A SURVEY ON EDGE DETECTION IN IMAGES

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ABSTRACT

This paper presents the main edge detection methods currently used. Given the importance of the issue in processing imaging domain, over time there were developed several techniques. They behave relatively close in terms of noise, but in practical situations, some may look more favorable than others. This paper aims to be brief conceptual and mathematical presentation of the most popular methods of edge detection.

KEYWORDS: *edge detection, classical operators, Robert operator, Sobel operator, Prewitt operator, Gaussian based methods, wavelet base methods, zero crossing, Laplacian of Gaussian, colored edges methods*

1. INTRODUCTION

One of the most common operations in the field of image analysis and at the same time one of the fundamental problems in this area is contour detection. A contour or edge is the boundary between the object and the background, it is therefore useful knowledge for the following steps of the image analysis: segmentation, registration and identification of objects.

Edge detection is a very important stage for different areas such as automated interpretation systems and machine vision. It is also frequently used as the front-end processing step for higher level object recognition and interpretation systems as we can find in [1].

An edge detector represents in mathematically terminology an operator of small spatial extent that responds in some consistent manner to discontinuities, commonly classifying each image pixel as representing an edge or not [2].

From the scientific point of view, an outline is defined as all pixels that have abrupt discontinuities of levels of gray.

In binary images, border crossings are defined as black pixels having at least one white neighbor in the vicinity, therefore pixel location like (m, n) where u (m, n) = 0 and g (m, n) = 1, where:

$$g(m, n) = [u(m, n) \oplus u(m \pm 1,n)].\ \mathrm{OR}.\ [u(m, n) \oplus u(m, n \pm 1)]$$

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For a continuous image f (x, y), its derivative assumes a local maximum in the direction Edge. Therefore, an edge detection method is the measurement of the gradient of f along r in θ:

$$\frac{\partial f}{\partial r} = \frac{\partial f}{\partial x}\frac{\partial x}{\partial r} + \frac{\partial f}{\partial y}\frac{\partial y}{\partial r} = f_x cos\theta + f_y sin\theta$$

2. PROBLEM DEFINITION

Edge is a border along which brightness intensity suddenly changes, so it is characterized by sudden changes in intensity. It can be defined as a border separating the two areas of different intensity. Edge detection is a fundamental problem in the processing of images, it allows extracting useful information from an image, information necessary for image analysis. In image processing, edge is interpreted as a single class of singularities. In a function, singularities can be easily characterized by discontinuities, where the approach gradient is infinite. Edge detection is an important task in image processing. It is the main tool in pattern recognition, image segmentation, and scene analysis. An edge detector is essentially a high pass filter that can be applied to the extraction point edges in an image.

Edge detection is a fundamental problem in image processing area because it allows the extraction of the main information from an image, that is needed for the further computer analysis and understanding of it.

Edge detection is used in various image processing applications. As we can see in [3], these application can be: optical character recognition [4], infrared gait recognition [5], automatic target recognition [6], detection of video changes [7], medical image applications [8], machine vision an automated interpretations systems, satellite television, magnetic field resonance images and geographical information system [9] [10] [11].

Border detection in images is based on operators that approximates the gradient or the Laplacian image in discrete plane.

3. AVAILABLE METHODS

This Section presents the most important edge detection methods and explains their advantages and disadvantages and the relation between them. We will present some works in more details because of their major impact, while others will just referring at.

Border detection relies on operators that approximates the gradient or Laplacian image in discrete plane. Gradient vector represents direction and maximum magnitude of intensity variation within a point of an image and is defined by the partial derivatives of image function.

There might appear some problems in the process of edge detection. These are the potential problems in extracting contours, and in segmentation are the following: changing lighting conditions, changing the background, luminance and geometric characteristics, noise (which has a very big impact in edge shaping), detection of certain edges, detection of false edges, changing edge position from the real location.

Classical operators

The usual gradient operators are Roberts, Sobels and Prewitts operators and are defined for images with multiple levels of gray, but their use can be extended to color images. In the case of color images, how to apply the gradient operators is decomposing image in three fundamental areas of color (R, G, B) and then detecting, for every space, a border detection operator.

