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Performance Study of Noise Removal Techniques for Recognition of Modi Consonants

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***Abstract*— In digital image processing, scanned images are degraded by various kinds of noise. When an image is transformed from one form to another during scanning, transmitting, digitizing, storing etc., degradation occurs in the output image. Hence, the output image needs to be enhanced in order to be better analyzed. Denoising is considered to be one of the effective pre-processing techniques in digital image processing. This paper investigates the performance of linear as well as non linear filters namely; Gaussian filter, Mean filter, Median filter, Sobel filter and Canny filter for removing several noises such as Gaussian noise, Salt & Pepper noise, Speckle noise and Poisson noise. The performance of the above five linear and non linear filters is compared by using two performance parameters namely; Mean Square Error (MSE) and Peak to Signal Noise Ratio (PSNR). The experimental result shows that median filter performs best than other five filters for both performance parameters.**

Keywords— ***Gaussian noise, salt & pepper noise, speckle noise, poisson noise, linear and non linear filters, MSE and PSNR***

I. INTRODUCTION

Noise exists as a sharp transition in gray level of an image which is visible as grains. It is produced due to random variations in intensity values, variations in illumination, poor contrast etc. It has been introduced in an image during image acquisition or transmission phase. Thus, the pixel values in the noisy image show various intensity values instead of true value. There subsist several factors which can cause noise in an image mainly; environmental condition during image acquisition, distortion of image during transmission, type of sensing device, insufficient light levels etc. In general, noise may be classified broadly into several types namely; additive noise, multiplicative noise, impulse noise etc. There exist several noise removal algorithms which eliminate and compress the noise from an image by smoothening, sharpening and blurring [1]. At the same time, literature reveals that there exist several noise removal and filtering techniques for recognition of a variety of Indian language scripts such as Kannada, Bengali and Oriya etc [11]. Also, it is evident that very few efforts have been put over the recognition of Modi script which is an ancient script as compared to other Indian ancient languages. Modi handwritten characters are normally both cursive as well as unconstrained [2][3]. When the images are transmitted over channels, these may get corrupted with several kinds of noise due to sudden disturbances caused by an image signal such as bars over an image, constant noise level at dark areas of an image etc. However, there is a scope to recognize Modi consonants using various types of filters in presence of different types of noises before processing.

Noise creates distortion in the scanned image of various scripts that affects the intensity values of an image. In this paper, we are intended to analyze the effect of various existing filtering techniques in presence of different types of noises for recognition of Modi consonants. Section 2 deals with description of existing Modi consonants in brief. In Section 3, we present the overview of several types of noise that subsist in an image. Section 4 illustrates various existing noise removal techniques on scanned images of Modi consonants which in turn may enhance the structural characteristics of respective images effectively. In Section 5, we compare the performance of several kinds of filters using performance parameters as Mean Square Error (MSE) and Peak to Signal Noise Ratio (PSNR). Finally, we conclude with the conclusion and future scope in Section 6.

II. MODI SCRIPT- AN INTRODUCTION

Modi is a Brahmi based script used mainly for writing Marathi, an Indo-Aryan language spoken in western and central India. Modi alphabet was invented during the 17th century to write the Marathi language of Maharashtra [2]. Modi alphabet was used until 1950 when it was replaced by the Devanagari alphabet. It is one of the scripts used to write Marathi language. It is syllabic in nature and its alphabets are classified into vowels as well as consonants. Modi script consists of a typical character set with 14 vowels, 34 consonants, 13 vowel sign set and numerals set (0-9). Consonants of Modi script along with their phonics name are shown in Table I. Notable features of Modi consonants depicts that each letter contains inherent vowel. Other vowels are indicated using a variety of diacritics which appear above, below, in front of or after the main letter.

