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Robust Image Steganography Based on Hybrid Edge Detection

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Abstract: Steganography is a technique for hiding digital messages into other digital media, such as images, audio, video, and others so that the messages can be disguised and not directly visible to the human vision. There are two kinds of steganography by domain, i.e., spatial domain and frequency domain [7]. Least Significant Bit (LSB) is a popular method in spatial domains [8]. LSB is not a new method. However, this method has many advantages, such as simple algorithm and the quality of imperceptibility of relatively good stego-image [6, 9]. This makes the LSB still open for more development and further research. This paper presents the image hiding technique using Least Significant Bit (LSB) steganography based on hybrid edge detection that maximized the data embedding capacity of the cover image. The performance of the system is evaluated for hybrid edge detection using pairs of various edge detection techniques such as Canny, Kirsch, Sobel, and Prewitt. The results of the proposed steganography approach are estimated for different payload capacities based on Mean Square Error (MSE), Peak Signal to Noise Ratio (PSNR), Structural Similarity Index Metrics (SSIM), and Universal Image Quality Index (UQI). It is examined that the proposed approach performs better than the existing state of arts for image steganography.

Keywords: Least Significant Bit Steganography; hybrid edge detection, Payload Capacity; Image Hiding.

1. Introduction

In today's modern era, internet technology has provided a revolution and changed the landscape of communication technology. Digital communication is an easy and inexpensive thing to use the internet. Important and confidential data can be stolen without security when sending the data. Securing digital data can be done in various ways, generally can use data encryption and/or data hiding techniques [6]. The data hiding technique is a data security technique by hiding data or secret messages into certain media called containers media or covers media. Cover media can be in the form of digital media such as images, audio, video, and text [6, 17]

Data hiding techniques have two main sub-disciplines, i.e. steganography and watermarking. Watermarking techniques are generally used to use the frequency domain in embedding copyright because they are more robust to various attacks, while the steganography technique uses more spatial domains because the methods in the domain are relatively superior to imperceptibility quality and have a greater payload capacity.

Focusing on steganography techniques, research on steganography on images has been widely developed in various previous studies. A lot of research develops on one such aspect as payload capacity and/or security while maintaining and even enhancing the imperceptibility aspect. Payload capacity is the maximum size of a message that can be embedded in a cover image, usually; the payload capacity is measured using bits per pixel (bpp). But the amount of capacity that message pinned on the cover image will have an impact on changes level in the value of the cover image pixel. The size of the change in the pixel value of the cover image affects the quality of the stego image produced, where changes in the good pixel value should not be detected by the human senses, this is what imperceptibility means. Imperceptibility quality can be measured using a peak signal to noise ratio (PSNR) where the PSNR value is generated from the log value of the mean square error (MSE) generated from the calculation between the original cover image and the stego image. Need to underline that the size of the message pinned will greatly affect imperceptibility, logically the greater the size of the message pinned, then the quality of imperceptibility will decrease.

In order to increase payload capacity while maintaining even increasing imperceptibility, the LSB method combined with edge detection is one of the favorite combination methods in some studies [16, 17, 18, 19, 20, and 21].

LSB is a steganography method on the favorite spatial domain because it is simple but has very good imperceptibility and has a relatively high payload capacity (Tang et al., 2014). While the image edge area has a greater tolerance for changes in pixel values compared to non-edge areas so that embedding messages in this area can minimize the decrease in the quality of the stego image's imperceptibility [16]

2. Objective:

- To expand the edge area with the aim of optimizing the quality of stego images.
- To optimize the embedding messages on the edge area to increase in payload capacity while maintaining the imperceptibility quality of the stego image.

3. Methods

The proposed method is divided into two major phases such as secrete image embedding in the cover image and image extraction from stego-image. The proposed method uses a combination of two edge detection algorithms for hybrid edge detection.

3.1 Edge Detection Algorithms

Various edge detection algorithms are available for image edge detection in images. This paper considers a combination of two edge detection techniques to form the hybrid edge detection scheme among Canny, Kirsch, Sobel, and Prewitt edge detection techniques.

a) Kirsch Edge Detector

Kirsch's filter finds maximum edge strength in eight specified directions. It is a non-linear edge detector. Kirsch's filter finds the edges in 8 compass directions such as North (N), North-West (NW), West (W), South-West (SW), South (S), South-East (SE), East (E), and North-East (NE) as shown in Fig. 1 [19].

W=

5	5	5
-3	0	-3
-3	-3	-3

a) West direction mask

N=

-3	-3	5
-3	0	5
-3	-3	5

b) North direction mask

S=

5	-3	-3
5	0	-3
5	-3	-3

c) South direction mask

E=

-3	-3	-3
-3	0	-3
5	5	5

d) East direction mask

NW=

-3	5	5
-3	0	5
-3	-3	-3

e) North West direction mask

NE=

-3	-3	-3
-3	0	5
-3	5	5

f) North-East direction mask

SE=

-3	-3	-3
5	0	-3
5	5	-3

g) southeast direction mask

SW=

5	5	-3
5	0	-3
-3	-3	-3

h) South-West direction mask

Fig. 1 Kirsch's filter kernels in eight directions

These kernels are applied to the input image with the help of a convolution operator as given in equation 1.

$$K_m(n,k) = \sum_{i=-1}^{1}\sum_{j=-1}^{1} im(n+i,k+j).Fm(i,j) \tag{1}$$

Where, $K_m(n,k)$ is Kirsch's filter output, F_m is Kirsch's filter kernel, $im(n+i,k+j)$ is the Grayscale image. Here, n and k represent the number of rows and columns of the radiograph.