Laplacian operator that detects sudden transitions intensity of image requires fewer calculations, it is defined by second order partial derivatives:

$$\nabla^2 f(x,y) = \frac{\partial^2 f(x,y)}{\partial x^2} + \frac{\partial^2 f(x,y)}{\partial y^2}$$

Classical edge detectors uses groups of predefined templates for defining edges of each picture segment of a fixed size. 2D discrete convolutions are used here for finding the correlation between pre-defined templates and sample image segment.

These templates are represented as filters, which are vectors (1D) or matrix (2D). For faster performance, the size of these filters are 1x3 (1D) or 3x3 (2D). In terms of functions, filters are discrete operators of directional derivatives. Instead finding the local maximum gradient, it is set a threshold and establish those points of gradient below the threshold as points of edges.

Figure 1. Grayscale test image of brick wall and bike rack [12]

Robert operator

Figure 2. Gradient magnitude from Robert cross operator [13]

The components of the gradient at a pixel (x, y) is approximated by:

$$D + (x, y) = f(x + 1, y + 1) - f(x, y) \; D (x, y) = f(x, y + 1) - f(x + 1, y)$$

D + and D - is calculated with these two masks convolution [14]:

+ 1	0
0	-1

D-

0	+1
-1	0

D +

Figure 3. Masks used by Robert Operator [14]

Usually, the output produced by this detector is only the amplitude matrix, viewed as a gray scale images.

The main advantage of using this detector is simple calculations: addition and subtraction operations with the values of only 4 pixels.

The disadvantage: because it uses a very small nucleus, is very sensitive to noise. Also, response to real borders is weak if they are not very "abrupt" (a very intense transition).

Sobel operator

Figure 4. Gradient magnitude from Sobel operator [15]

The gradient is approximated by convolution of the image with the following masks [16]:

-1	0	+1
-2	0	+2
-1	0	+1

Dx

+1	+2	+1
0	0	0
-1	-2	-1

Dy

Figure 5. Masks used by Sobel Operator [16]

The masks are designed for maximum response at fronts with vertical and horizontal directions. They can be applied separately to input image, then they are used to calculate the magnitude and direction in each pixel of the front entrance.

Sobel operator require more calculations than Roberts operator, but because convolution mask is larger, it smooths more the image and is therefore less sensitive to noise. It produce amplitude values higher than those produced by Roberts operator, for the same borders. Matrix amplitudes produced by this operator can be visualized as a gray scale image.

Due to the smoothing effect that it has, boundaries often appear as lines whose width has more pixels. Border thinning post-processing is required, such as that of "hysteresis" Canny algorithm.

Prewitt operator

Figure 6. Gradient magnitude from Prewitt operator [26]

It is similar to Sobel detector and is used for detecting vertical and horizontal edges in images. It uses masks [17]:

-1	0	+1
-1	0	+1
-1	0	+1

Dx

+1	+1	+1
0	0	0
-1	-1	-1

Dy

Figure 7. Masks for the Prewitt gradient edge detector [17]

Gaussian based methods

They are symmetrical along the edge, and also reduce noise by smoothing the image. The most important operator is Canny operator.

Canny operator is the most used today, even though it’s not part of the newest detectors being invented in 1986. It was created by John Canny under his dissertation thesis for a Master at MIT. He addressed the issue of detection of edges as an optimization problem of signal processing [18] therefore he implemented a function, then he optimize it for operator designing. The function was designed so that:

- To maximize SNR to provide better detection,
- Develop a good location to mark with precision edges,
- To minimize the number of responses for a single edge. This promotes the true negative, which involves marking points that are not edges.