TABLE I: CONSONANTS OF MODI SCRIPT

S.No	Modi Script	Hindi Literal	S.No	Modi Script	Hindi Literal	S.No	Modi Script	Hindi Literal	S.No	Modi Script	Hindi Literal
1	𑘎	क	11	𑘘	ट	21	𑘣	फ	31	𑘧	य
2	𑘏	ख	12	𑘙	ठ	22	𑘤	ब	32	𑘨	र
3	𑘐	ग	13	𑘚	ड	23	𑘥	भ			
4	𑘑	घ	14	𑘛	ढ़	24	𑘦	म			
5	𑘒	ङ	15	𑘜	ण	25	𑘪	व			
6	𑘓	च	16	𑘝	त	26	𑘫	श			
7	𑘔	छ	17	𑘞	थ	27	𑘬	ष			
8	𑘕	ज	18	𑘠	ध	28	𑘭	स			
9	𑘖	झ	19	𑘡	न	29	𑘮	ह			
10	𑘗	NYA	20	𑘢	प	30	𑘩	ल			

[Resource: Proposal to Encode the Modi Script in ISO/IEC 10646]

III. Effect Of Various Noises On Modi Consonants

Noise is the result of undesirable effects which hampers the quality of an image. During image acquisition and transmission phase, noise is usually caused due to several factors such as environmental condition, distortion of an image etc. Variation in corrupted pixels values determines the quantification of noise [3]. The original noise free scanned image of Modi consonants is shown in Fig. 1. Noise creates disturbance in an image and affects quality of an image to various extent. There exist varied kinds of noise that produce distortion, change in contrast values, poor illuminations etc. in scanned image. Thus, several types of noise have been identified that affect entire quality of an image as follows:

A. Gaussian Noise

Gaussian noise is additive in nature and follows Gaussian distribution with Probability Density Function (PDF) expressed as in Eq. (1). Further, each pixel in the noisy image is the sum of the true pixel value and a random Gaussian distributed noise value and is independent of intensity of pixel value at each point [4][5]. It is a major part of the read noise of an image sensor that is of the constant level of noise in the dark areas of the image [8]. Effect of Gaussian noise on the scanned image of Modi consonants is shown in Fig.2 (i).

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} * e^{-\frac{(x-\mu)^2}{2\sigma^2}} \quad ; -\infty < x < \infty \qquad (1)$$

where x represents the gray level of an image, μ and σ is the mean and standard deviation respectively.

B. Poisson Noise

Poisson noise is also known as shot photon noise. It is produced when the number of photons sensed by sensor is not sufficient to provide detectable statistical information. Hence, various types of electronic noise may be created when the finite number of particles that carry energy such as electrons in electronic circuit and photon in optical device. This type of noise creates detectable statistical fluctuations during measurement [5]. The detection of individual photon can be treated as independent event which follows random temporal distribution. As a result, photon counting is described by the discrete probability distribution, which is termed as standard poisson distribution is shown in Eq. (2) as:

$$Pr(N = n) = \frac{e^{-(\lambda t)} * (\lambda t)^n}{n!} \qquad (2)$$

where N is the number of photons measured by a given sensor element over a time interval t and λ *is* the expected number of photons per unit time interval. The uncertainty described by this distribution is called as photon noise. Further, Fig. 2(ii) shows the effect of Poisson noise on scanned image of Modi consonants.

C. Salt & Pepper Noise

It is also termed as Impulse valued noise/ spike noise. It is usually caused by failure of memory cells, malfunctioning of camera's cells as well as during image digitization/ transmission. The pixel values of an image are randomly replaced by corrupted pixel values as maximum/ minimum pixel value. Thus, maximum value achieved in an image by salt & pepper noise is 255 which represent salt noise and minimum value gathered is 0 that represents pepper noise [10]. The PDF of impulse noise is specified in Eq. (3) as:

$$f(x) = \begin{cases} f_a & for\ x = a \\ f_b & for\ x = b \\ 0 & otherwise \end{cases} \qquad (3)$$

if $a>b$, gray-level a appears as light dot in the image otherwise appears as dark dot. In case of impulse noise *f(x)* is 0 which is called as unipolar. Fig. 2(iii) shows an image with 25% of Salt & Pepper noise.

