

# Performance Analysis of Corner Detection Algorithms Based on Edge Detectors

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## ABSTRACT

Detecting corner locations in images plays a significant role in several computer vision applications. Among the different approaches to corner detection, contour-based techniques are specifically interesting as they rely on edges detected from an image, and for such corner detectors, edge detection is the first step. Almost all the contour-based corner detectors proposed in the last few years use the Canny edge detector. There is no comparative study that explores the effect of using different edge detection method on the performance of these corner detectors. This paper fills that gap by carrying out a performance analysis of different contour-based corner detectors when using different edge detectors. We studied four recently developed corner detectors, which are considered as current state of the art and found that the Canny edge detector should not be taken as a default choice and in fact the choice of edge detector can have a profound effect on the corner detection performance. We examined commonly used predefined threshold-based Canny detector with the adaptive Canny detector and found that adaptive Canny detector gives better results to work with.

## Keywords

corners, edge detector, Canny, adaptive Canny

## 1 INTRODUCTION

Corners play an important role in different computer vision applications such as image matching and pattern recognition. Among different types of corner detectors, contour-based corner detectors are more stable and less sensitive to noise [Fmo01, Xia04, Moh07, Xia07, RMN11b]. The primary step of these detectors [Moh08, RMN11a, Moh09, Fmo01, Moh07, Zha10] is to extract the edges that are relevant for corner detection. A few applications like medical imaging requires perfect edge identification which is time-consuming, while different applications like mobile robot vision requires real time vision calculations and do not rely on impeccable edge recognition.

For contour-based corner detection, researchers have been using the Canny edge detector since its popular-

isation by [Moh08] and this trend has continued without question in [Moh08, RMN11a, Moh09, Fmo01] and others. As a part of our work, we analyse the role of edge detection method on the current state of the art chord-based corner detectors and what role, if any, different edge detectors can play in this process.

We considered the performances of very popular chord-to-point distance accumulation (CPDA) corner detector [Moh08], Chord to Triangular Arms Ratio (CTAR) [RMN11a], Difference of Gaussian (DoG) [Xia09] and Curve to Chord Ratio (CCR) [Ten15]. The DoG detector is not a chord-based detector, but it is presented to compare against a popular non-chord-based corner detector. Previous studies like [Ten15] have performed a comparative study on multiple edge detection techniques i.e. Canny [Can86], Sobel, Roberts, Prewitt [Pre70], LoG [Kam98] and Zerocross [Av113] from an edge-quality perspective. In this paper we compare these techniques in the context of corner detection, more specifically, we tried to investigate its role on corner detection techniques based on some questions for the diverse nature of the different techniques:

1. Does Canny edge detector give best result in all conditions?

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2. If not, then which edge detector performs better for detecting corners under which situations?
3. Which edge detector results in the maximum number of repeatably found corners?
4. Which edge detector 'works best' for which transformation?
5. Which edge detector is fast for which corner detector?
6. Which detector finds and extracts the edges quickly?

We observe that most of the contour-based corner detectors use Canny edge detector with threshold 0.2 and 0.7, which is not suitable to find corners in natural images. Thus, instead of following the trend, we examined the performance using the adaptive Canny edge detector and found that it gives excellent results for extracting edges, which results in detecting more corners.

This paper is organised as follows. Section 2 discusses about some classic edge detection techniques. Section 3 explains the importance of edge detection methods for detecting corners, while section 4 discusses about some current state of the art corner detectors. The performance analysis is presented in section 6. Finally, section 7 concludes the paper.

## 2 EDGE DETECTION

Generally, Edges refer to the sharp change in image brightness. So, if there is a high difference between two neighbouring pixels, a possible edge is detected. The edge detector determines the transition between these two regions based on grey level discontinuity. Edge detectors can be classified into two classes: First, the classical operators such as Roberts, Prewitt and Sobel operators and then Gaussian operators like Canny. Gaussian operator is used to blur images and remove noise. Both classes of edge detectors apply some simple convolution masks on the entire image in order to compute the first order (Gradient) and/or second order derivatives (Laplacian).