Based on these criteria, Canny detector performs firstly an image smoothing for noise removal. Then it calculates the gradient image to highlight areas with high intensity variation. Next, the algorithm goes through these areas and remove any pixel that is not a local maximum gradient direction. The gradient matrix is further reduced with hysteresis. Two thresholds are used, T1 < T2. If the amplitude value is below T1, the pixel is removed; if the value is greater than T2, the pixel is retained as pixel border. If the pixel amplitude value is between two thresholds, then the pixel is removed if there is no way from it to a pixel with amplitude gradient greater than T2, otherwise it is noted that pixel border.

The Canny‘s edge detection algorithm checks if its amplitude is larger than that of its neighbors and marks a point as an edge in this case. The problem here is that this algorithm does not check if the differences between this point and its neighbors are higher than what is expected for random noise as we can see in [19]. Thereby this technique induces the algorithm to be slightly more sensitive to weak edges. In the same time it makes it more susceptible to spurious and unstable boundaries every time there is an insignificant change in intensity. We can observe this problem for example on smoothly shaded objects and on blurred boundaries.

Wavelet base methods

If the image is affected by noise, classical operators can not differentiate between a pixel affected by noise and a pixel belonging to an edge and can get rid of edge pixels. To solve this problem, wavelet transform can be used. In fact, every operator can be described as a discrete model of orthogonal functions.

Edge detectors are actually discretized wavelet functions. Convolution with edge detectors provides an image at a correct scale to wavelet transform. Here, the continuous wavelet model is approximated and it will became a classical edge detector at discretization. Once we have continuous model, we can change the scale and detect edges on different levels of scales.

In [20] we can notice how Heric and Zazula have described an edge detection algorithm using Haar wavelet transform and Haar wavelet as the main wavelet function, these being orthogonal, without spatial shifting in the transform space and also compact. They showed the intensity magnitude variation between adjacent intervals on a time-scale plane by applying WT. They proved that the wavelet transform within the edge region was constant and solely dependent on edge slope and scale considering an extended model of step edge formed mathematically by a slope function affected by noise. They also noticed that edges modulus maxima are larger than noise modulus maxima. In the same time they observed that the influence of noise decreases with progressing toward higher scales. This happened because Haar wavelets perform averaging.

Zero crossing

Previous methods of estimating gradients works best when gray scale transitions are abrupt, step-like function. How the transition region becomes broader, it is more advantageous to apply a second-order derivatives.

A very common operator is the Laplacian operator defined as:

$$\nabla^2 f = \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2}$$

Laplacian operator requires fewer calculations, but it is more sensitive to sudden transitions intensity and noise. Also, the threshold size produces sometimes double edges. For these reasons, along with that the direction detects no edge, Laplacian operator is not considered a very good operator for detection of edges.

This operator is used rather in relation to its zero crossings, which led to generate a new edge detector, called Zero Crossing. It has fixed characteristics in all directions and is sensitive to noise, like Laplacian operator.

A zero crossing detection is defined as:

$$h(m,n) \triangleq c[1 - \frac{(m^2+n^2)}{\sigma^2}]\exp\,(-\frac{(m^2+n^2)}{2\sigma^2})$$

Where σ controls the size of the Gaussian kernel and c normalizes elements sum of a given mask. Zero crossings of an image convolution with h (m, n) give the edge locations. h (m, n) is the sampling impulse response of an analog bandpass filter whose frequency response is proportional to:

$$(\xi_1^2 + \xi_2^2)\exp\,[-2\sigma^2(\xi_1^2 + \sigma_2^2)]$$

So zero crossing detector is equivalent to a low pass filter with a Gaussian impulse response type, followed by a Laplacian operator. The parameter controls the output amplitude response of the filter without changing the position of the zero crossing.