D. Speckle Noise

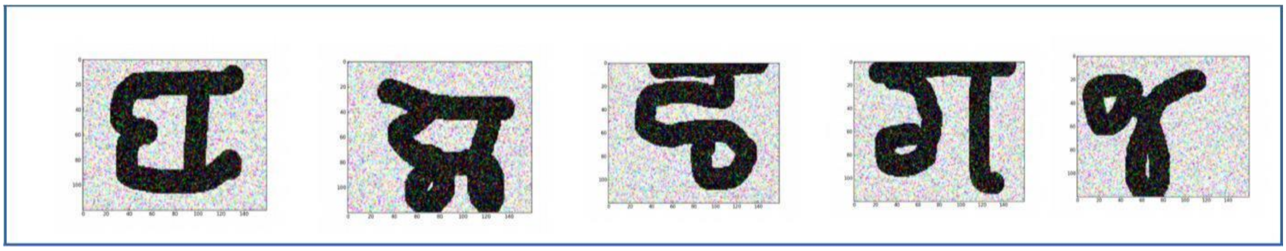
It is multiplicative in nature, which may be seen in coherent imaging system such as laser, radar, acoustics etc. It is alike Gaussian noise but PDF follows gamma distribution which is expressed in Eq. (4) as follows:

$$f(x) = \frac{g^{(\alpha-1)}}{(\alpha-1)!\,a^{\alpha}} * e^{-g/a} \quad (4)$$

where a^{α} is variance and g is the gray-level of an image. Speckle noise is applied on scanned image of Modi consonants as shown in Fig. 2(iv).