In the following sections we will present a few popular edge operators.

### 2.1 Sobel Operator

The Sobel operator is a pair of  $3 \times 3$  convolution kernels as shown in Figure 1. These kernels are orthogonal to each other and is perfect for the edges that existed vertically and horizontally. This two masks are convolved with the image to calculate the gradient magnitude and gradient orientation.

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

Figure 1: Masks used by Sobel Operator.

### 2.2 Robert Cross operator

The Roberts Cross operator consists of a pair of  $2 \times 2$  convolution kernels as shown in Figure 2. These kernels respond to edges that existed at  $45^\circ$  to the pixel grid. One kernel is used for each of the two perpendicular orientations.

-1	0	0	-1
0	1	1	0

Figure 2: Masks used for Robert Operator.

### 2.3 Prewitt operator

Similar to Sobel Operator, Prewitt Operator also uses two  $3 \times 3$  matrix which are convolved with the original image to find vertical and horizontal edges [Pre70]. This operator calculates the gradient of the image intensity at each point and gradient orientation shows how abruptly the image changes at that point.

-1	-1	-1	-1	0	1
0	0	0	-1	0	1
1	1	1	-1	0	1

Figure 3: Masks used for Prewitt Operator.

### 2.4 Laplacian of Gaussian (LoG) operator

The Laplacian of Gaussian operator calculates the second derivative of an image and does not require the edge direction [Kam98]. Commonly used kernels for LoG operator is shown in Figure 4.

### 2.5 Canny Operator

The Canny edge detector is one of the most popular methods to find edges by separating noise from input image. [Can86]. The steps of the Canny edge detection algorithm are filtering, hysteresis thresholding,

0	1	0	1	1	1
1	-4	1	1	-8	1
0	1	0	1	1	1

Figure 4: Masks used for LoG

edge tracking and non-maximal suppression. It uses Gaussian filter  $G_\sigma$  to smooth the image in order to remove the noise.

$$g(m,n) = G_\sigma(m,n) * f(m,n) \quad (1)$$

$$\text{where } G_\sigma = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{m^2+n^2}{2\sigma^2}\right)$$

We have used Canny operator along with Canny using predefined high and low threshold, 0.7 and 0.2 respectively. We referred Canny with this predefined threshold as Canny\_threshold in our experiment. Most of the corner detectors in the literature are using Canny\_threshold edge detectors [Moh08, RMN11a, Moh09, Fmo01, Moh07, Zha10].

## 2.6 Zero cross

The Zerocross Operator finds the location where the Laplacian value goes through zero. The main disadvantage is susceptibility to noise [Av113].

## 3 IMPORTANCE OF EDGE DETECTION FOR DETECTING CORNERS

A corner can be defined as the intersection of two edges or, as a point for which there are two dominant and different edge directions in a local neighbourhood. Therefore, corner detection process is closely related to edge detection.

The goal of an edge detection process is to mark the points at which the intensity changes sharply. Different effects, such as change of direction, or poor focus can result in change in the intensity values, resulting in errors such as false edge detection, loss of true edges, poor edge localization, as well as high computational time and problem due to noise.

Edge detectors that depend on Gaussian smoothing, leads to poorer localization of corner position for the rounding effect at corner neighbourhood. Moreover, the non-maximum suppression used in common edge detectors can make the straight lines curved.

Therefore, the choice of an edge detection process has significance of chord-based corner detectors. It may be obvious that the number of detected corners is depends on the number of edges extracted. However, it is not just how many edges are detected, but which edges are detected, that may be more important in the actual application of corner detectors.

## 4 CORNER DETECTION

A corner is one of the most stable features in a 2D image. In this section we will discuss four recent contour-based corner detectors [Moh08, RMN11a, Xia09]. All such detectors first extract the image edges, which they call contours, and then traverse these edges to search for points at which the curvature values are locally maximum or minimum [Fmo01, Xia04, Moh08]. As almost all methods in this category apply a Gaussian denoising step, the actual curvature value estimation is relatively robust against noise.

