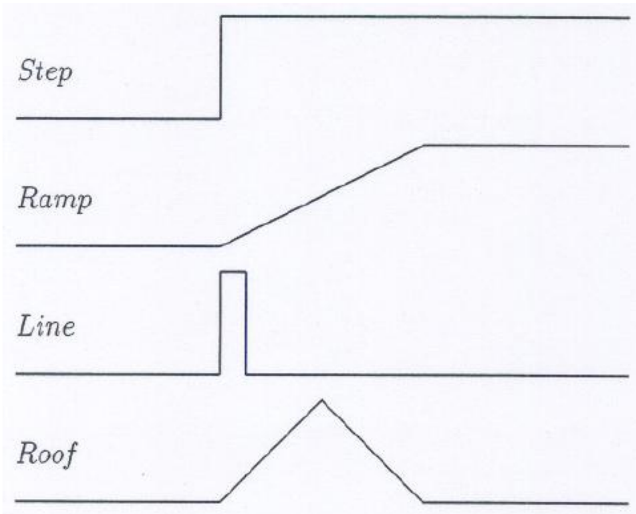

Figure 1: profiles of edge discontinuity [6].

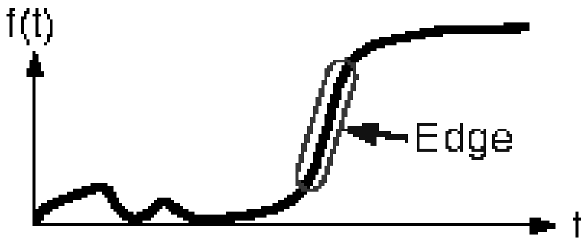

Figure 2: The gradient of a signal; the first derivative [11].

In Figure 3, the gradient with a large peak is centered on the edge, when comparing the gradient with the threshold, the threshold is exceeded and the edge is determined. Since the edge is determined at the peak, one dimension Laplacian operation can be applied, which can be defined as the second

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derivative with considering the t and achieve the zero crossings.

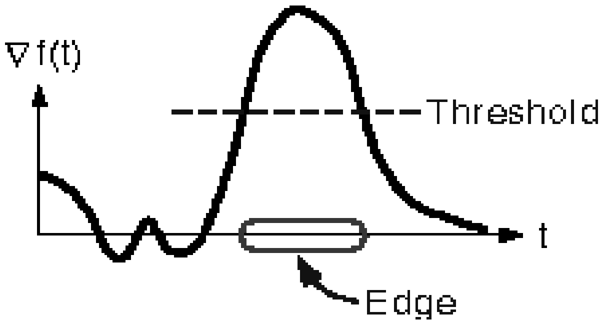

Figure 3: Second derivative [11].

Figure 4 explains the application of Laplacian operation on one dimensional signal where the edge corresponds zero crossing, as seen in Figure 3 there is a small ripples in the signal can be detected which corresponding to a zero crossings [11].

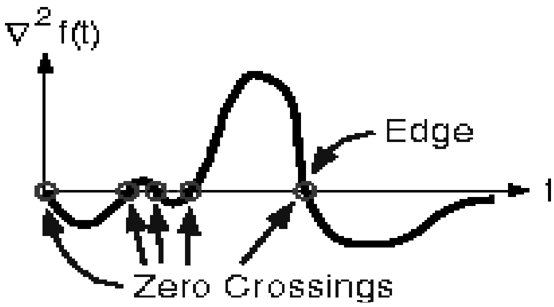

Figure 4: Zero crossing representation [11].

V. Edge Detection Methodologies

Edge detection techniques can be divided into two main categories, Gradient and Laplacian edge detection techniques as shown in Figure 5 [12][3]:

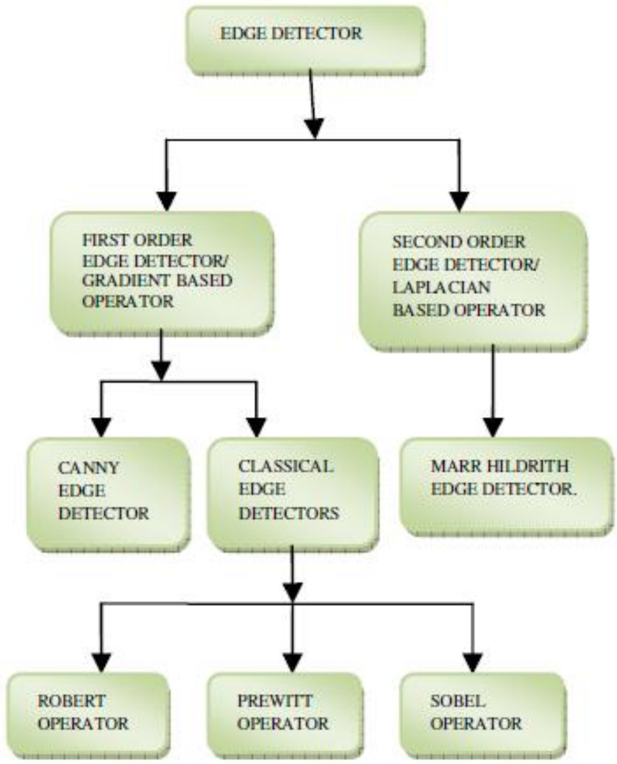

Figure 5: Types of edges detector [12].

VI. Gaussian Mixture Model

One of the parametric statistical approaches is Gaussian model. In order to classify any set of data, there are a deterministic number of Gaussian mixture models available to fit the data by identifying that data into a number of classes such that each Gaussian model fits and models s specific class of data [13]. Gaussian parameters required a suited estimation to distribute the data into classes properly, parameters estimation can be performed using some iterated algorithms such Expectation Maximization (EM) algorithm [14][15]. Gaussian model construct a probability density functions (pdfs) for each class of data. Generally, Gaussian model considered as an unsupervised classifier where the estimated parameters demanded for the pdf of the given data are calculated at the training stage.

A. *Gaussian Univariate Model*

Univariate or bimodal Gaussian classifier, for any variable x the data is defined in one dimensional space and their

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distribution is described in one peak. The main pdf parameters are represented by the mean μ value and standard deviation σ or variance σ^2 since they represent the location and squander of data respectively [14]. In a single Gaussian the pdf can be defined by equation (1) while the mixture of single Gaussian can be defined in equation (2):

$$p(x;\mu,\sigma^2) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(\frac{-(x-\mu)^2}{2\sigma^2}\right) \quad (1)$$

$$g(x) = \sum_{j=1}^{K} w_j\, p(x;\mu_j,{\sigma^2}_j) \quad (2)$$

Where K define the number of mixture Gaussians, and w_j represents the weight of each j_{th} mixture, while $g(x)$ describes the probability of x in a mixture form, the w_j should agree the rule explained in equation (3)

$$\sum_j^K w_j = 1 \quad \text{and} \quad 0 \le w_j \le 1 \quad (3)$$

B. Gaussian Multivariate Model

Multivariate Gaussian is closely used where a lot of recent applications modelled the data with at least two dimensions [13], and the required pdf parameters are defined using the mean μ value and covariance matrix Σ [14]. The pdf of multivariate Gaussian version model is shown in Equation (4) and the mixture version in Equation (5):

$$p(x;\mu,\Sigma) = \frac{1}{(2\mu)^{d/2}\,|\Sigma|^{1/2}} \exp\left(-\frac{1}{2}(x-\mu)^T\,\Sigma^{-1}(x-\mu)\right) \quad (4)$$

$$g(x) = \sum_{j=1}^{K} w_j p\left(x;\mu_j,\Sigma_j\right) \quad (5)$$

Where x is a d dimensional vector, i.e. $x = \{x_1, x_2, \dots, x_d\}$, $\mu = \{\mu_1, \mu_2, \dots, \mu_d\}$ and the covariance matrix Σ is explained in equation (6).

