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# ROBUST EDGE DETECTION BASED ON CANNY ALGORITHM FOR NOISY IMAGES

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#### ABSTRACT

The aim of many edge detection techniques is to highlight edges in an image. However, due to nature of the edge detection that is based on the derivative operation, this process often amplifies noises too. Therefore, there is always a trade-off in the edge detection technique between extracting information and suppressing noise. There is variety of edge detectors or operators with different sizes of kernel. This paper proposes an edge detection technique based on traditional Canny edge detector. Unlike many established edge detection techniques that focus on the gradient in grayscale image, the proposed technique includes two more features: the length and the directional change of the edges. The inclusion of the two features helps to increase the robustness of the proposed technique towards noise. The proposed technique is tested with synthetic and natural images. Results are compared with other established edge detection techniques and demonstrate that the proposed technique is able to detect low contrast edges and highly resistance to different types of noise. As a result, the trade-off between the information and noise in image edge detection is reduced.

Keywords: Canny Edge Detection; Edge Gradient; Edge Length; Directional Change; Noise Suppression.

#### 1. INTRODUCTION

Edge detection is one of the most fundamental features in image processing. An ideal edge detector needs to be able to detect edges in various conditions and at the same able to reduce noises and provide good edge localization. This is a challenging task because there is always a trade-off between keeping the information and reducing the noise simultaneously. The performance of the edge detector can be assessed by its edge localization and noise reduction capability. In standard edge detectors like Robert, Sobel, and Prewitt, to achieve high accuracy of edge localization, the size of the kernel needs to be small. However, with the reduction of the kernel size, the edge detectors are very sensitive to noises [1][2][3[4]. Using larger kernel can helps edge detector to increase its resistance to noises, like Rotating Kernel Transformation (RKT) [5] that uses kernels with sizes from  $5 \times 5$  pixels to  $9 \times 9$  pixels, but low contrast edges and short edges may be omitted. In addition, edge detector with large kernel requires high computational cost.

Apart from relying on the kernel size, Canny edge detector (CED) [6] uses additional approaches in order to improve the edge localization as well as able to detect edges that are low contrast and short. There are many improved edge detection techniques that are based on Canny operator such as Estimated Ground Truth (EGT) [7] which uses multiple scale Canny to strengthen true edges and eliminating false edges. EGT is more robust to noises compare to the conventional Canny but it is slow and impractical [8]. Scale Multiplication of Canny (SMC) [9] also uses multiple scale in order to be high resistant to noises. The number of scales and their values in the SMC determine the accuracy and speed of this edge detector.

Edge detection with nonlinear operator such as Nonlinear Filtering Scheme (NLFS) [10][11] is suitable to remove impulsive type noise like salt & pepper noise. However, this technique suffers from slight dislocation of the edges as it tends to be bias to light area and may create non continuous edges.

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Using different type of filters or transformations like morphological analysis [12][13][14][15], multiple radon or beamlet transform [16][17][18], and Hilbert transform [19][20][21] are not suitable to handle noise. This is because over using these filters and transformations or by using large scales might reduce edge localization, which might reduce their ability to detect short edges and create non continuous edges.

Other works focused on thresholding techniques to handle noise like adaptive filter [22], type-2 fuzzy filter and OTSU adaptive thresholding [23][24]. Using different types of thresholding techniques is not suitable to deal with some types of noise like speckle and salt & pepper noises. This is because selecting only the right threshold does remove the high contrast noisy edges created from speckle and salt & pepper noises.

Incorporating more features for edge detection like colour and depth features [25][26][27][28][29] leads to better edge detection. However, these features are not always available and might be difficult to be obtained. Finally, edge detection algorithms using machine learning [28][30][31] is just making the problem more complicated and not practical. Besides, the results are not guaranteed as these types of edge detection depend heavily on the training samples.

In general all the above mentioned algorithms suffer when dealing with noise as the trade-off between information and noise is large. From the literature, the old edge detection methods do not have strong resistance toward noise, using certain method or filter may work with one type of noise but may not work with other noises. It may add distortion to the non noisy images in term of localization, creating non continuous edges and ignoring low contrast edges.