### 4.1 CPDA: Distance accumulation with multiple chord lengths

Chord to Point Distance Accumulation technique (CPDA) was proposed in [Moh08] and is one of the most instructive contour-based corner detectors. The method uses the distance accumulation technique to measure the curvature of every point on an edge.

CPDA detector uses three different chords of length 10, 20 and 30. These chords are moved along each curve. Before calculating the curvature values, each curve is smoothed with an appropriate Gaussian kernel (i.e.  $\sigma = 1, 2$  or  $3$ ) in order to remove quantization noises. The accumulated curvature values for each chord are then normalized.

Next, CPDA finds the candidate corners by rejecting weak corners using local maxima of absolute curvature by comparing the curvature values with threshold  $T_h$ , which the authors set to 0.2. Based on the hypothesis that a well defined corner should have a relatively sharp angle [Xia04], CPDA calculates angle from a candidate corner to its two neighbouring candidate corners from the previous step, and compare with the angle threshold  $\delta$  to remove false corners. The angle-threshold  $\delta$  is set to  $157^\circ$ .

### 4.2 CCR: Distance accumulation using distance ratio

CCR first puts a chord along the curve and then calculates the flatness by using the ratio of the length of the curve to the length of the chord. Before that it uses Gaussian smoothing to remove the noise. The number of pixels within the curve segment intersected by the chord is 7 and Gaussian smoothing  $\sigma = 3$  have been used to detect the corners. The threshold for the corners is defined as  $Th = 0.986$ .

### 4.3 CTAR: Chord to Triangular Arms Ratio

CTAR uses triangular measurement theory to estimate the curvature values. First it places a chord that is moved along the curve and a triangle is formed using the two intersection points between the chord and the

curve, and the middle point within those two intersected points. The ratio between the Euclidean distance of the two intersected points and the summation of the other two arms length of that triangle is computed. The main advantage of CTAR method is that it is not sensitive to noise as it does not use any derivative based measurements.

Like CCR detector, CTAR also used only one chord of length 7 along the curve. After estimating the curvature values, the local minima that are found from each curve estimation, is considered as corner location based on a threshold which is set to 0.989. The angle-threshold  $\delta$  is set to  $163^\circ$

#### 4.4 DoG: Difference of Gaussian detector

DoG detector [Xia09] applies multiple levels of Difference of Gaussian (DoG) on a curve to obtain several corresponding planar curves. These planar curves are then convolved with Difference of Gaussian (DoG) filters for detecting the corners. The main advantage of DoG detector is that it uses two scales, a low and a high scale, and then combines them into the detection of the candidate corner so that the coarse-to-fine tracking may be supplanted

### 5 USING ADAPTIVE CANNY EDGE DETECTOR

The choice of an edge detection process has a great significance in chord-based corner detectors. It may be obvious that the number of detected corners depends on the number of edges extracted. Most of the contour-based corner detection process uses Canny edge detector [Moh08], [RMN11a], [Moh07] for the initial edge extraction step. CPDA corner detector [Moh08] first uses Canny edge detector with thresholds low = 0.2 and high = 0.7 and this trend continues in [RMN11a], [Moh07] and other recent chord-based corner detectors. Instead of following the trend, we analyse the role of Canny edge detection method with both adaptive and pre-defined threshold on the current state of the art chord-based corner detectors. We use adaptive Canny edge detection method that follows the most popular Otsu method to calculate the thresholds which is deduced by least square(LS) method based on gray histogram. We use the adaptive Canny edge detector from the implementation of MATLAB 2012b. The result has been discussed in Section 6.

### 6 PERFORMANCE STUDY

In this section, we discuss the performance of the edge detectors while applying them to detect corners using the corner detectors. First, the dataset is described. Next, the evaluation method and Finally the results are shown.