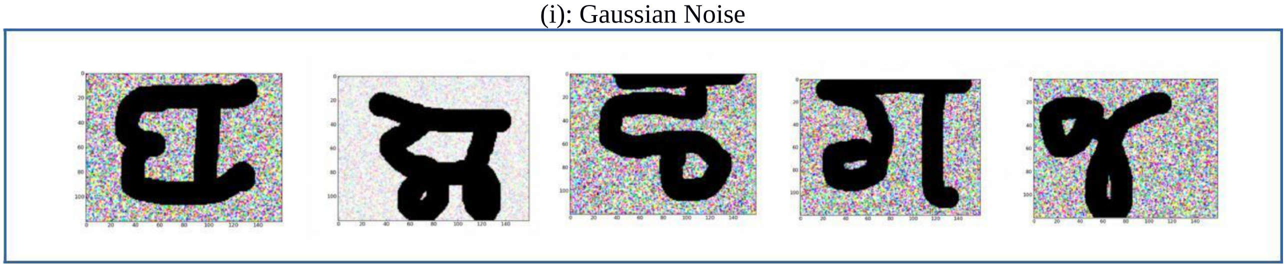
(a) ब (b) क (c) ढ़ (d) ग (e) ज

Fig. 1: Noise Free Images of Modi Consonants



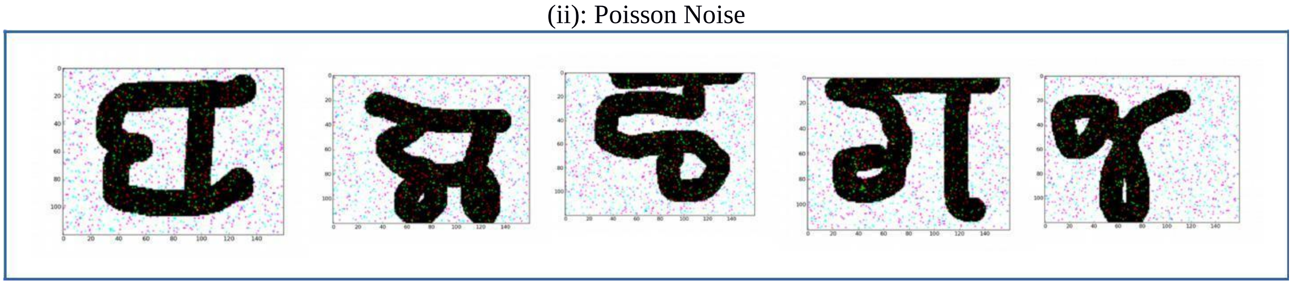
(a) ब (b) क (c) ढ़ (d) ग (e) ज

(i): Gaussian Noise



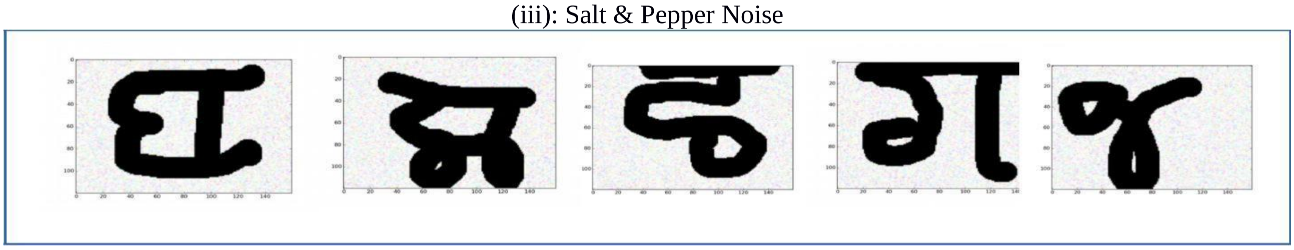
(a) ब (b) क (c) ढ़ (d) ग (e) ज

(ii): Poisson Noise



(a) ब (b) क (c) ढ़ (d) ग (e) ज

(iii): Salt & Pepper Noise



(a) ब (b) क (c) ढ़ (d) ग (e) ज

(iv): Speckle Noise

Fig. 2: Various Types of Noises applied on Images of Modi Consonants

IV. NOISE REMOVAL TECHNIQUES AND PERFORMANCE STUDY ON MODI CONSONANTS

As our main aim lies at the comparative study of filtering techniques, various types of filters applied on Modi consonants have been discussed. The selection of filtering technique is determined by two factors namely; the nature of task performed by filter as well as the behavior and type of data. Noise removal technique is broadly classified into two types mainly: linear and non linear. Now, we discuss these two types of filter applied as follows:

A. Linear Filter

Linear filter is a technique in which the value of an output pixel is a linear combination of the values of the pixels in the input pixel's neighborhood. It is spatially invariant, which is implemented using convolution mask. In general, convolution determines the values of a central pixel by adding the weighted values of its entire neighboring pixel. It creates blurs on the sharp edges as well as keeps smooth areas of an image intact. Further, smoothening of an image destroy the fine details and performs worst in the presence of signal dependent noise [7]. Linear operations calculate the resulting value in the output image pixel *f(i, j)* as a linear combination of brightness in a local neighborhood of the pixel *h(i, j)* in the input image. Eq. (5) depicts discrete convolution performed on an image as follows:

$$f(i,j) = w*k = \sum_{k=0}^{n}\sum_{k=0}^{n} w*(m,n)*h*(i+n) \quad (5)$$

where function *w* is called a convolution kernel or a filter mask. Linear filters are further divided into several types described as follows:

- ***Gaussian Filter***

Gaussian filter commonly used in image processing for smoothing, reducing noise and computing derivative of an image. It is non- uniform low pass filter based on convolution which uses a Gaussian matrix as its underlying kernel [8]. The Gaussian function is used in various fields thereby it defines the PDF for noise or act as a smoothing operator. When working with images it is defined as two dimensional function expressed as in Eq. (6). The Gaussian filters works by using the 2D distribution as a point-spread function, which is achieved by convolving the 2D Gaussian distribution function with the image. Gaussian filter is applied on 'ढ' image with mean (0, 0) and σ = 1on different noises as shown in Fig. 3(i).

$$f(x,y) = \frac{1}{2\pi\sigma^2} * e^{-\frac{x^2+y^2}{2\sigma^2}} \quad (6)$$

where, μ and σ is the mean and standard deviation respectively.

- ***Mean Filter***

It is a simple sliding window spatial filter of linear class. It replaces the center value in the window of an image with average of all the pixel values in the window. There exist several types of mean filter such as arithmetic mean filter, geometric mean filter, harmonic mean filter etc. These filters respond differently in presence of different noises [10]. The simplest form of mean filter is arithmetic mean which is expressed in Eq. (7). It computes the average value of corrupted image *g(x, y)* in the area defined by S_{xy}, where S_{xy} represents the set of coordinates in a rectangular sub image window of size S_{xy} . Effects of mean filter applied on various noises of 'ब' image as shown in Fig. 3(ii). The *f(x, y)* is the restored image at point *(x, y)* which is simply computed using the pixels defined by $m \times n$ region.