Laplacian of Gaussian

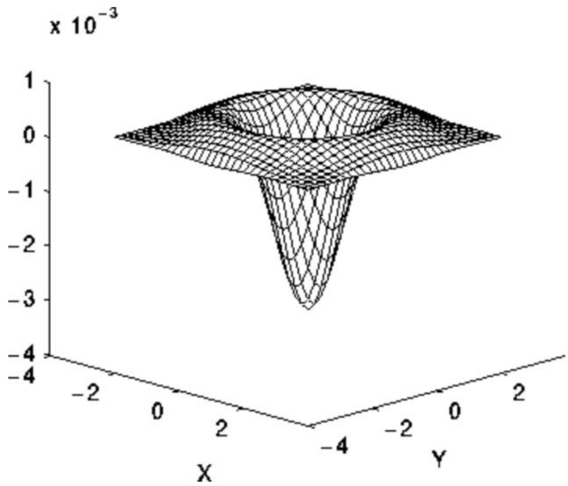

Figure 8. The 2-D Laplacian of Gaussian (LoG) function [21]

This type of detection was invented by Marr and Hildreth in 1980. For an effective edge detection, this method combines Gaussian filtering with Laplace operators and break the image in the places where the intensity varies.

It is about a gradient using Laplacian operator to extract a second order derivative of the image. A difference of intensity in the image appears in the chart of the second order derivative as a pass through zero.

Marr-Hildreth operator began to be widely used for the following reasons:

- The operator is symmetrical. The edges are determined in every direction, as opposed to the operator using the directional derivative of the first order;
- Zero crossings of the second order derivative are easier to determine than are the maximum in the first order derived, because the most important thing are sign changes in signal;
- Zero crossings of closed contours always generates a signal, which is very useful if it is desired to separate objects in the scene.

There are some problems, though with this method:

- Being an operator that uses second order derivative, noise will have a considerable influence
- Sometimes, generation of closed edge it’s not realistic, Marr-Hildreth operator creating contours and in places where they do not exist.

Colored edges methods

Most edge detectors operate on the gray level images. This divides to three the amount of data they work with (one channel instead of three), which also produces loss of detail. By incorporating the color component of the image, the detector should be able to detect edges even in regions with small variations in color intensity.

There are other methods worthy of mention like multi-resolution methods, nonlinear methods, statistical methods, machine learning methods, contextual methods, line edge methods. [22]

There are several types of color detectors. Detectors that use fusion methods, multidimensional gradient methods and vector methods.

Fusion methods do edge detection for each channel, R, G and B, after which it combines the three resulted maps into one. In [23] Alberto Salinas et al. shows this algorithm, using a method of regularization to constrain map to fit the image edges and to have few twists.

Multidimensional gradient methods use three channels at the same time to calculate a single gradient. Starting from directional derivatives for each channel, Di Zenzo shows in [24] formulas for the size and direction of the gradient, which is a tensor with 3 dimensions in color space.

Several methods are used to process pixel from vector point of view. Yang and Tsai [25] used a two-level thresholding method using 8x8 blocks to find the best 3D projection axis with which to convert each block in gray levels.

4. RESULTS AND DISCUSSIONS

In [1] article is presented a set of experiments in edge detection domain using the geometric proprieties of a binary image. Connectivity, projection, area and perimeter are important components in binary image processing.

The proposed algorithm receives a grayscale image input as is showed in Fig. 9 and returns the edge detection image output as is showed in Fig. 10. It consist in a classification of all pixels that satisfy the criterion of homogeneousness, then a detection of all pixels on the borders between different homogeneous areas with some intermediates parts [1].

Figure 9. Original Image with its parts [1]

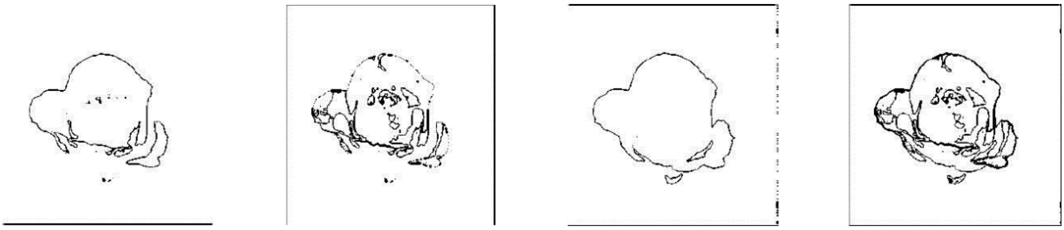

Figure 10. Edge images of original image with its parts and final output image [1]

This algorithm used the characters of Shannon entropy and Rényi entropy, in order to calculate the global and local threshold values [1].