### 6.1 Dataset

We have used an image dataset of 23 different types of grey scale images to evaluate the performance of the corner detectors using different edge detectors. Seven different transformations have been applied to these base 23 images that includes Scaling, Shearing, Rotation, Rotation-Scale, Non-uniform Scale, JPEG Compression, Gaussian Noise to obtain more than 8000 transformed test images (see Table 1) . All the experiments were run on Matlab 2012b on an Windows 7 (64bit) machine with an Intel Core i5-3470 processor and 8GB of RAM.

Transformations	Transformation factors	Number of images
Scaling	Scale factors $s_x=s_y$ in [0.5,2.0] at 0.1 apart, excluding 1.0	345
Shearing	Shear factors $sh_x$ and $sh_y$ in [0, 0.012]at 0.002 apart.	1081
Rotation	18 different angles of range $-90^\circ$ to $+90^\circ$ at $10^\circ$	437
Rotation-Scale	in [-30 , +30 ] at $10^\circ$ apart, followed by uniform and non uniform scale factors $s_x$ and $s_y$ in [0.8, 1.2] at 0.1 apart.	4025
Nonuniform Scale	Scale factors $s_x$ in [0.7, 1.3] and $s_y$ in [0.5, 1.5] at 0.1 apart.	1772
JPEG compression	Compression at 20 quality factors in [5, 100] at 5 apart.	460
Gaussian noise	Gaussian (G) noise at 10 variances in [0.005,0.05] at 0.005 apart.	230

Table 1: Image Transformations applied on 23 base images

### 6.2 Evaluation Method

We have applied automatic corner detection evaluation process proposed by Awarangjeb [Moh08] to examine the number of repeated corners. In this process the detected corner locations of an image are referred to as the reference corners and then compared the locations of the detected corners in the transformed image of the former one with the reference corners. If a reference corner is detected in a corresponding transformed location, then that corner is considered as repeated. The repeatability is the process of detecting the same corner locations in two or more different images of the same scene. The main advantage of this process is that

there is no limit on the number of images in the dataset. Moreover, this process does not require any human intervention.

### 6.3 Results and Discussion

We studied the most commonly used Canny [Can86], Sobel, Roberts, Prewitt [Pre70], LoG [Kam98] and Zerocross [Av113] edge detection methods and conducted our experiment to find out the answers of the questions mentioned earlier.

Figure 5 shows the detected corner locations for only CPDA corner detector after using different edge detectors to an image. It is clearly seen that each edge detector gives different corner locations for the same image because of the discrete edge extraction structures. As Canny, LoG and Zerocross extracts a good number of edges, the number of detected corners are also high. Prewitt, Roberts and Sobel derives less edges, resulting in low numbers of corner locations.

Initially, we have conducted our test to find out the effects of different geometrical transformations for finding edges, corner and repeatable corners. The comparative results of the edge detectors in terms of number of extracted edges, detected corners and repeatable corners under various conditions are presented in Figure 6, 7, 8 respectively.

First, we tried to find out the average number of edges retrieved using different corner detectors with different edge detectors after applying the transformations mentioned earlier. Our first experiment is conducted to notice the effects of different geometrical transformations on the images for detecting edges. Figure 6 shows that the Canny edge detector lefts others behind for detecting edges in almost every conditions. Each edge detectors perform differently in various geometrical changes. Evaluation of the images showed that under several conditions, Canny, LoG, Zerocross, Sobel, Prewitt, Roberts exhibit better performance, respectively.

Numbers of detected corners also depend on the number of extracted edges. However, if an edge detector extracts a good number of loosely connected edges, the detected corners will be few and not suitable for practical application (see Figure 5). We performed our experiment to figure out the average numbers of corners using different edge detectors under several transformations and from Figure 7, we found that Canny edge detector results best under most of the geometrical transformations for finding corners. This happened for the same reason as Canny finds more edges results in finding more corners. However, Zerocross and LoG operators performs better in scale and shear transformations than Canny edge detector.

