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PERFORMANCE ANALYSIS OF CANNY AND OTHER COMMONLY USED EDGE DETECTORS

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Abstract: Edge detection refers to the process of locating edges in any given image. Edge detection is considered as primary image artifacts for the extraction of image features and segmenting objects using low level image processing techniques. This step lays the foundation of computer vision and Image processing which are the most advanced branches of science in modern world. Due to this reason there always has been efforts to improve the techniques of edge detection. The edge detection is an important step to perform target tracking, object recognition, data compression, image reconstruction and segmentation. This paper includes the explanation of canny edge detectors and its comparison and preference over other edge detectors.

Keywords: Edge Detection, Image processing, Canny Edge Detection, Sobel Edge Detection, Robert and Prewitt Edge Detectors.

INTRODUCTION

An edge can be defined as a set of contiguous pixel positions where an abrupt change of intensity value or gray level occur. Edges are sets of connected edge pixels. An image without edges would have a constant color and is therefore a useless image. Edge can be regarded as an uncertainty, the more the thing is uncertain the more it is informative making that thing more useful. We can consider three fundamental step that are to be performed in edge detection.

1-image smoothing for the reduction of noise, so that a lot of extra information is wasted out.

2-detection of the edge points, the points which are potential candidates to become edge points.

3-edge localization, to select those point which are true edges.

Edges in any image can be extracted using the directional derivatives of a digital image. Derivative of digital functions are defined in terms of differences. 1^{st} order derivatives and 2^{nd} order derivatives are used to accomplish this task. 1^{st} order derivative can be defined as:

1-must be zero in the areas having constant intensity.

2-must be non-zero at the onset of a ramp or a step intensity functions.

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3-must be non-zero along ramps and zero along step intensity functions.

$$\partial f/\partial x = f(x + 1) - f(x)$$

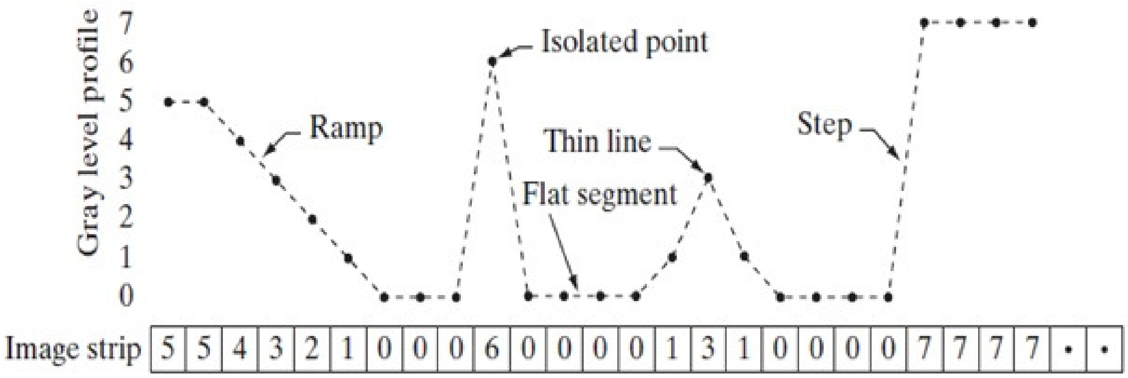
2^{nd} order derivative in similar fashion can be defined as:

1-must be zero in areas having constant intensity.

2-must be non-zero at the onset and at the end of any ramp or step intensity function.

3-must be zero along ramps of constant slope.

$$\partial f^2/\partial x^2 = f(x + 1) + f(x - 1) - 2f(x)$$



DEVELOPMENT OF EDGE DETECTORS

Based on the concept of derivatives different edge detectors were proposed. The Roberts cross-gradient operators (Roberts [1965]) are the earliest ones to use 2-D masks with a diagonal preference. The Roberts operators are based on implementing the diagonal differences. These derivatives can be implemented by using the masks given in fig. masks of 2 X 2 are simple but they are not useful for computing edge direction as masks that are symmetric about the center point, the smallest mask of which are of size 3 X 3. Using this concept of mask size (Prewitt [1970]) introduced masks called Prewitt operators. These masks used a weight of 2 in the center coefficient which provided smoothing of image. Similarly Sobel operators were proposed (Sobel [1970]) which were 3 X 3 masks. The Prewitt masks are easier to implement than the Sobel but Sobel masks have better noise compression (smoothing) making them preferable because noise suppression is an important issue when dealing with derivatives. These masks are used to obtain the gradient components g_x and g_y at every pixel location in an image. These partial derivatives are then used to estimate edge strength and direction.