This paper proposes an edge detection technique based on Canny algorithm to detect edges by combining three features of the edges; gradient, length and directional change of the edges. The aim of this algorithm is to increase the robustness of edge detection technique in noisy images. This algorithm is required when the user has no prior knowledge about the type and amount of noise or if the image contains different types of noises in different parts of it. The key idea of this technique is that true edges tend to be longer and straighter. By incorporating more features to measure the length and the directional change of the edges, this technique guarantees to remove noisy edges. The paper is organized as follow; the proposed algorithm that is based on traditional Canny edge detection is presented in section 2. Results are presented in section 3. Finally, this paper ends with a conclusion in section 4.

## 2. METHODOLOGY

Handling different types of noise using the old methods mostly leads to a large trade-off between noise and information. This limitation motivated us to design a new edge detection algorithm toward reducing the trade-off between noise and information which satisfies the criteria of good edge detection. The criteria of good edge detection is good at detecting edges including low contrast edges, good at localization and highly resistant to noise [6][32].

Canny edge detection (CED) is a popular edge detection algorithm for many applications because of its simplicity, good edge localization and noise reduction [6] [32]. Suppose that an image I is smoothed with horizontal,  $G_x$  and vertical,  $G_y$  Gaussian filters.

$$S = I * G_x * G_y \tag{1}$$

where  $G_x$  and  $G_y$  are Gaussian filters. The image is convolved horizontally and vertically as given in Equation 2 and 3.

$$S_x = S * dG_x \tag{2}$$

$$S_v = S * dG_v \tag{3}$$

where  $dG_x$  and  $dG_y$  are the derivative of Gaussian. The magnitude of the gradient, M is given in Equation 4. Non-maxima suppression is applied to the local maxima image,  $I_M$  to remove edges that are not at the local maxima and then hysteresis thresholding is applied to detect only the true edges.

$$M = \sqrt{S_x^2 + S_y^2} \tag{4}$$

In the conventional Canny technique, only the edge gradient is considered. In addition to that, the proposed technique also considers the length and directional change of the edge. The measurement of the length of the edge is illustrated in Figure 1. The length of the edge in the local maxima image  $I_M$  is measured from the starting pixel of the edge to the ending pixel and compared the length with a predetermined line segment. The length of the edge is measured from the starting pixel to the ending pixel of the edge and in all possible directions, such as horizontal, vertical, and

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diagonal. The measurement of the edge length also considers edge with branches. A line segment with a length of 29 pixels,  $l_{max}$  is used to track the edges. If edge is shorter than the line segment, the length of the edge, l is measured form the starting pixel to the ending pixel of the edge as shown in Figure 1a. If the edge is longer, the line segment scans, like a moving window, the entire length of the edge. In order to ensure the smoothness of the edge measurement, the line segment moves halfway of its size as shown in Figure 1b. If the edge has branches, the edge is divided into three or more edges from the branch points and each edge branch is treated as new edge and its length is measured in a similar fashion either the edge is shorter or longer

a similar fashion either the edge is shorter or longer than the line segment,  $l_{max}$ . This procedure is performed on all edges in the image to generate a length image,  $I_L$ .



Figure 1: Edge segmentation. (a) Short edge, (b) long edge and (c) edge with branches (d) legends.

In order to measure the directional change, each edge segment is divided into four subsegments with equal length. Each sub-segment has a direction,  $\theta$  ranging from  $0 \le \theta < 2\pi$ . The directional change between two sub-segments  $\Delta \theta_k$ is calculated using Equation 5, where k = (1, 2, 3)and  $0 \le \Delta \theta_k < \pi$ . As a result, each segment has three directional changes  $\Delta \theta_k$ . If the edge segment has branches, additional directional change,  $\Delta \theta_b = \pi$  is included, otherwise  $\Delta \theta_b = 0$ . Finally, directional change of the segment, *d* is calculated using Equation 6, where  $0 \le d \le 1$ . The higher value of *d*, the straighter the edge. This procedure is performed on all edges in the image to generate a directional change image  $I_D$ .