We analyzed how the different edge detectors effect the performances of finding repeatable corners under ge-

Corner Detector	Edge Detector	Edge Detection time	Curve extraction time	Corner Detection time	Total time
CPDA	Canny	2.128	37.622	3.728	43.477
	Canny_th	2.09	4.456	1.314	7.861
	Prewitt	0.282	39.126	1.039	40.447
	log	0.76	29.869	2.921	33.551
	Roberts	0.309	46.604	0.586	47.499
	Sobel	0.282	38.601	1.078	39.962
	Zerocross	0.74	29.374	2.837	32.951
CTAR	Canny	2.188	37.574	0.537	40.299
	Canny_th	2.077	4.33	0.168	6.575
	Prewitt	0.302	39.437	0.181	39.92
	log	0.764	30.408	0.423	31.596
	Roberts	0.31	46.865	0.113	47.289
	Sobel	0.302	39.078	0.179	39.559
	Zerocross	0.759	29.506	0.413	30.678
CCR	Canny	2.587	46.644	0.632	49.864
	Canny_th	2.414	5.098	0.194	7.705
	Prewitt	0.305	39.706	0.172	40.183
	log	0.926	37.597	0.568	39.091
	Roberts	0.399	59.435	0.139	59.974
	Sobel	0.309	40.901	0.176	41.386
	Zerocross	0.768	30.337	0.428	31.533
DoG	Canny	0.059	0.55	0.082	0.692
	Canny_th	0.057	0.048	0.024	0.128
	Prewitt	0.006	0.309	0.027	0.342
	log	0.024	0.374	0.053	0.451
	Roberts	0.007	0.398	0.028	0.432
	Sobel	0.006	0.301	0.029	0.336
	Zerocross	0.023	0.368	0.053	0.443

Table 2: Time computation for different detectors (in seconds)

ometrical changes in Figure 8. It is noticeable that though Canny edge detector finds a large number of edges, resulting more corners, it is not best for finding repeatable corners. LoG operator is best followed by Zerocross operator for finding average repeatable corners. Though LoG and Zerocross operators give better result than Canny, it malfunctions at corners and curves. The edges are not connected like Canny, thus it results more edges and corner locations which may not be significant for practical applications.

To find which detector is more efficient, we have examined the execution time for each of the four corner detectors using different edge detectors showed in table 2. We have found that Prewitt and Sobel detectors are fast compared to others to detect edges and Robert operator is quicker than others for curve extractions. However, Canny edge detector using thresholds is best for finding corners followed by Zerocross and log operator.

Now from figure 9, we found that Canny edge detector using adaptive threshold extracts more edges, results in finding a good number of corners, instead of using pre-defined threshold values. We evaluate the performance of these two edge detectors after applying seven different transformations and from figure 10 we find that Adaptive Canny edge detector performs better than Canny using pre-defined threshold in terms of the number of edge extractions and finding corners and repeated corners. So we use adaptive Canny edge detection method in the primary edge extraction step before detecting corners.