$$M(x,y) \approx |g_x| + |g_y|$$

$$\alpha(x,y) = \tan^{-1}[g_y / g_x]$$

−1	0	0	−1
0	1	1	0

Roberts

−1	−1	−1	−1	0	1
0	0	0	−1	0	1
1	1	1	−1	0	1

Prewitt

−1	−2	−1	−1	0	1
0	0	0	−2	0	2
1	2	1	−1	0	1

Sobel

Fig.1 Original, Gradient and Angle Images
Fig.2 Roberts, Sobel and Prewitt 3X3 masks

ADVANCED TECHNIQUES FOR EDGE DETECTION

The discussed methods are the attempts for edge detection based on filtering masks with no provisions made previously for edge characteristics and noise content. After these, one of the advanced, sophisticated and modern techniques is Marr-Hildreth edge detector (Marr-Hildreth [1980]). Marr-Hildreth argued that:

1-intensity changes are not independent of image scale and so their detection requires the use of operators of different sizes.

2-a sudden intensity change will give rise to a peak in the 1^{st} derivative or, equivalently to a zero crossing in the 2^{nd} derivative.

Marr-Hildreth proposed that the most satisfactory operator fulfilling these conditions is the filter $\nabla^2 G$, where ∇^2 is the Laplacian operator ($\partial^2/\partial x^2 + \partial^2/\partial y^2$) and G is the 2D Gaussian function.

$$G(x,y) = \exp -(x^2+y^2)/2\sigma^2$$

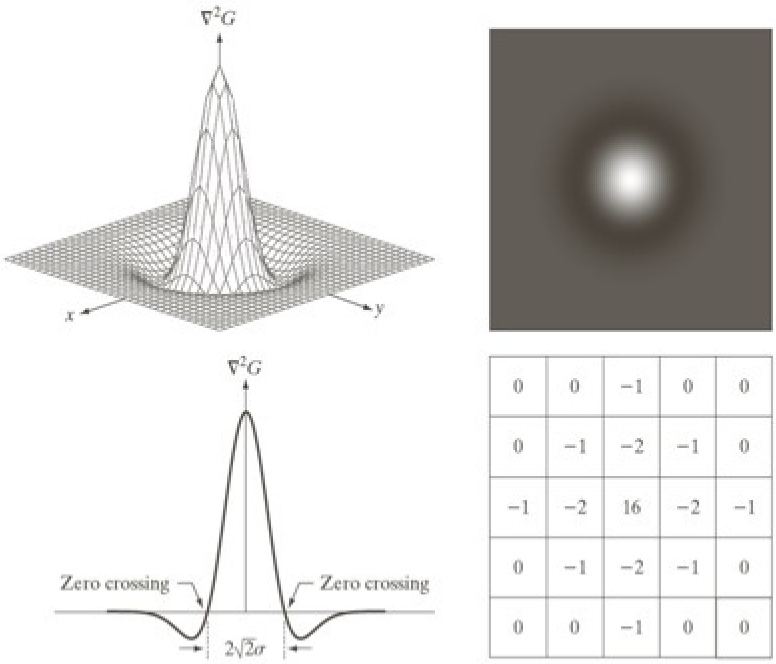
$$\nabla^2 G(x,y) = \partial^2 G(x,y) / \partial x^2 + \partial^2 G(x,y)/y^2$$

$$\nabla^2 G(x,y) = [(x^2+y^2-2\sigma^2)/ \sigma^4]. \exp [-(x^2+y^2)/2\sigma^2]$$

This is called Laplacian of Gaussian (LoG) sometimes also referred to as Mexican hat operator. The Mar-Hildreth algorithm consists of convolving the LoG filter with the input image, f(x,y) and then finding the zero crossings of g(x,y). The size of a LoG filter should be n X n, where n is the odd integer greater than or equal to 6σ.