To find the resultant strength of the edge, the maximum from all eight of Kirsch's filter output is selected using equation 2.

$$K_{max}(n,k) = \max\,(K_1(n,k), K_2(n,k), K_3(n,k), \ldots, K_8(n,k)) \tag{2}$$

Kirsch's edge detector can keep the edge details and provides better edge accuracy, edge thickness, less sensitivity to internal and external noise.

b) Sobel Edge Detector

The Sobel edge detector used horizontal gradient and vertical gradient kernel is given in Equations3 and 4. The magnitude of the horizontal and vertical gradient is considered as Sobel edges as given in equation 5. The orientation of edges is given in equation 6.

$$Gxs = \begin{bmatrix} -1 & 0 & +1 \\ -2 & 0 & +2 \\ -1 & 0 & +1 \end{bmatrix} \tag{3}$$

$$Gys = \begin{bmatrix} +1 & +2 & +1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix} \tag{4}$$

$$E_s = \sqrt{Gxs^2 + Gys^2} \tag{5}$$

$$\theta = atan2(Gys, Gxs) \tag{6}$$

c) Canny Edge Detector

The Canny edge detection is a multistage edge detection process. The first stage consists of image smoothening using a Gaussian filter. In the second phase, the edge gradient is computed using equations 3-6 (Sobel edge detector). The third stage includes the minimization of spurious edges using gradient magnitude thresholding. Then, double thresholding is applied to decide potential edges. The last stage encompasses edge tracking using hysteresis that suppresses feeble edges and edges not linked to strong edges.

d) Prewitt Edge Detector

The Prewitt edge detector used horizontal gradient and vertical gradient kernel is given in Equations7 and 8. The magnitude of the horizontal and vertical gradient is considered as Prewitt edges as given in equation 9.

$$Gxp = \begin{bmatrix} -1 & 0 & +1 \\ -1 & 0 & +1 \\ -1 & 0 & +1 \end{bmatrix} \tag{7}$$

$$Gyp = \begin{bmatrix} +1 & +1 & +1 \\ 0 & 0 & 0 \\ -1 & -1 & -1 \end{bmatrix} \tag{8}$$

$$E_p = \sqrt{Gxp^2 + Gyp^2} \tag{9}$$

3.2 Secrete Image Embedding Phase

In this phase, the secrete image data having dimension $m{\times}n$ is hidden into the edge and non-edge pixels of the cover image without damaging the visual quality of the cover image having dimension $M{\times}N$. Here, m and n are the number of rows and columns in the secrete image whereas *M* and *N* represent several rows and columns in the cover image. The dimensions of the cover image must be larger than the dimensions of the secrete image to avoid the loss of data. The image embedding phase is shown in Fig. 2. The process of secrete image embedding into cover image considering Canny and Kirsch edge detection can be given as:

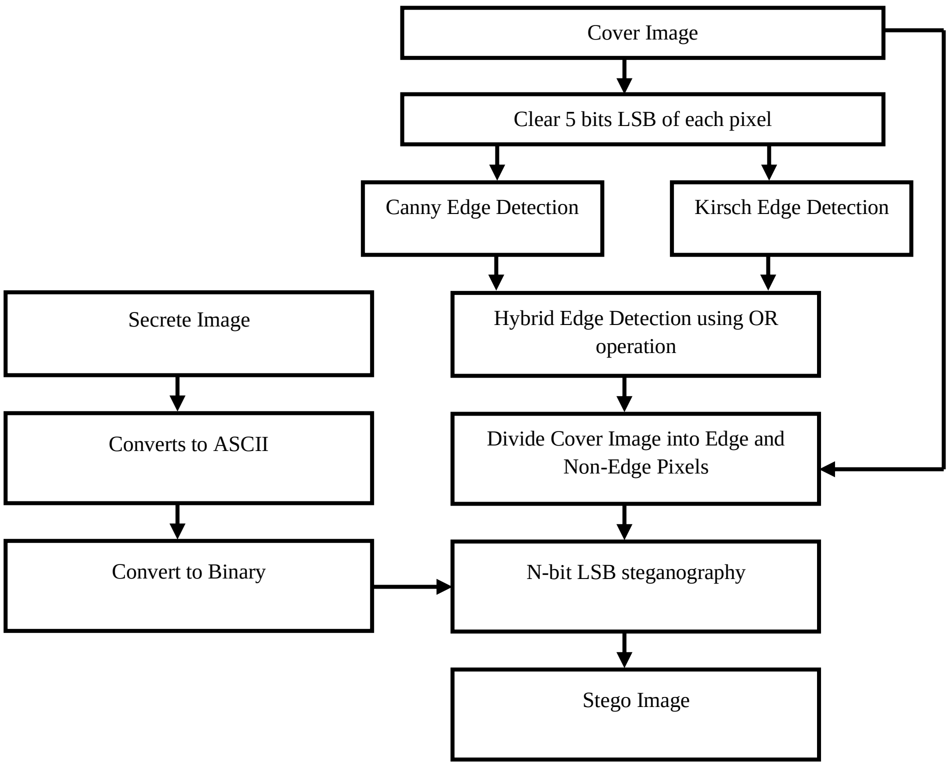

Fig. 2 Proposed Steganography: Data Embedding Phase

1. Read Cover Image: In this step, the cover image (X1) is read and converted to a gray scale image. The cover image is then copied to another variable (X2).
2. Clear 5 bit LSB: Clear the 5 bits LSB of all pixels of the cover image (X2). The first to fifth LSB is set to 0 and then the whole pixel value is again converted to an integer. Because of setting 5 bit LSB to 0, the individual pixel value may reduce by 0 to 32.
3. Edge Detection: Perform the Canny edge detection on X2 and save the results to E_c. Also, perform the Kirsch edge detection on X2 and store the result in $\mathrm{E_k}$.
4. Hybrid Edge Detection: The hybrid edges $(E_h)$are obtained by taking the OR operation of E_c and E_k. Further, morphological dilation is applied to minimize the noise in hybrid edges and enhance the edges.
5. Edge and Non-Edge pixel Decision: The pixels of the cover image (X1) is divided into edge pixels and non-edge pixels based on hybrid edges.
6. Read Secrete Image: On the other hand, read the secrete image and convert it to ASCII equivalent.
7. ASCII to Binary Conversion: Convert the ASCII value of secrete image into a binary equivalent (Xb) for LSB steganography.
8. Data Embedding: Embed the x bits of the Xb to LSB of X1 if the pixel is edge pixel otherwise embed the bits of Xb to LSB of X1. The x and y value should not exceed 5 bits because the current approach can only accommodate 5 bits per pixel. Again, the value of x must be greater than y because the edge area provides better tolerance.
9. Stego Image (S1): Stego image (S1) can be obtained by embedding all the bits of Xb to X1.

3.3 Secrete Image Extraction Phase

In this phase, the secrete image from the stego image is retrieved without loss of secrete image information. The secrete image extraction phase considering Canny and Kirsch edge detection is shown in Fig. 3. The process of secrete image extraction from stego image can be given as:

1. Read Stego Image: In this step, stego image (S1) is read. The stego image is then copied to another variable (S2).
2. Clear 5 bit LSB: Clear the 5 bits LSB of all pixels of stego image (S2). The first to fifth LSB is set to 0 and then the whole pixel value is again converted to an integer.
3. Edge Detection: Perform the Canny edge detection on S2 and save the results to E_c. Also, perform the Kirsch edge detection on S2 and store the result in E_k.
4. Hybrid Edge Detection: The hybrid edges (E_h) are obtained by taking the OR operation of $E_c$andE_s. Further, morphological dilation is applied to minimize the noise in hybrid edges and enhance the edges.
5. Edge and Non-Edge pixel Decision: The pixels of stego image (S1) is divided into edge pixels and non-edge pixels based on hybrid edges.
6. Extraction of LSB: Extract x bits LSB from edge pixel area and y bits LSB from non-edge pixels area of stego image.
7. ASCII to Binary Conversion: Group every 8 bits of extracted bits convert it to ASCII value.
8. Secrete Image Extraction: Finally, the secrete image is extracted by resizing the ASCII values to M×N dimensions.

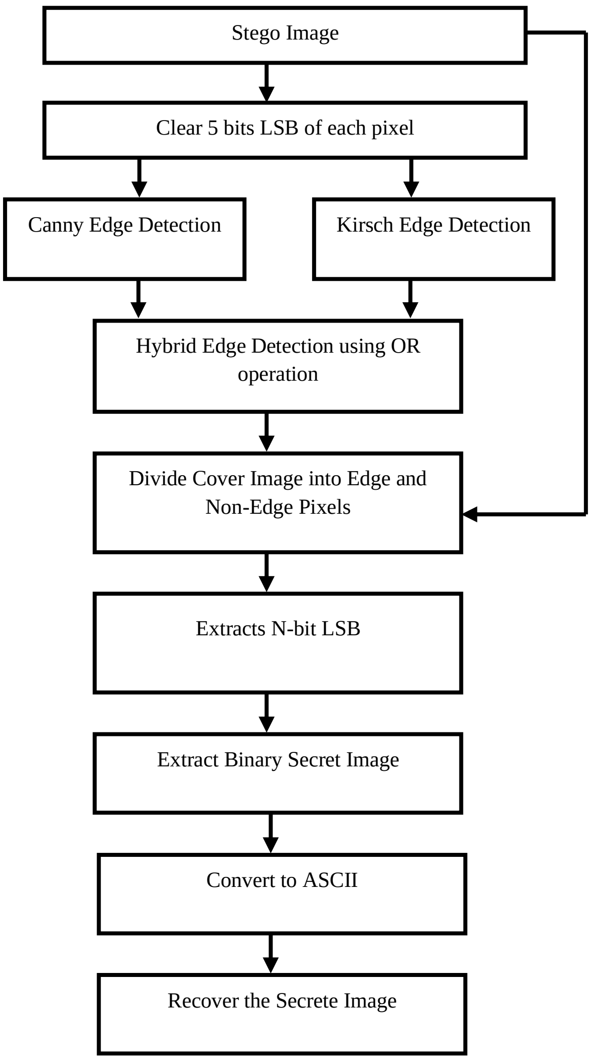

Fig. 3 Proposed Steganography: Data Extraction Phase

4. Results

The proposed system is simulated using MATLAB software on the Windows platform using a personal computer having a core i3 processor and 8 GB RAM. We have selected four cover images and four message images for the performance evaluation of the proposed system as shown in Fig.4. We have selected the medical image, satellite image, natural image, portrait image as sample images for the cover image and secrete image. The dimensions of the cover image are set to 256×256.