$$f(x,y) = \frac{1}{mn}\sum_{(s,t)\in S_{xy}} g(x,y) \quad (7)$$

B. Non- Linear Filter

Non-Linear filters are considered as order-statistics filters. Basically, these filters are based on ordering (termed as ranking) the pixels. Further the value of the center pixel contains the value determined by ranking result. Median filters are measured effectively and provide excellent noise reduction capabilities. In order to overcome the shortcomings of linear filter, variety of non-linear median filter such as rank conditioned, weighted median, relaxed median, rank selection have been developed for further processing [7][10]. Non linear filters whose performance study has been carried out are described below.

- ***Median Filter***

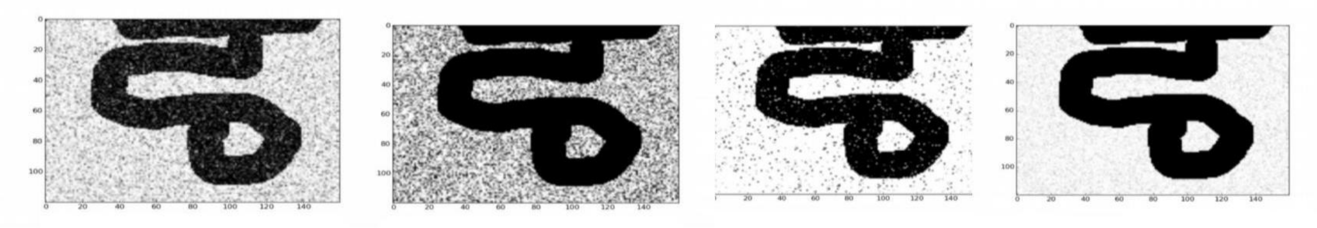
It is based on order statistics and chiefly measured as order filter. Median filters are primarily effective in presence of impulse noise mainly; salt & pepper noise. It changes the image intensity mean value, if the spatial noise distribution in the image is not symmetrical within the window. In order to provide a symmetrical window shape, the median filter preserves the location and the shape information of edges [9][10]. It replaces the center value of the pixel by median of the pixel values under filter region which is expressed in Eq. (8) as:

$$f(x,y) = \underset{(s,t)\in S_{x,y}}{median}\{g(s,t)\} \quad (8)$$

Eq. (9) represents an NxN image and window W(x, y) along with pixels (x, y) being the midpoint of W. The pixel intensity values of pixels in W are ordered from smallest to the largest as follows:

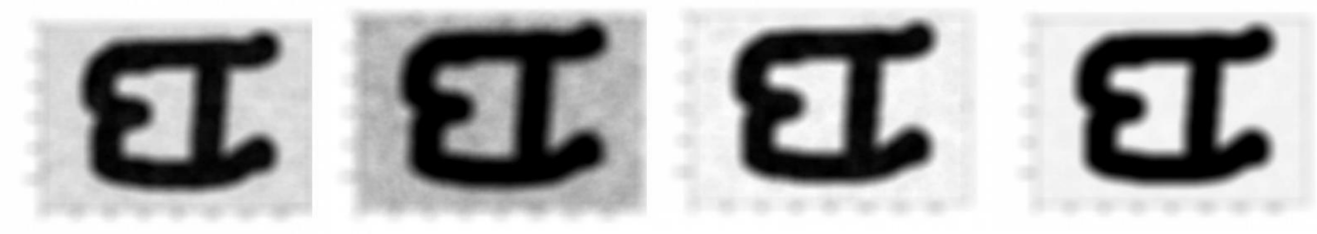
$$W(x,y) = \begin{bmatrix} 110 & 110 & 104 \\ 100 & 114 & 104 \\ 95 & 88 & 85 \end{bmatrix} \Rightarrow \text{Median } (W(x,y)) = 104 \quad (9)$$

Median filter selects the middle value as the value of (x, y), which is applied on scanned 'ढ' image of Modi consonants as shown in Fig. 4(i).