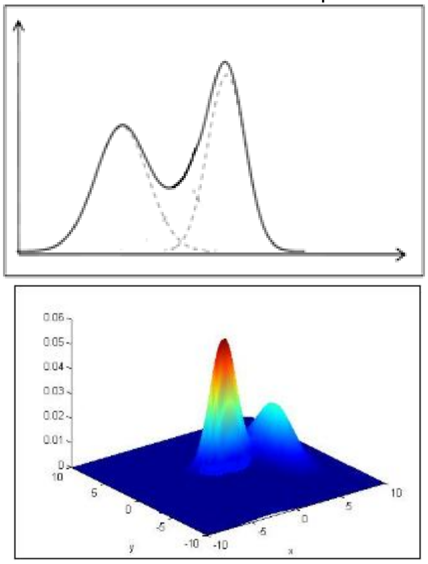
$$\Sigma = \begin{bmatrix} \Sigma_{x_1,x_1} & \Sigma_{x_1,x_2} & \cdots & \Sigma_{x_1,x_d} \\ \Sigma_{x_2,x_1} & \Sigma_{x_2,x_2} & \cdots & \Sigma_{x_2,x_d} \\ & \vdots & & \\ \Sigma_{x_d,x_1} & \Sigma_{x_d,x_2} & \cdots & \Sigma_{x_d,x_d} \end{bmatrix} \quad (6)$$

Where

$$\Sigma_{XY} = E[XY] - E[X] \times E[Y], \forall\, X,Y \in d \quad (7)$$

And $$E[X] = \sum_{i=0}^{n} \frac{x_i}{n} \quad (8)$$

The representation of this model is explained in Figure 7.



A

B

A: Univariate Gaussian mixture model [16]. B: Multivariate Gaussian mixture modeling [16].

Figure 7: Univariate and Multivariate Gausssian mixture classifiers.

VII. ALGORITHM DESCRIPTION

The frame work of the mixture Gaussian model for any edge detection or segmentation method can be demonstrate using the following algorithm as explained in Figure 8.

VIII. RELATED WORKS

In the related works, we considered researches that deal with Gaussian model, since it is our concern in this work is to focus on the characteristics and main influential properties. Various methods used GM and GMM for edge detection purposes, for example Stauffer et al. in [18] applied Gaussian mixture model GMM to model the background with low illumination changes, long-term scene changes, and repetitive motions in variant environment. However, the number of Gaussian distributions used to model the background is constant for different video frames, this shortcoming besides some other problems such as miss classification in case of

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unexpected lighting changes, and the extracted moving objects includes some shadows and severance contour, some solutions have been applied to overcome these problems [18]. Yinghong Li, et al. in [17] developed an edge mixture Gaussian model for moving vehicle detection; the proposed system contains four steps; 1) image preprocessing, 2) constructing Gaussian mixture model for the image edges with standard deviations within 2.5 and the foreground matching is performed to one of the K Gaussian models, 3) detecting the foreground object from the moving vehicle with threshold value 0.8, and 4) updating GMM model's parameters such as the mean μ, the covariance matrix Σ and the update weights ω. The filter applied in this work is canny edge detector [17].

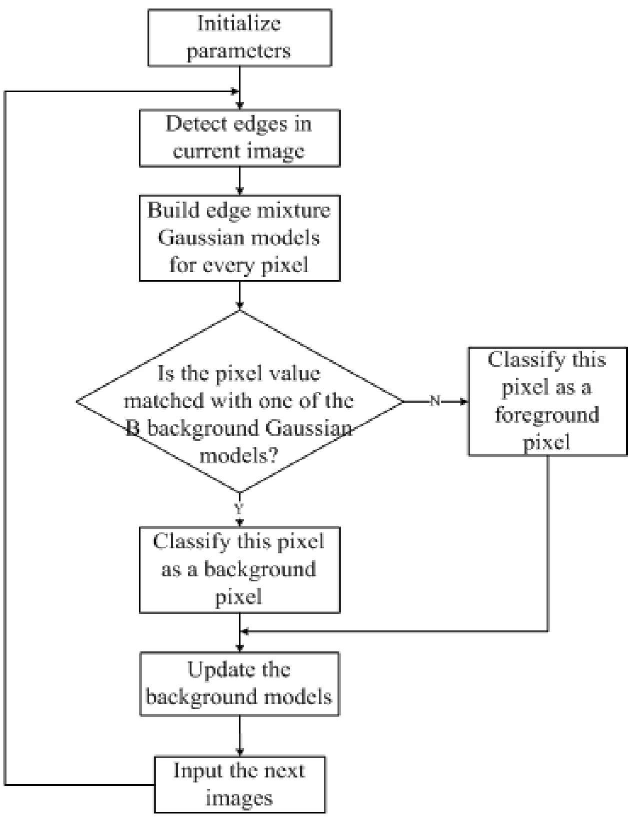

Figure 8: Mixture Gaussian model framework [17].