Marr and Hildreth also stated that it is possible to approximate the LoG filter by a difference of Gaussians (DoG).

$$DoG(x,y) = 1/2\pi\sigma_1^2.\exp[-(x^2+y^2)/2\sigma_1^2] - 1/2\pi\sigma_2^2.\exp[-(x^2+y^2)/2\sigma_2^2]$$



0	0	−1	0	0
0	−1	−2	−1	0
−1	−2	16	−2	−1
0	−1	−2	−1	0
0	0	−1	0	0

Fig. (a) 3D plot of negative of LoG (b) LoG displayed as an image (c) Cross section of (a) (d) 5 X 5 approximated LoG mask

CANNY EDGE DETECTOR

One of the most advanced techniques for edge detection is Canny Edge Detector (Canny [1986]). The algorithm of canny is more complex than all of the discussed methods but gives superior results. It was the first time after Canny when the idea of True Positives, True Negatives, False Positives and False Negatives was really implemented. This method proposed by Canny has 3 basic objectives:

Low Error Rate: All the true edges should be found and there should be no spurious responses i.e. the edges detected should be as close as possible true edges.

Edge Points Should Be Well localized: The distance between pointed and marked edges should be minimum.

Single Edge Point Response: A single edge be detected instead of 2 edges separated by dark intensity pixels as they were in case when simple double derivative was applied on any image. This task can be accomplished by first smoothing the input image with a circular 2D Gaussian function, computing the gradient of the results and then using the gradient magnitude and direction to estimate the edge strengths and directions at every point. For this input image f(x,y) is convolved with the Gaussian function giving smoothed image $f_s(x,y)$.

$$f_s(x,y) = G(x,y) * f(x,y)$$

$$M(x,y) = (g_x + g_y)^{1/2}$$

$$\alpha(x,y) = \tan^{-1}[g_x / g_y]$$

M(x,y) and α(x,y) are the magnitude and directional images having sizes equal to the input image. Now M(x,y) contain wide ridges around local maxima and next step is to thin those ridges which can be done by using the approach of non-maxima suppression. The essence approach now is to specify a number of discrete orientations of the edge normal (gradient vector).

Let d_1, d_2, d_3 and d_4 be the four basic directions for a 3 X 3 region; horizontal, -45°, vertical and $+45^\circ$ respectively. Now finding the direction d_k which is closest to α(x,y) and if the values of M(x,y) is less than at least one of its two neighbors along d_k then $g_N(x,y) = 0$ (suppression) otherwise, let $g_N(x,y) = M(x,y)$ where $g_N(x,y)$ is the non-maxima suppressed image.

The final task is to threshold $g_N(x,y)$ to reduce false edge points. Now if we set the threshold too low, there will still be some false edges disturbing the results (false positives) and if the threshold is kept too high then actual edge points will be eliminated (false negative). To cope this Canny's Algorithm gives a solution called hysteresis thresholding consisting of a low threshold T_L and a high threshold T_H. Canny also suggested that the ratio of the high to low threshold should be three to one.