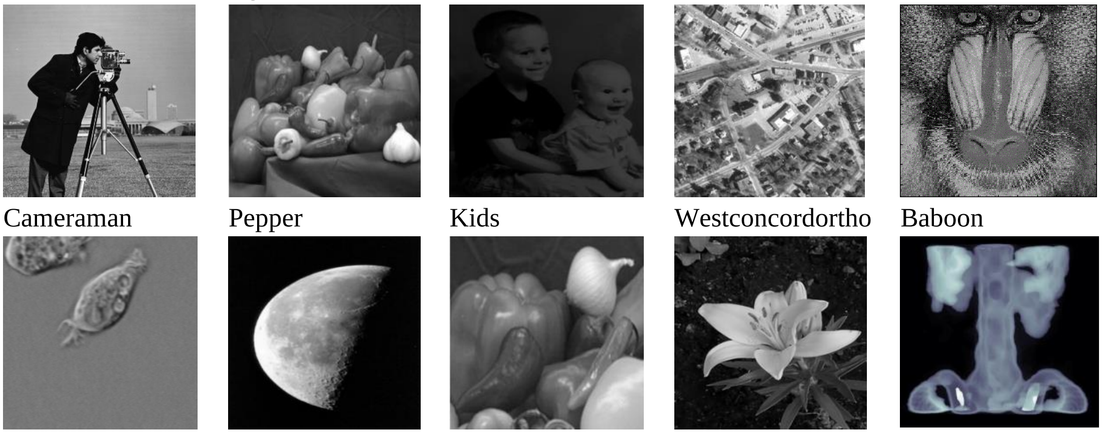

Fig. 4 Sample cover and secrete images

We have evaluated the effectiveness of the proposed system for different payload capacities based on Mean Square Error (MSE), Peak Signal to Noise Ratio (PSNR), Structural Similarity Index Metrics (SSIM), and

Universal Image Quality Index (UQI).

MSE and PSNR are used to measure the overall quality of the cover image after steganography which can be given using equation 10 and 11.

$$MSE = \frac{1}{mn}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}[I(i,j) - N(i,j)]^2 \tag{10}$$

$$PSNR = 10.log_{10}\left(\frac{2^B - 1}{MSE}\right) \tag{11}$$

Where $I(i,j)$ and $N(i,j)$ are cover image and stego image, *m* and *n* stand for rows and columns of images, and *B* is a number of bits per sample.

The SSIM provides the information about structural content of the stego image and cover image which can be given using equation12.

$$SSIM(x,y) = \frac{(2\mu_x\mu_y + c_1)(2\sigma_{xy} + c_2)}{(\mu_x^2 + \mu_y^2 + c_1)(\sigma_x^2 + \sigma_y^2 + c_2)} \tag{12}$$

Where, μ_x , μ_y stands for an average of the cover image and stego image, μ_x^2 , μ_y^2 stands for the variance of the cover image and stego image, σ_{xy} is the covariance of cover and stego image, $c_1 = (k_1L)^2$ and $c_2 = (k_2L)^2$ weak denominator stabilizer L is the dynamic range of cover image pixels (up to 255 for an 8-bit image), $k_1 = 0.01$ and $k2 = 0.03$. SSIM value lies between 0 and 1. The higher value of SSIM shows

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superior quality of the cover image after data hiding. SSIM is calculated over the window size (x,y) of 5×5 pixels.