They run the Canny, LOG, and Sobel methods and also the algorithm that was proposed 20 times for each image with different sizes. They noticed that the proposed edge detector works effectively for different gray scale digital images comparing to the run time of LOG, and Sobel methods [1].

They observed that the proposed method in this article works well comparing to the previous methods, LOG and Sobel as shown in Fig. 11 [1].

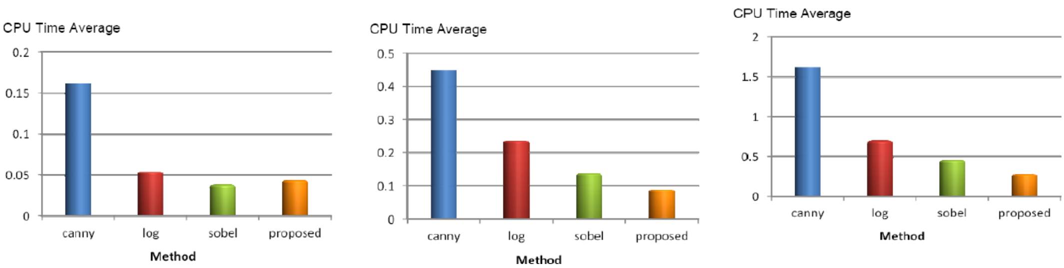

Figure 11. CPU time with 256x256, 512x512, 1024x1024 test images [1]

5. CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

The purpose of this paper is to present different approaches in edge detection domain and also some results. For this we summarized the characteristics of the various operators that have been used over the years on this issue.

For noisy images there aren't large qualitative differences between these operators but for practical applications, where there is used ordinary image, the algorithm currently used is Canny. On the other hand the Canny detector color offers even better results than the version with gray levels using fusion methods of color planes.

In this area there are still many opportunities for research, and for this reason, in the future we plan to design an algorithm to provide a new approach for detecting the edges in order to recognize objects.

The advances in edge detection research may contribute to improvements in research area relies on the edge structure and consistency, like: image calibration and validation of slanted edges [28], line and contour detection [29], image segmentation [30], image deblurring followed by edge augmentation [31], document skew detection and correction [32].