While other researchers applied GMM for objects segmentation aims, for example, Shuying Zhao, et al. [19] applied Gaussian distribution on two different color models YCbCr, and Nrg, mean and covariance matrix parameters are calculated using Maximum likelihood estimation MLE. Rahman Farnoosh [20] used GMM with the modified EM algorithm called EM-MAP (Expectation Maximization-Maximum a Posterior) algorithm to define GMM parameters such as; number of classes, means, variances, and weights, however, the suggested system is suitable for simple images and not applied for real images. Demir Gokalp [21] proposed GMM to identify human skin color, the probability density function pdf used to estimate human skin color. The initial parameters were determined using K-means algorithm, and estimated using Minimum Description Length (MDL) algorithm. GMM performed on three various color spaces chromatic space, log-opponent and YES, for the YES color model only one parameter is utilized which is the E channel to minimize the interference between skin and non-skin pixels [21].

IX. Advantages and Disadvantages of Edge Detector Methods

For an accurate detection of edges, it is an essential to figure out the true edges in order to ensure correct result, besides that the selection of the proper edge detectors plays an important role to achieve the best fitting on the selected application [3][1]. However, advantages and disadvantages of the given edges detection methods are in general according to the category described in subsection 3 above, table 1 demonstrates some advantages and disadvantages of edge detection methods [4][1].

Table 1: Advantages and disadvantages of some edge detection methods

X. Conclusions

Edge can be defined as a set of connected points that constructs a boundary between two separated regions. Edge detection has an effective role in various image processing applications such as motion analysis, and pattern recognition. It is necessary to explain major differences among edge detection methods. In this paper we studied the most commonly applied edge detection methods of Gradient and Laplacian edge detection techniques. Gradient methods have the main drawback by sensitivity to noise, and the difficulty to adapt kernel's size and parameters according to the input image, Laplacian methods introduces butter results than Gradient methods but still suffering from noise effect. Although Gaussian model is computations consuming but it

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overcomes the existence of the noise successfully and proves its accuracy and efficiency in various applications. To examine the effectiveness of any technique some performance measurements should be applied to analysis the results accurately such as in [3] while other systems use real system such as in traffic video surveillance in [17].

Table 1: comparison analysis of different methods that applied Gaussian model for various applications

Method reference	Purpose of application	Type of color model	Number of samples	Initializing Gaussian parameters
Stauffer et al. [18]	edge detection purposes	HSV Color model	four experiments under different conditions	Parameters initialized manually
Yinghong Li, et al. [17]	edge detection purposes	RGB color model	about 1000 images are taken to make actual measured statistic	Parameters initialized manually
Shuying Zhao, et al. [19]	Segmentation purposes	YCbCr, and Nrg space	20 samples	Maximum likelihood estimation
Demir Gokalp [21]	Segmentation purposes	Normalized CbCr, Yes, log-opponent color model	144 and 60 images for training, and testing data	EM algorithm
Rahman Farnoosh, and Behnam Zarpak [20]	Segmentation purposes	RGB color model	Simple images	EM algorithm

Table 2: advantages and disadvantages of edge detector operator

Edge detector operator	Advantage	Disadvantage
Gradient method (First derivative)	Detected the edges and its related orientation, simplicity	High noise sensitivity, errors embedding, and The size of the kernel filter and coefficients are fixed and difficult to be adapted for a given image.
Laplacian method (second derivative)	Detected the edges and its related orientation, the including parameters are fixed in all directions	High noise sensitivity, effective with some available edges
Gaussian Model (GM), and Gaussian Mixture Model (GMM)	Apply the probability to discover the error rates, develop signal to noise ratio (SNR), superior in edge detection especially in case of noise appearance	False zero crossing, complex computations consuming, time consuming

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Reference ID: IJCS-154 PAGE NO: 935-941

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