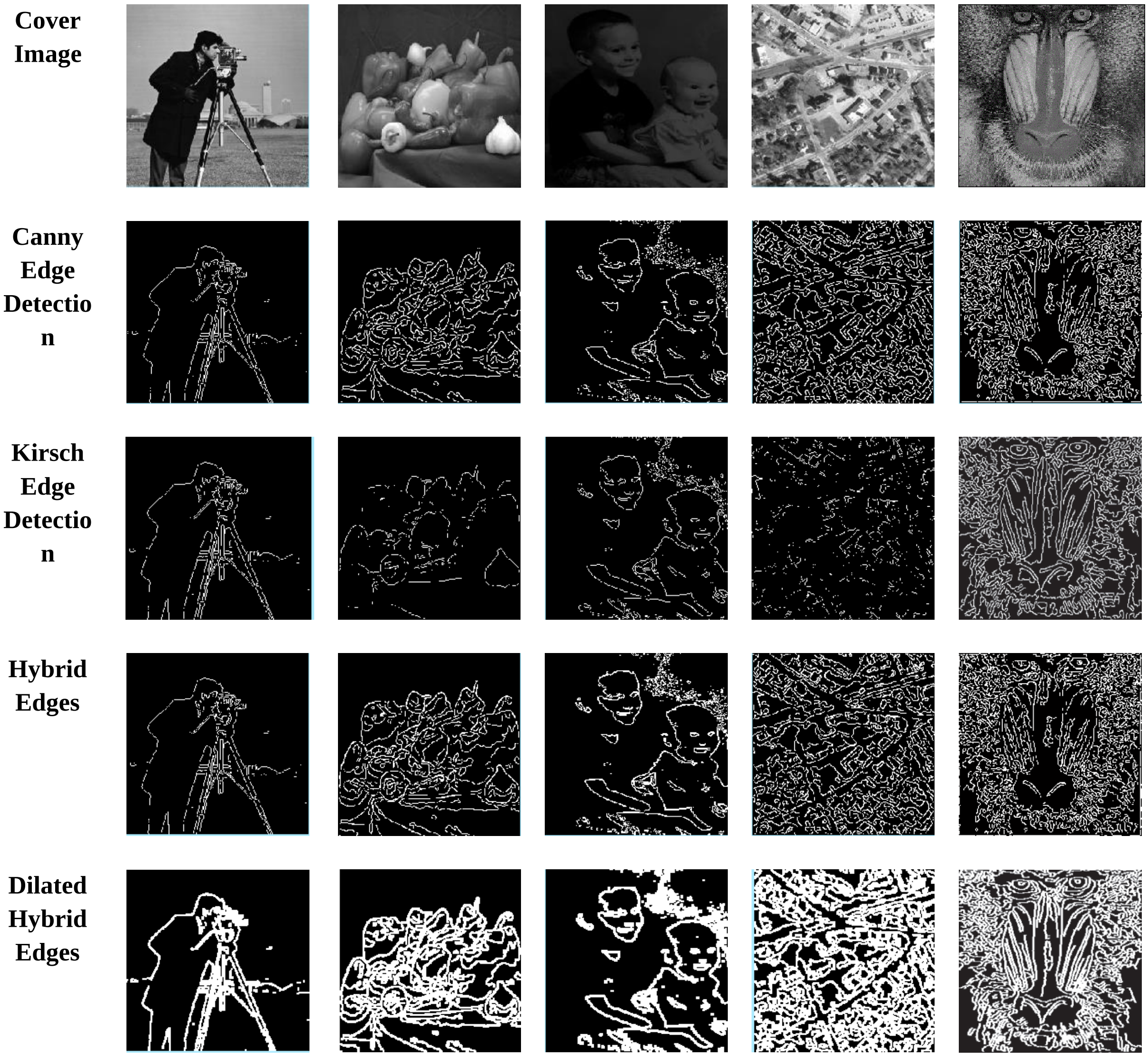

Fig. 5 Dilated hybrid images for different cover images

The various dilated hybrid edges are shown in Fig. 5 show the noteworthy improvement in the edge pixel area after the dilation process. The hybrid edges combine the edges obtained from Sobel and Kirsch edge detectors. The dilation process increases the thickness of the edge and hence helps to improve the payload capacity of the image.

Tables 1-5 provides the experimental results of image steganography by considering different pairs of cover and secrete images for variable payload capacity. It is observed that a hybrid edge detection algorithm based on Canny-Kirsch gives better performance compared to hybrid edge detection based on Canny-Sobel, Canny-Prewitt, Sobel-Prewitt, Sobel-Kirsch, and Kirsch-Prewitt.

Table 1: Performance of proposed approach (Cover Image: Cameraman, Secrete Image: Cell)

Payload Capacity	Edge Detector 1	Edge Detector 2	MSE	PSNR	SSIM	UQI
1024	Canny	Sobel	0.055527	60.7198	0.99998	1
	Canny	Prewitt	0.053986	60.842	0.99998	0.99998
	Canny	**Kirsch**	**0.05368**	**60.8666**	**0.99995**	**1**
	Sobel	Prewitt	0.055756	60.7019	0.99998	1
	Sobel	Kirsch	0.05394	60.8457	0.99998	1
	Kirsch	Prewitt	0.056015	60.6818	0.99995	0.99987
4096	Canny	Sobel	0.2261	54.6217	0.9999	0.9999
	Canny	Prewitt	0.22621	54.6197	0.99991	0.99967
	Canny	**Kirsch**	**0.12038**	**57.3594**	**0.99993**	**0.99987**
	Sobel	Prewitt	0.13528	56.8523	0.99991	0.99934
	Sobel	Kirsch	0.22017	54.7372	0.99991	1
	Kirsch	Prewitt	0.13284	56.9314	0.99991	0.99988
16384	Canny	Sobel	0.31744	53.1481	0.99989	0.99955
	Canny	Prewitt	0.31479	53.1846	0.9999	0.99976
	Canny	**Kirsch**	**0.11316**	**57.6279**	**0.99993**	**0.99994**
	Sobel	Prewitt	0.1255	57.1782	0.99991	0.99978
	Sobel	Kirsch	0.31421	53.1926	0.99989	0.99985
	Kirsch	Prewitt	0.12781	57.0992	0.99991	0.9997

Table 2: Performance of proposed approach (Cover Image:Pepper, Secrete Image: Moon)