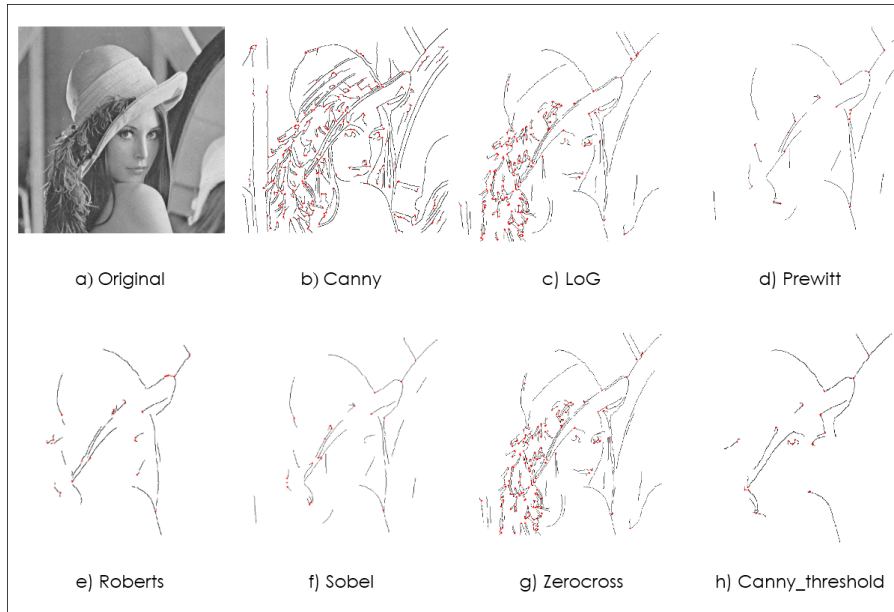


Figure 5: Corner detected by CPDA method using different edge operators

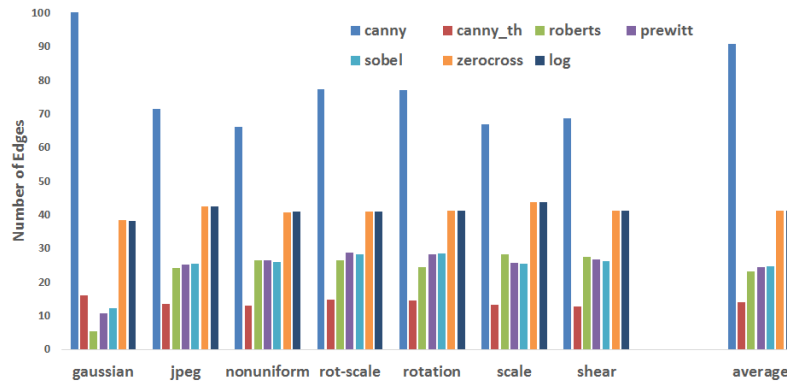


Figure 6: Number of extracted edges after applying different transformations

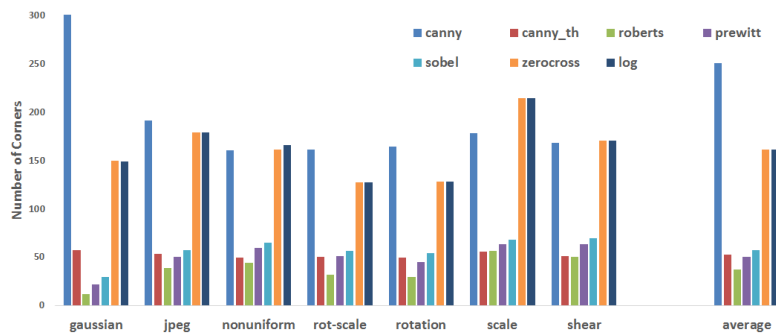


Figure 7: Number of corners after applying different transformations

## 7 CONCLUSION

We have analysed the performance of different edge operators on different contour-based corner detectors and investigate the performance under different transformations. Since edge detection is the early step in of

contour-based corner detection, it is significant to know the performance of different edge detection techniques. In this research paper, the relative performance of various edge detection techniques is carried out with four contour-based corner detectors. It has been observed