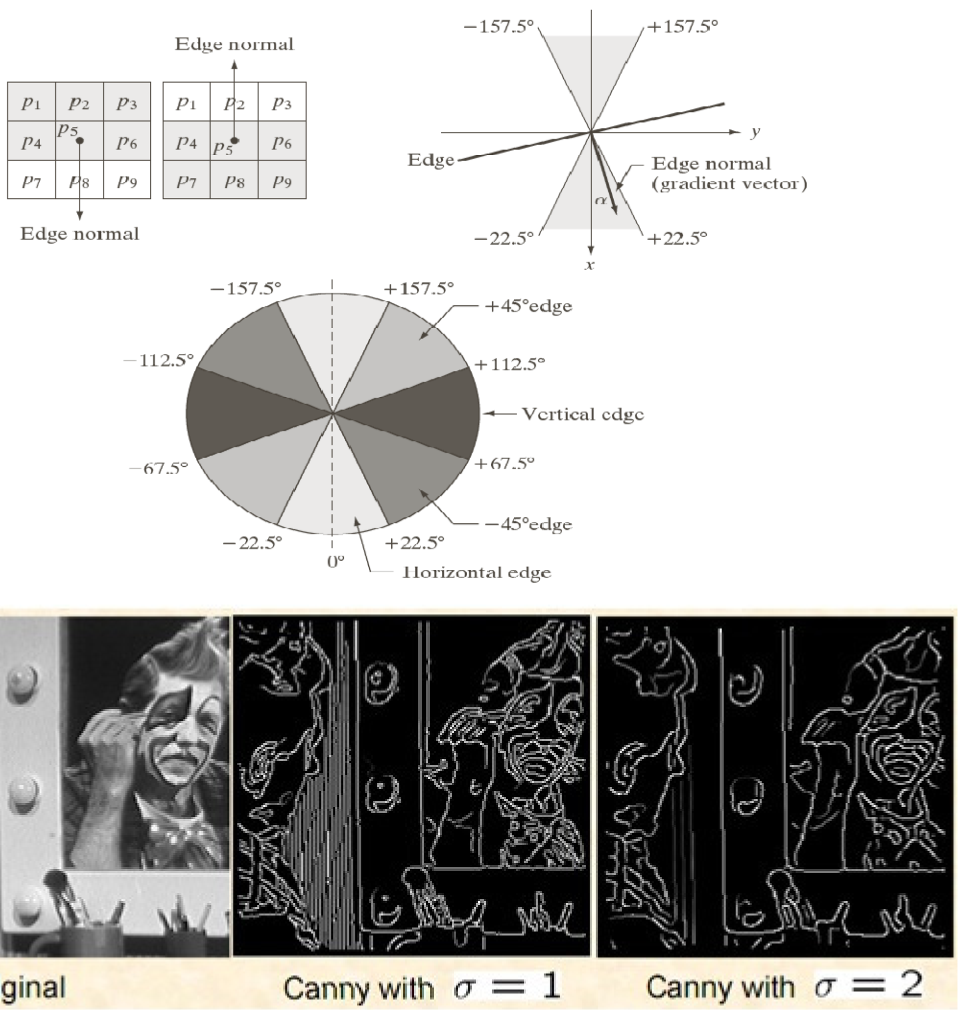
$$g_{NH}(x,y) = g_N(x,y) \geq T_H$$

$$g_{NL}(x,y) = g_N(x,y) \geq T_L$$

Initially both $g_{NH}(x,y)$ and $g_{NL}(x,y)$ are set to zero. After thresholding $g_{NH}(x,y)$ will have fewer non-zero pixels than $g_{NL}(x,y)$ but all the non-zero pixels in $g_{NH}(x,y)$ will be contained in $g_{NL}(x,y)$ because the later image is formed with a lower threshold.

$$g_{NL}(x,y) = g_{NL}(x,y) - g_{NH}(x,y)$$

The nonzero pixels in $g_{NH}(x,y)$ and $g_{NL}(x,y)$ can be viewed as being strong and weak edge pixels, respectively. At the end of the procedure, the final image output by the Canny Algorithm is formed by appending to $g_{NH}(x,y)$ all the non-zero pixels from $g_{NL}(x,y)$. The price paid for improved performance of Canny Edge detection is in form of extreme complexity and a long execution time of Algorithm.



(a) Two possible orientations of a horizontal edge (b) Range of values of α for a horizontal edge(c) Angle ranges of Edge normal for four types of edges in 3 X 3 mask.(d) Original image and applied Canny Algorithm by differing smoothing factor.

Fig. (a) Original Image 834 X 1114 (b) Threshold Gradient of smoothen image (c) Applying Mar-Hildreth Algorithm (d) Applying Canny Algorithm

The Canny Edge Detection can be summarized as follows:

1- Smooth the input image with a Gaussian filter. The filter size can be estimated by using the process as discussed in the Mar-Hildreth detection process.

2- Compute the Gradient magnitude and angle images.

3- Apply non-maxima suppression to the gradient magnitude image.

4- At the end use hysteresis thresholding and apply connectivity analysis to detect and link the edges.

(a) Orignal image ***(b) Canny edge Detection***

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