Payload Capacity	Edge Detector 1	Edge Detector 2	MSE	PSNR	SSIM	UQI
1024	Canny	Sobel	0.0364	62.5186	1	1
	Canny	Prewitt	0.0374	62.3974	1	1
	Canny	**Kirsch**	**0.0342**	**62.7956**	**1**	**1**
	Sobel	Prewitt	0.0354	62.6432	1	1
	Sobel	Kirsch	0.0357	62.5993	1	1
	Kirsch	Prewitt	0.0360	62.5690	1	1
4096	Canny	Sobel	0.4313	51.7826	1	0.99999
	Canny	Prewitt	0.4262	51.8347	1	0.99999
	Canny	**Kirsch**	**0.1487**	**56.4086**	**1**	**0.99999**
	Sobel	Prewitt	0.1588	56.1226	1	1
	Sobel	Kirsch	0.4315	51.7806	1	1
	Kirsch	Prewitt	0.1624	56.0257	1	1
16384	Canny	Sobel	0.6363	50.0944	1	0.99999
	Canny	Prewitt	0.6201	50.2061	1	0.99999
	Canny	**Kirsch**	**0.2164**	**54.7786**	**1**	**0.99999**
	Sobel	Prewitt	0.2334	54.4500	1	0.99999
	Sobel	Kirsch	0.6319	50.1243	1	0.99999
	Kirsch	Prewitt	0.2342	54.4342	1	0.99999

Table 3: Performance of proposed approach (Cover Image: Kids, Secrete Image: Onion)

Payload Capacity	Edge Detector 1	Edge Detector	MSE	PSNR	SSIM	UQI

		2				
1024	Canny	Sobel	0.05751	60.5334	0.99989	0.99971
	Canny	Prewitt	0.06233	60.1838	0.99988	0.99946
	Canny	**Kirsch**	0.0133	66.8923	1	1
	Sobel	Prewitt	0.01491	66.3960	0.99992	0.99975
	Sobel	Kirsch	0.0528	60.9045	0.9999	1.0003
	Kirsch	Prewitt	0.06973	59.6966	0.99989	1.0065
4096	Canny	Sobel	0.06303	60.1353	0.99988	1.0009
	Canny	Prewitt	0.05751	60.5334	0.99989	0.99971
	Canny	**Kirsch**	0.0528	60.9045	0.99993	0.99971
	Sobel	Prewitt	0.0497	61.1672	0.99989	0.99996
	Sobel	Kirsch	0.06233	60.1838	0.99988	0.99946
	Kirsch	Prewitt	0.04572	61.5297	0.99989	0.99955
16384	Canny	Sobel	0.07259	59.5220	0.99988	1.0013
	Canny	Prewitt	0.06973	59.6966	0.99989	1.0065
	Canny	**Kirsch**	0.0497	61.1672	0.99992	0.99975
	Sobel	Prewitt	0.0528	60.9045	0.9999	1.0003
	Sobel	Kirsch	0.07317	59.4875	0.99988	0.99968
	Kirsch	Prewitt	0.0607	60.2989	0.99989	1

Table 4: Performance of proposed approach (Cover Image: Westconcordortho, Secrete Image: Yellow lilly)

Payload Capacity	**Edge Detector 1**	**Edge Detector 2**	**MSE**	**PSNR**	**SSIM**	**UQI**
1024	Canny	Sobel	0.05751	60.5334	1	1
	Canny	Prewitt	0.06233	60.1838	1	1
	Canny	**Kirsch**	**0.04572**	**61.5297**	**1**	**1**
	Sobel	Prewitt	0.0528	60.9045	1	1
	Sobel	Kirsch	0.0497	61.1672	1	1
	Kirsch	Prewitt	0.07259	59.5220	1	1
4096	Canny	Sobel	0.41228	52.0129	1	1
	Canny	Prewitt	0.41553	51.9788	1	1
	Canny	**Kirsch**	**0.33514**	**52.9125**	**1**	**1**
	Sobel	Prewitt	0.3571	52.6369	1	1
	Sobel	Kirsch	0.41298	52.0055	1	1
	Kirsch	Prewitt	0.3441	52.7979	1	1
16384	Canny	Sobel	1.0273	48.0476	1	0.99999
	Canny	Prewitt	1.0176	48.0889	1	1
	Canny	**Kirsch**	**0.38803**	**52.2761**	**1**	**1**
	Sobel	Prewitt	0.40865	52.0513	1	1
	Sobel	Kirsch	1.0303	48.0351	1	1
	Kirsch	Prewitt	0.39476	52.2015	1	1

Table 5: Performance of proposed approach (Cover Image: Baboon, Secrete Image: Spine)

Payload Capacity	**Edge Detector 1**	**Edge Detector 2**	**MSE**	**PSNR**	**SSIM**	**UQI**
1024	Canny	Sobel	0.01783	65.61929	0.99997	1
	Canny	Prewitt	0.01899	65.345554	0.99997	1