(a)With Gaussian Noise (b) With Poisson Noise (c) With S&P Noise (d) With Speckle Noise

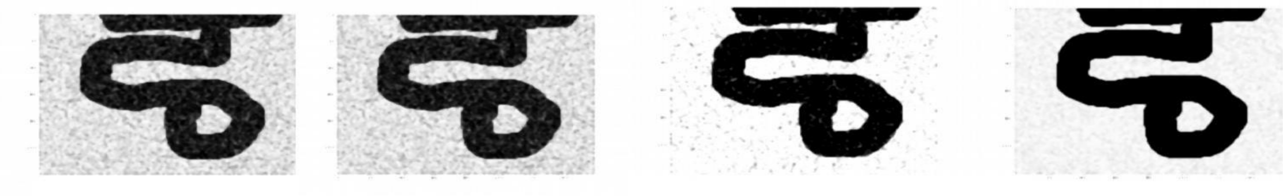
(i) Gaussian Filter using ‘ढ़’ image



(a)With Gaussian Noise (b) With Poisson Noise (c) With S&P Noise (d) With Speckle Noise

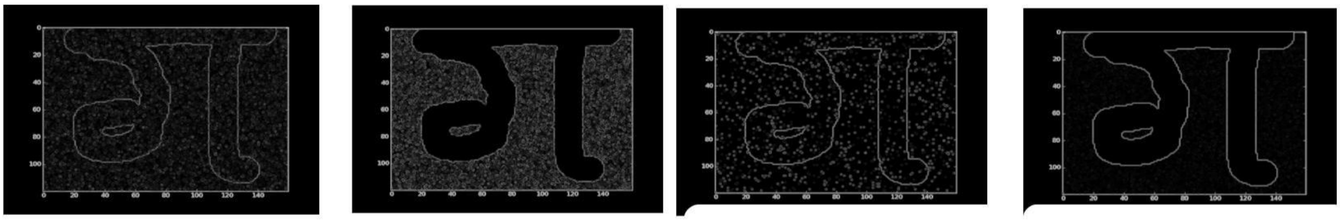
ii) Mean Filter using ‘ब’ image

Fig. 3: Performance of Linear Filters on Modi Consonants



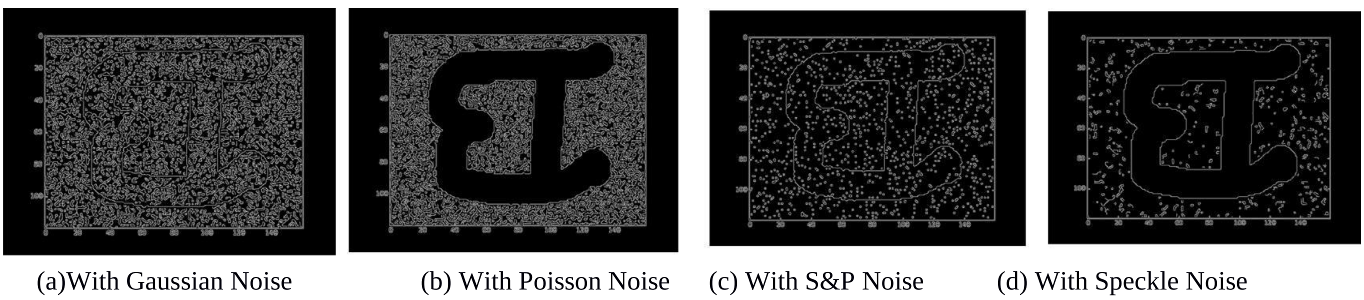
(a)With Gaussian Noise (b) With Poisson Noise (c) With S&P Noise (d) With Speckle Noise

(i) Median Filter using ‘ढ़’ Image



(a)With Gaussian Noise (b) With Poisson Noise (c) With S&P Noise (d) With Speckle Noise

(ii) Sobel Filter using ‘ग’ Image



(a)With Gaussian Noise (b) With Poisson Noise (c) With S&P Noise (d) With Speckle Noise