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$$\Delta \theta_{k} = \min\left(\left|\theta_{d}\right|, \left|\theta_{d} - 2\pi\right|, \left|\theta_{d} + 2\pi\right|\right)$$
(5)

where  $\theta_d = \theta_k - \theta_{k+1}$ 

$$d = \frac{3}{4} \left( 1 - \sum_{k=1}^{3} \frac{\Delta \theta_k}{3\pi} \right) + \frac{1}{4} \left( 1 - \frac{\Delta \theta_b}{\pi} \right) \tag{6}$$

All the three edge features: gradient, m; length, l; and directional change, d are scaled using a non-linear sigmoid function as given in Equation 7 and shown in Figure 2. The sigmoid function provides soft tolerance to the features at the thresholding point instead of using a hard on/off step function. Here, the features, m, l and d are represented by variable x in Equation 7.

$$h(x) = \frac{1}{1 + e^{-w(2x-1)}} \tag{7}$$



The variable *w* in Equation 7 is set to 4 in order to get three equal parts (off, transferring, and on) from the second order derivative of the sigmoid function as shown in Figure 3. The variable *x* in Equation 7 is rescaled using non-linear scaling  $x^p$ . If  $x \le 0.5$ , then

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$$p = \frac{\ln(0.5)}{\ln(t)} \tag{8}$$

and

$$H_{x \le 0.5}(x,t) = \frac{1}{1 + e^{-w(2x^{P} - 1)}}$$
(9)

where *t* is the threshold of the function.

If x > 0.5, then

$$p = \frac{\ln\left(0.5\right)}{\ln\left(1-t\right)} \tag{10}$$

and

$$H_{x>0.5}(x,t) = \frac{1}{1+e^{-w\left(2\left(1-(1-x)^{p}\right)-1\right)}}$$
(11)



Figure 3: Second order derivative of the sigmoid function.

The ranges of the threshold values, *t* on the sigmoid function is shown in Figure 4.



Figure 4: Ranges of threshold, t from 0.1 to 0.9.

Equation 9 and 11 are the basis for the generation of three functions: function  $H_M(I_M, t_M)$  is used to detect edges from the local maxima image,  $I_M$ , while functions  $H_L(I_L, t_L)$  and  $H_D(I_D, t_D)$ 

are used to remove noises in the length image,  $I_L$ and directional change image,  $I_D$ , respectively.  $t_M$ ,  $t_L$ , and  $t_D$  are the thresholds of the gradient, length, directional change, respectively. The threshold parameters of the proposed algorithm are determined using a procedure similar to CED in determining the threshold. The gradient threshold  $t_M$  is determined based on the high threshold value in the hysteresis step in Canny [6]. The value of thresholds  $t_L$  and  $t_D$  are determined from the histograms of the images  $I_L$  and  $I_D$ , respectively.



Figure 5: Example of edge detection of the proposed algorithm. (a) 'Cameraman' image with Gaussian noise. (b) Vertical derivative component. (c) Horizontal derivative component. (d) Magnitude/gradient. (e) Local maxima. (f) Edge gradient feature. (g) Edge length feature. (h) Edge directional change feature. (i) Edge image.

Finally, all the three functions,  $H_M$ ,  $H_L$ , and  $H_D$ , are combined to generate an edge image,  $I_E$  as given in Equation 12. The emphasis of each function can be controlled by multiplying them with weights. The weight of the  $H_M$  function,  $k_M$  is set to 50%, while the weights for the  $H_L$  and  $H_D$  functions,  $k_L$  and  $k_D$ , are set to 25% each.  $t_E$  is the threshold for the edge image,  $I_E$  that determines whether the pixel is edge or background. The minimum condition for the edge to pass the three sigmoid functions  $H_M$ ,  $H_L$  and  $H_D$  required that  $H_M$  = 1, which is at the maximum of the "on" part of the second derivative of the functions,  $H_L \ge 0.2$  and  $H_D \ge 0.2$ , which are greater than the minimum of

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the transferring part. Based on these conditions and the weights of the functions, the minimum passing condition was set to  $t_E = 0.6$ . Figure 5 illustrates stages of the proposed edge detection applied on a 'Cameraman' image degraded with Gaussian noise.

$$I_{E} = \begin{cases} 1, & (k_{M}H_{M} + k_{L}H_{L} + k_{D}H_{D}) > t_{E} \\ 0, & (k_{M}H_{M} + k_{L}H_{L} + k_{D}H_{D}) \le t_{E} \end{cases}$$
(12)