REFERENCES

[1] H. T. Tan, S. B. Gelfand, and E. J. Delp, "A Comparative Cost Function Approach to Edge Detection, IEEE Tran, Systems, Man, and Cybernetics, December, 1989.
[2] P. H. Eichel, D. J. Delp, "Quantitative Analysis of a Moment-Based Edge Operator," IEEE Tran. Systems, Man, and Cybernetics, January/February 1990.
[3] Mohamed A. El-Sayed (2012), Edges Detection Based on Renyi Entropy with Split/Merge, Computer Engineering and Intelligent Systems, Vol 3, No.9
[4] J. Lzaro, J.L. Martn, J. Arias, A. Astarloa, C. Cuadrado (2010), Neuro semantic thresholding using OCR software for high precision OCR applications. Image Vision Comput. 28(4), 571-578.
[5] Z. Xue, D.Ming, W. Song, B. Wan, S. Jin (2010), Infrared gait recognition based on wavelet transform and support vector machine. Patt. Recog., 2904-291.
[6] G.C. Anagnostopoulos (2009), SVM-based target recognition from synthetic aperture radar images using target region outline descriptors. Nonlinear Anal.-Theor. Meth.
[7] Y.-T. Hsiao, C.-L. Chuang, Y.-L.Lu, J.-A. Jiang (2006), Robust multiple objects tracking using image segmentation and trajectory estimation scheme in video frames. Image Vision Comput.
[8] M.T. Doelken, H. Stefan, E. Pauli, A. Stadlbauer, T. Struffert, T. Engelhorn, G. Richter, O. Ganslandt, A. Doerfler, T. Hammen (2008), 1H-MRS profile in MRI positive- versus MRI negative patients with temporal lobe epilepsy. Seizure.
[9] Abdallah A. Alshennawy, and Ayman A. Aly (2009), Edge Detection in Digital Images Using Fuzzy Logic
[10] Technique. World Academy of Science, Engineering and Technology 51.
[11] K. A. Panetta, E. J. Wharton, and S. S.Agaian (2008), "Logarithmic Edge Detection with Applications", Journal of Computers, Vol. 3, No. 9.
[12] http://en.wikipedia.org/wiki/File:Bikesgray.jpg
[13] https://en.wikipedia.org/wiki/Roberts_cross#/media/File:Bikesgray_roberts.JPG
[14] Raman Maini & Dr. Himanshu Aggarwal, "Study and Comparison of Various Image Edge Detection Techniques", Figure 2
[15] https://en.wikipedia.org/wiki/Roberts_cross#/media/File:Bikesgray_sobel.JPG
[16] Raman Maini & Dr. Himanshu Aggarwal, "Study and Comparison of Various Image Edge Detection Techniques", Figure 1
[17] Raman Maini & Dr. Himanshu Aggarwal, "Study and Comparison of Various Image Edge Detection Techniques", Figure 3
[18] E.Nadernejad, S.Sharifzadeh, H.Hassanpour, "Edge detection techniques: Evaluations and comparison", Applied Mathematical Sciences, Vol.2, 2008, nr.31, 1507-1520.
[19] Mitra Basu, Gaussian-Based Edge-Detection Methods—A Survey‖, IEEE Transactions On Systems,
[20] Man, And Cybernetics - Part C: Applications and Reviews, Vol. 32, No. 3, August 2002.
[21] D. Heric, and D. Zazula, "Combined edge detection using wavelet transform and signal registration", Elsevier Journal of Image and Vision Computing 25 (2007)
[22] http://homepages.inf.ed.ac.uk/rbf/HIPR2/log.htm, Figure 2.

[23] Mohammadreza Asghari Oskoei and Huosheng Hu (2009), "A Survey on Edge Detection Methods", Technical Report: CES-506.
[24] R. Alberto Salinas, C. Richardson, M.A. Abidi and R.C. Gonzalez, "Data fusion: Color edge detection and surface".
[25] S. Di Zenzo, "A note on the gradient of a multi-image". CVGIP, 33(1):116–125, January 1986.
[26] C.K.Yang, W.H.Tsai, "Reduction of Color Space Dimensionality by Moment-Preserving Thresholding and its Application for Edge-Detection in Color Images", Pattern Recognition Letters, vol.17
[27] https://en.wikipedia.org/wiki/Roberts_cross#/media/File:Bikesgray_prewitt.JPG
[28] Costin-Anton Boiangiu, Alexandru Victor Stefãnescu, "Target Validation and Image Color Calibration", International Journal of Circuits, Systems and Signal Processing, Vol. 8, 2014, pp. 195-202
[29] Costin-Anton Boiangiu, Bogdan Raducanu. "Line Detection Techniques for Automatic Content Conversion Systems". WSEAS Transactions on Information Science, Applications, Issue 7, Vol. 5, pp. 1200 – 1209, July 2008
[30] Costin-Anton Boiangiu, Radu Ioanitescu, "Voting-Based Image Segmentation", The Proceedings of Journal ISOM Vol. 7 No. 2 / December 2013 (Journal of Information Systems, Operations Management), pp. 211-220
[31] Mihai Zaharescu, Costin-Anton Boiangiu, "An Investigation of Image Deblurring Techniques", International Journal of Mathematical Models and Methods in Applied Sciences, Vol. 8, 2014, pp. 75-83
[32] Mihai Zaharescu, Costin-Anton Boiangiu, Ion Bucur, "A Survey on Document Image Skew Detection", The Proceedings of Journal ISOM, Vol. 9 No. 2 / December 2015 (Journal of Information Systems, Operations Management), pp. 367-383.