(iii) Canny Filter using ‘ब’ image

Fig. 4: Performance of Non-Linear Filters on Modi Consonant

- ***Sobel Filter***

Sobel filtering technique is particularly used in edge detection algorithm in order to create an image emphasizing edges. An edge in image occurs when gradient is greatest, and Sobel operator produces better approximations of the gradients exist in an image. It is a discrete differential operator and performs a 2-D spatial gradient measurement on an image to emphasize regions of high spatial frequency that corresponds to the edges [10]. The operator utilizes two 3x3 kernels: one estimates the gradient in the x-direction, while the other one estimates the gradient in the y-direction [11]. It is based on convolving the image with both kernels to approximate the derivatives in horizontal and vertical change. At each point of an image, the gradient magnitude can be approximated using Eq. (10). It highlights the small specs such as foreign matter/ miniscule imperfections as well as enhances small discontinuities. Edge detection of 'ग' image of Modi consonants on various noises is shown in Fig. 4(ii).

$$G = \sqrt{G_x^2 + G_y^2} \qquad (10)$$

- ***Canny Filter***

Canny filter is also considered as an edge detection technique and widely known as optimal detector. Canny operator uses a multi-stage algorithm to detect a wide range of edges in an image. It significantly reduces the amount of data in an image while preserving the structural properties which are used for further image processing. The adjustable parameters improve the effectiveness of canny method. Small filters are preferable for detection of small, sharp lines; since it causes fewer instances of blurring where as large filters are desirable for detecting larger, smoother edges. However, it causes higher instances of blurring. It also enhances the signal to noise ratio and immune to noisy environment. Effects of Canny filter applied on 'ब' image of Modi consonants along with several noises is shown in Fig. 4(iii).

V. COMPARATIVE STUDY OF FILTERS ON MODI CONSONANTS

It is worth to state that the performance parameters such as Mean Square Error and Peak to Signal Noise Ratio are highly useful for further analysis. Thus, we discuss these two performance parameters in brief first. Subsequently, case study is prepared to compare performance of various filters along with existing noises on Modi consonants.

A. Performance Parameters:

It is recognized as a measure of image quality. In order to quantify the clarity of an image as well as achieve good discrimination, an effective measure of image clarity is used. Two commonly used measures are mainly; Mean Square Error and Peak to Signal Noise Ratio which is described as follows:

- ***Mean Square Error (MSE):***

MSE is usually applied when the distortion is caused by degradation of additive noise. The MSE is the cumulative square error between the encoded and the original image defined in Eq. (11):

$$MSE = \frac{1}{m*n} \sum_0^{m-1} \sum_0^{n-1} \| f(i,j) - g(i,j) \|^2 \qquad (11)$$

Where *f* is the original image and *g* is the noisy image. The dimension of the images is m x n. Thus, MSE should be as low as possible for effective noise removal.

- ***Peak to Signal Noise Ratio (PSNR):***

It is usually expressed in terms of the logarithmic decibel scale and measured as peak error. PSNR is the ratio between maximum possible power of a signal and the power of distorting noise which affects the quality of its representation. It is defined in Eq. (12) as:

$$PSNR = 20 * log_{10}\left(\frac{MAX_f}{\sqrt{MSE}}\right) \qquad (12)$$

Where, MAX_f is the maximum signal value that exists in our original noise free image. The signal value for MAX_f is considered as 255 when pixels are represented using 8 bits per sample.

B. A Comparative Study FTs and NSs

In the absence of noise, the two images *f* and *g* are identical thereby value of MSE is represented as zero whereas the value of PSNR is measured as infinite. The minimum value for MSE shows slighter amount of noise in an image. On the other hand, maximum value for PSNR indicates ratio of noise in minute quantity on an image. Thus, it is obvious that the noise removal scheme having a lower MSE and higher PSNR can recognize an image in an efficient way. We represent this scheme as {*min*(MSE), *max*(PSNR)}.

We have studied the performance of various noise removal techniques by introducing different types of noises on Modi consonants and shown it in Table II. It is evident that there exist a variety of results in Table II and hence, we discuss the observations in terms of cases as follows:

Case I: Comparative Performance of Filters

This case pertains to the scheme possessing minimum value for MSE and maximum value for PSNR in favor of each filter. As depicted in Table II, the scheme for median filter on Salt & Pepper Noise is {0.002, 22.28}. Thus, it is evident that the performance of median filter for Salt & Pepper Noise shows effective results for recognition of Modi Consonants. Moreover, the performances of Gaussian filter and Mean filter show effective results in presence of speckle noise i.e. with {0071, 21.38} and {.0088, 20.55) respectively as highlighted in Table II. On the other hand, Sobel and Canny filters with poisson noise show the better performance as highlighted.