### 3. RESULTS

Images that are used in the analyses include synthetic and natural images. These images contain varying degrees of contrast, length, and shape of the edges. For each image, three types of noise: Gaussian, speckle and salt & pepper are added. Results of several edge detectors like CED, EGT, SMC, NLFS, RKT, and the proposed algorithm are compared. These algorithms are selected for the comparison based on the literature. Each algorithm has a different method to handle noise which can help in the comparison of this study. For example: CED reduces noise using Gaussian filter, removing non maxima edge then applying hysteresis thresholding. EGT handles noise using pseudo image generated from Canny then applying receiver operating characteristics thresholding. SMC applies multiple scales of Canny to hand noise as noise does not likely to appear in all scales. NLFS is non-linear edge detection which is robust to impulse noise and RKT is an example of using a large kernel.

Quantitative assessment is done using precision, recall, accuracy, and F1 value, which all of them are based on true positive (TP), true negative (TN), false positive (FP), and false negative (FN) as in Equations 13-16.

$$Precision = \frac{TP}{TP+FP}$$
(13)

$$Recall = \frac{TP}{TP+FN}$$
(14)

Accuracy = 
$$\frac{TP+TN}{TP+TN+FP+FN}$$
 (15)

$$F1=2\frac{Precision \times Recall}{Precision + Recall}$$
(16)

For the 'Letters' image in Figure 6, the first row shows the image without noise and results of several edge detection techniques, and the second rows shows the image degraded with Gaussian noise and the edge detection results. Third row shows the image degraded with speckle noise and the results, while the forth row shows the image degraded with salt & pepper noise. The purpose of the analysis on the image without noise is to evaluate the performance of the edge detectors to detect edges in low contrast situations, like letters 'B' and 'E', and also the boundary of boxes of letters 'L', 'O', and 'P'. Only the proposed edge detection technique is able to detect all the edges including letters 'B' and 'E' as well as boxes of letters 'L', 'O', and 'P'. Analysis on the noisy images demonstrated that the proposed technique is able to suppress the noise as well as detect the edges. Figure 7 shows results on the 'Circles' image without noise (first row) and with Gaussian noise (second row), speckle noise (third row), and salt & pepper noise (fourth row). Here, the proposed edge detection technique demonstrated its superiority in detection low contrast edges like the outermost circle and less sensitive to noise. The average F1 value, accuracy, precision and recall measured from the two synthetic images are presented in Tables 1-4. Figure 8 shows F1 values measured for ranges of standard deviation for the Gaussian, speckle, salt & pepper noises. In general the proposed technique produced the best results.

Besides the synthetic images, two natural images are used. Figure 9 shows the 'Cameraman' image and Figure 10 shows the 'House' image. These images contain long, short, straight, curvy, irregular edges. The performance of edge detection algorithms is evaluated under different conditions, such as, without noise, with Gaussian, speckle, and salt & pepper noises. Results of edge detection techniques on the natural image are difficult to assess quantitatively because derivation of a ground truth image is difficult and subjective to users. Therefore, analysis on the natural image is only performed qualitatively. The proposed edge detection technique produced better results when compare to the other five techniques as it is able to detect low contrast edges, ignore unwanted edges and high resistance to noises. For example, in the 'Cameraman' image, edges at the pocket, hand, and building are well detected and ignoring unwanted texture pattern on the ground. The proposed edge detection algorithm also demonstrated high resistance when noises are included.

The difference in the results between the proposed algorithm and other tested algorithms is obvious. For example, the proposed algorithm is able to detect more true edges than other algorithms when there is no noise. On the other hand, it tends to remove most of the noisy and false edges when noise is applied. This suggests that it has low trade-

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off between noise and information compare with others. The source of improvement is by making the algorithm focus on longer and straighter edges as noise less likely to create long and straight edges.

The novelty in this work is how to handle noise in an image. This is done by tracking the edges and considering three edge features then use these features to differentiate between true and false edges. This approach only removes noisy edges and does not affect the non noisy edge. In addition it allows low contrast non noisy edges to be detected.