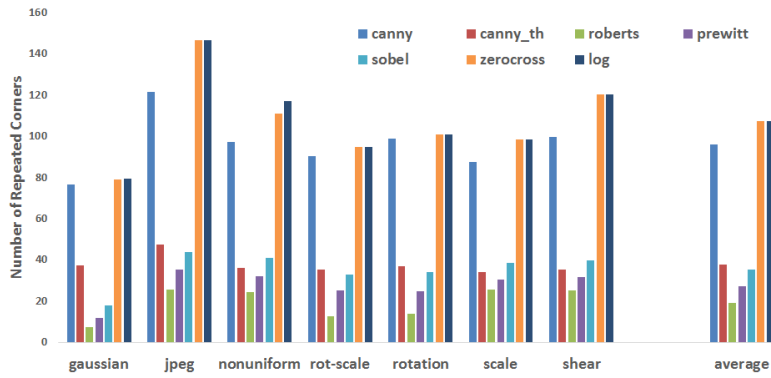


Figure 8: Number of repeated corners after applying different transformations

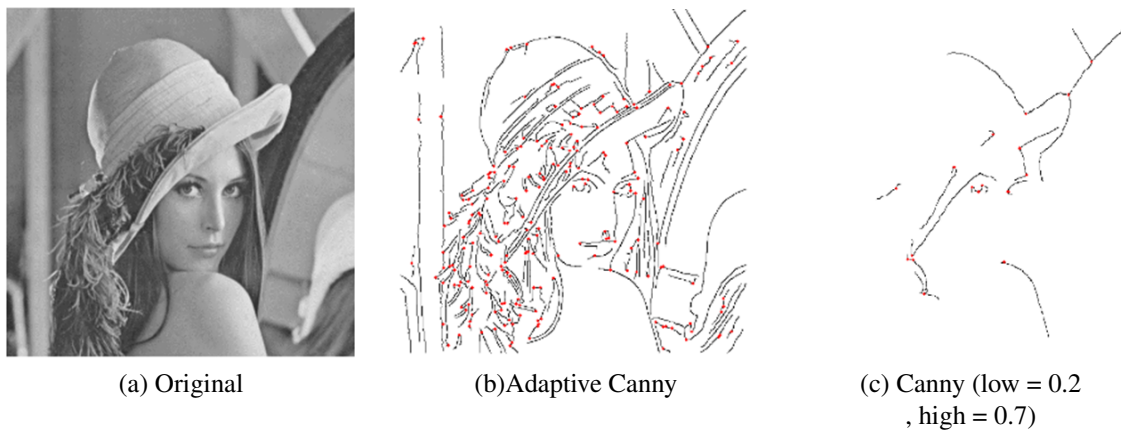


Figure 9: Extracted edges and detected corners using Canny adaptive and Canny (0.2-0.7)

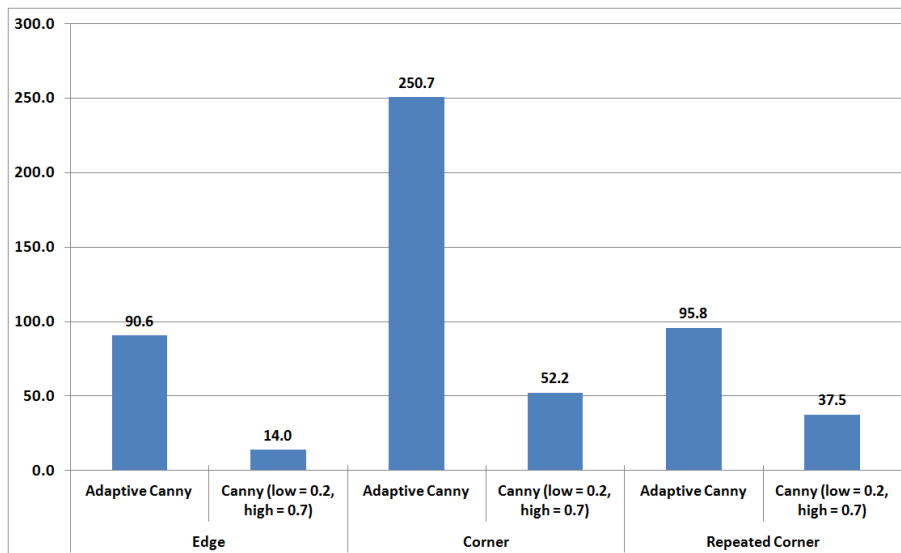


Figure 10: Performance comparison of Canny adaptive and Canny(0.2-0.7)

that Canny edge detection algorithm results higher accuracy in detection of edges and corners, but it is not best for finding repeatable corners, which is considered as one of the most important criterion to evaluate the performance of corner detection. Instead, LoG opera-

tor gives best results. In terms of efficiency, Prewitt, Roberts and Sobel operators are fast compared to others to detect edges. Therefore, we can choose different edge detectors, rather than choosing Canny edge detector as an ideal for each scenario. More importantly, we

observed the limitations of commonly used Canny edge detector using predefined threshold and applied adaptive Canny detector instead, which shows better results.

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