Case II: Performance Study of FTs and NSs on Modi Consonants

Using aforesaid scheme, we analyze the results of various filtering techniques corresponding to different Modi consonants as described in Table II. It is observed that the usage of Median filter in presence of S&P noise for image of 'क' consonant results significantly in to the schematic value as {.002, 22.28}. Similarly, it is apparent that Median filter works well with S&P noise on the images of 'ब' and 'ग' consonants as highlighted in Table II. It is important to notice that Gaussian filter performs effectively in case of recognition of the consonants 'ढ़' and 'ज' as the corresponding schematic values are {.0089, 20.42} and {.0072, 21.38} respectively.

TABLE II: MSE & PSNR VALUES OF DEFINED FILTER WITH DIFFERENT NOISES

CONSONANT	Filtering Techniques (FTs)										
	NOISES (NSs)	Gaussian		Mean		Median		Sobel		Canny	
		MSE	PSNR	MSE	PSNR	MSE	PSNR	MSE	PSNR	MSE	PSNR
ब	Gaussian	.0279	15.59	.0294	15.30	.0162	17.30	.491	3.08	.541	2.66
	Poisson	.0637	11.95	.0645	11.90	.0482	13.16	.369	4.32	.436	3.59
	S&P	.0102	19.81	.0115	19.36	.0062	20.81	.606	2.17	.605	2.17
	Speckle	.0089	20.55	.0103	19.85	.0084	20.53	.582	2.49	.608	2.30
ढ़	Gaussian	.0274	15.44	.0295	15.31	.0185	17.31	.474	3.24	.535	2.71
	Poisson	.0631	12.24	.0635	11.97	.0536	12.70	.352	4.52	.421	3.75
	S&P	.0103	19.73	.0121	19.20	.0140	18.66	.586	2.32	.592	2.27
	Speckle	.0089	20.42	.0107	19.68	.0158	18.53	.563	2.49	.588	2.30
क	Gaussian	.0268	15.67	.0276	15.58	.0148	18.29	.478	3.20	.534	2.72
	Poisson	.0107	12.55	.0121	12.97	.0093	15.69	.527	2.77	.456	3.40
	S&P	.0092	20.11	.0108	19.64	.0020	22.28	.578	2.37	.576	1.57
	Speckle	.0071	21.22	.0091	20.19	.0086	19.64	.561	2.51	.589	2.29
ज	Gaussian	.0252	15.84	.0268	15.71	.0137	18.60	.531	2.75	.557	2.53
	Poisson	.0650	12.17	.0666	11.75	.0377	13.47	.392	4.06	.453	3.44
	S&P	.0084	20.67	.0097	19.94	.0087	20.45	.634	1.97	.637	1.95
	Speckle	.0072	21.38	.0088	20.55	.0096	20.11	.628	2.01	.643	1.91
ग	Gaussian	.0277	15.56	.0291	15.36	.0154	18.11	.472	3.26	.532	2.73
	Poisson	.0613	11.85	.0637	11.95	.0449	14.22	.345	4.61	.418	3.79
	S&P	.0102	19.90	.0101	19.32	.0081	21.06	.585	2.37	.582	2.34
	Speckle	.0087	20.62	.0101	19.92	.0178	19.95	.557	2.53	.581	2.35

VI. Conclusion

In general, noise is generated due to random variations of intensity values in an image during image acquisition. We have studied different types of noises that affect the quality of images of Modi consonants particularly. Also, several filtering techniques have been explored on the consonants along with aforesaid noises. Using the scheme i.e. {min(MSE), max(PSNR)}, we have presented a comparative study of filtering techniques using several noises on Modi consonants. On the basis of this study, it is advisable to use median filters in presence of S&P noise as it works significantly on scanned image of Modi consonants. This study will be highly useful to enhance as well as to restore the structural properties of scanned images.

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