	Canny	**Kirsch**	**0.0100**	**68.12646**	**0.99997**	**1**
	Sobel	Prewitt	0.0174	65.725311	0.99997	1
	Sobel	Kirsch	0.01485	66.413539	0.99997	1
	Kirsch	Prewitt	0.02001	65.118333	0.99997	1
4096	Canny	Sobel	0.48408	51.281632	0.99993	0.99998
	Canny	Prewitt	0.4883	51.243936	0.99994	0.99998
	Canny	**Kirsch**	**0.32239**	**53.046988**	**0.99993**	**0.99998**
	Sobel	Prewitt	0.36861	52.465132	0.99992	0.99999
	Sobel	Kirsch	0.48414	51.281094	0.99992	0.99999
	Kirsch	Prewitt	0.35045	52.684543	0.99992	0.99999
16384	Canny	Sobel	1.434	46.565312	0.99985	0.99994
	Canny	Prewitt	1.4217	46.602724	0.99985	0.99994
	Canny	**Kirsch**	**0.44872**	**51.611049**	**0.99985**	**0.99994**
	Sobel	Prewitt	0.48174	51.302677	0.99992	0.99998
	Sobel	Kirsch	1.4325	46.569857	0.9999	0.99998
	Kirsch	Prewitt	0.47185	51.392764	0.99991	0.99998

The effectiveness of the proposed steganography (Canny-Kirsch) is based on hybrid edges for the Baboon cover image for different load capacities and different values of LSB bits. Fig. 6 shows that the proposed system provides higher accuracy for one bit LSB and goes on decreasing as the number of LSB bits increases.

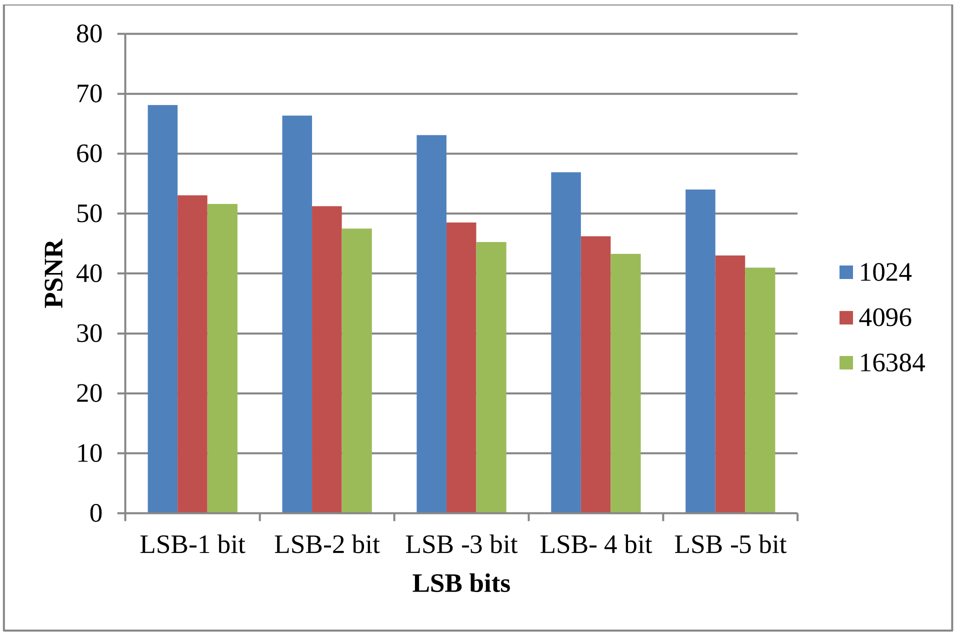

Fig. 6PSNR comparison of the proposed approach (Canny-Kirsch) for various LSB bits (Cover Image: Baboon, Secrete Image: Spine)

The proposed scheme shows robustness to the various external noises. The hybrid edge detection approach using Canny-Kirsch helps to preserve the edge information as Canny provides sharpness in edges and Kirsch provides thickness in edges. Fig. 7 shows significant PSNR for the Baboon cover image for different load capacities and different types of noise with SNR of 30dB.

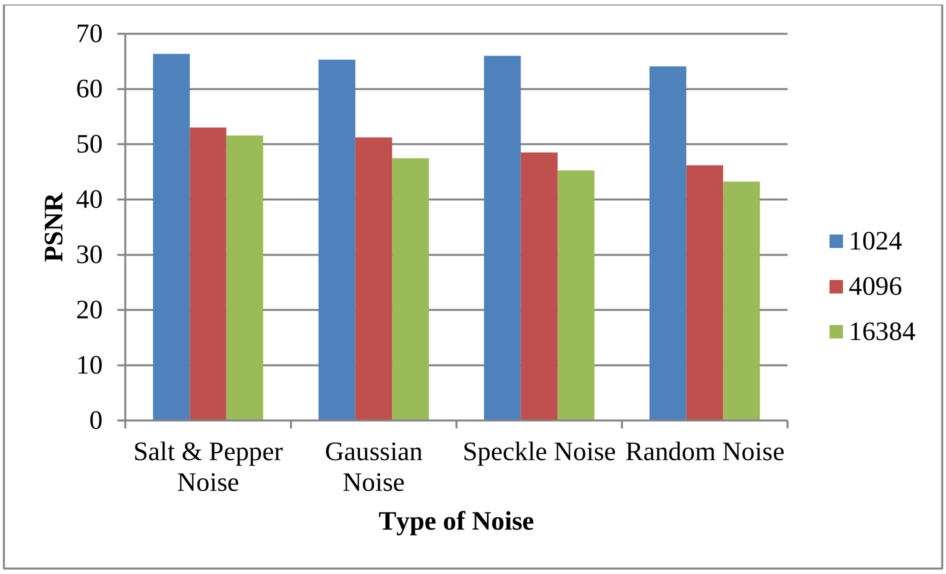

Fig. 7PSNR comparison of the proposed approach (Canny-Kirsch) for various types of noise (Cover Image: Baboon, Secrete Image: Spine)

The performance of the proposed approach is also compared with the previous state of arts given in [16] and [17] for the same cover image (Baboon) and payload capacity. It is observed that the proposed technique offers efficient edge detection for the information hiding in the cover image as shown in Fig. 8 and Fig.9.