The advantages of the proposed algorithm are very good at detecting low contrast edges in non noisy images at the same time very resistant to noise. This means low trade-off between noise and information. It is also good at localization following CED method. Limitation of this work might be the speed where in experiments it is found that the proposed algorithm is slower three times than traditional CED due to tracking of the edges. However this time is used to find new features that can be used for further image processing and analysis.

# 4. CONCLUSIONS

In this paper, a new edge detection technique based on Canny edge technique is proposed by combining three edge features: gradient, length, and directional change. The technique is tested with synthetic and natural images by considering images without noise and different types of noise. From the results and comparisons with other algorithms, the proposed technique is able to detect low contrast edges, ignore unwanted edges and remove noise. The results also demonstrate that the proposed technique is more robust to noises as compare to other established edge detection techniques. The key success of this technique is by incorporating length and directional changes edge features to the Canny edge detector.

In this work, it is clear that incorporating more edge features like length and directional changes besides the gradient helped in detecting true edges and ignoring noise. The proposed algorithm satisfies the criteria of good edge detection which is good at detection, good at localization and highly resistant to noise. This means it has low trade-off between noise and information compare with other methods in the light of literature. Future work will consider incorporating more edge features and demonstrate it advantages in different environments and applications.

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Figure 6: Results of edge detection techniques on 'Letters' image. Original (first row). Degraded with Gaussian noise (second row), speckle noise (third row), salt & pepper noise (fourth row).



Figure 7: Results of edge detection techniques on 'Circles' image. Original (first row). Degraded with Gaussian noise (second row), speckle noise (third row), salt & pepper noise (fourth row).

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Table 1 Ave	erage F1	value of th	e synthetic	images.	Table 2 Av <u>erage</u> acc	Average accuracy of the			
No noise		Gaussian	Speckle	Salt & Pepper	No noise	Gaussian			

	noise		1	Pepper
Canny	0.9833	0.5394	0.6271	0.5914
EGT	0.9009	0.5988	0.6438	0.6492
SMC	0.9101	0.6801	0.7208	0.6479
NLFS	0.9515	0.7146	0.7825	0.6966
RKT	0.9121	0.6865	0.6603	0.6077
Proposed	0.9970	0.7328	0.8788	0.6865

Table 2 Average accuracy of the synthetic images.									
	No noise	Gaussian	Speckle	Salt & Pepper					
Canny	0.9974	0.7632	0.8995	0.8806					
EGT	0.9864	0.7704	0.9167	0.8872					
SMC	0.9886	0.9023	0.9524	0.9081					
NLFS	0.9928	0.9345	0.9605	0.9335					
RKT	0.9880	0.9248	0.9441	0.9128					
Proposed	0.9995	0.9594	0.9809	0.9498					

### Table 3 Average precision of the synthetic images.

	No noise	Gaussian	Speckle	Salt & Pepper
Canny	1.0000	0.3900	0.4849	0.4608
EGT	1.0000	0.4610	0.5308	0.5315
SMC	0.9978	0.6071	0.7146	0.5654
NLFS	1.0000	0.6482	0.7348	0.6161
RKT	0.9961	0.6778	0.6455	0.5444
Proposed	1.0000	0.7456	0.8728	0.6804

Table 4 Average recall o	of the synthetic images.
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	No noise	Gaussian	Speckle	Salt & Pepper
Canny	0.9677	0.9252	0.8933	0.8376
EGT	0.8196	0.9322	0.8204	0.8709
SMC	0.8377	0.8340	0.7369	0.7931
NLFS	0.9076	0.8233	0.8399	0.8171
RKT	0.8415	0.7424	0.6805	0.7058
Proposed	0.9940	0.7220	0.8980	0.6976



Figure 8 Average F1 value for two synthetic images where sigmas,  $\sigma$  of the (a) Gaussian, (b) speckle, and (c) salt & pepper noises were varied.

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Figure 9: Results of edge detection techniques on 'Cameraman' image. Original (first row). Degraded with Gaussian noise (second row), speckle noise (third row), salt & pepper noise (fourth row).



Figure 10: Results of edge detection techniques on 'House' image. Original (first row). Degraded with Gaussian noise (second row), speckle noise (third row), salt & pepper noise (fourth row).