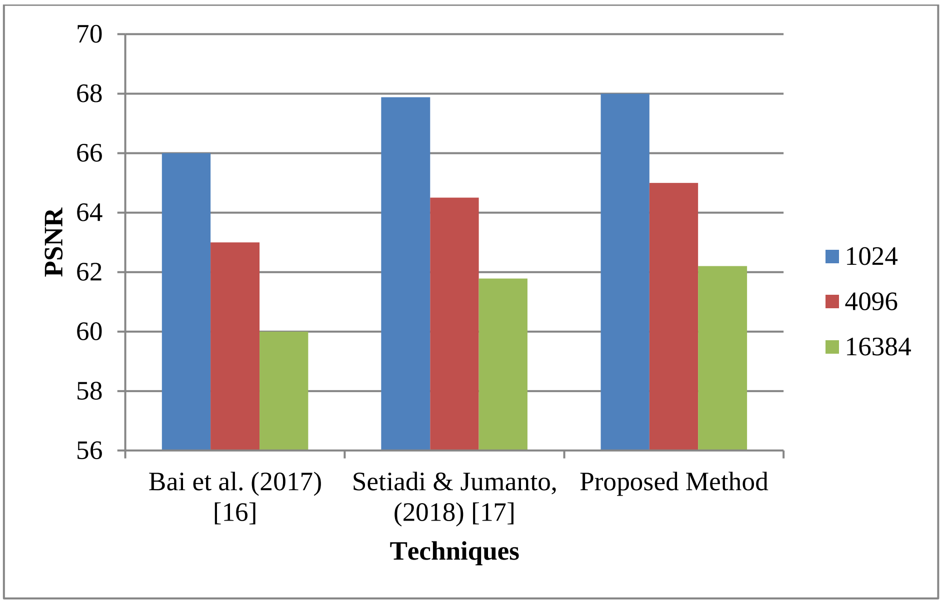

Fig. 8PSNR comparison of the proposed approach (Canny-Kirsch) with the previous state of arts (Cover Image: Baboon, Secrete Image: Spine)

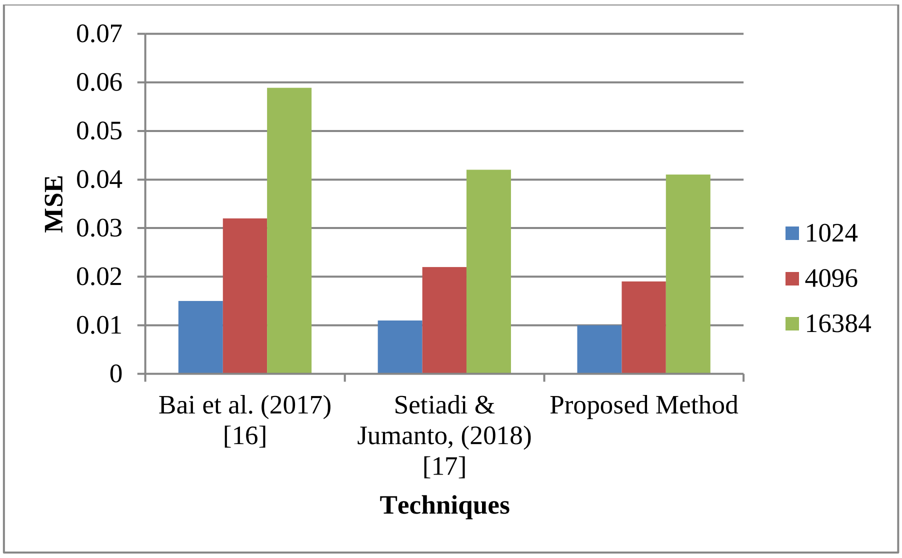

Fig. 9MSE comparison of the proposed approach (Canny-Kirsch) with the previous state of arts (Cover Image: Baboon, Secrete Image: Spine)

5. Discussion

Thus, this paper presents image hiding based on improved steganography based on dilated hybrid edge detection and LSB steganography technique. The proposed hybrid edge detection based on Canny-Kirsch provides better results for a payload capacity of 1024. The Canny-Kirsch hybrid edge detection provides better edge preservation, thickness, and quality under noisy conditions. The information hiding using LSB at hybrid edge pixels has shown more robustness in case of noise and gives better image quality. It has shown significant improvement in the different evaluation metrics such as MSE, PSNR, SSIM, and UQI for higher payload capacity. The proposed approach has given better PSNR and MSE compared with the previous state of arts used for information steganography. In the future, the performance of the proposed image steganography approach can be evaluated for the various noisy conditions and higher payload capacity. Color image steganography is a challenging and time-consuming approach, in the future the existing approach can be extended for color image steganography.

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