Universal De-Noising Framework with a New Impulse Detector Algorithm

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Abstract

In this paper, new detection mechanism for universal noise and a universal noise-filtering framework based on the nonlocal means (NL-means) has been proposed. It introduce new statistics ROR for describing the outlyingness of the pixels and propose a new detection mechanism. The proposed approach can be adapted to various models such as salt and pepper impulse noise and random-valued impulse noise by modifying some parameters in the algorithm. Extensive simulations reveal that the performance of the proposed algorithm is impressive as compared to the previously used median filter.

1. Introduction

Digital images are representation of 2-dimensional images as set of pixel-intensity values. Digitization implies that a digital image is an approximation of a real scene. In a mathematical view, a monochromatic image is a two dimensional function f(x, y) where x and y are spatial coordinates, and the amplitude of at any pair of coordinates(x, y) is called the intensity or gray level of the image at that point. There are three types of digital images based on the number bits required to store the intensity value for each pixel position:

Black and White (1 bit per pixel) are the simplest type of images and can take only 2 values-black and white, or 0 or 1 and thus only 1 bit is required to represent every pixel. These types of images are frequently used in applications where the only information required is general shape or outline. Binary images are created from gray-scale images using a threshold operation where all the pixels above the threshold value is turned white ('1') and those below are turned black ('0'). Greyscale (8 bits per pixel): are referred to as monochrome (one-color) images. They provide gray level information and no colour information. The number of bits per pixel determines the gray levels available. The typical gray-scale image contains 8-bits/pixel allowing 256 gray-levels.

2. Noise

Noise means any unwanted signal. Image noise is random (not present in the object image) variation of brightness or colour information in images, and is usually an aspect of electronic noise. Digital images could be contaminated by noise during image acquisition and transmission. Little useful information can be acquired from the corrupted images without their being restored, and the corrupted images severely impede subsequent image processing operations. Thus digital image processing is performed to restore the images for subsequent use. Most noise added to images can be adequately represented by two models, namely, additive Gaussian noise and impulse noise. Gaussian noise affects all pixels of the image. Such noise is usually introduced during image acquisition. Gaussian noise represents statistical noise having probability density function (PDF) equal to that of the normal distribution, which is also known as the Gaussian distribution. In other words, the values that the noise can take on are Gaussian-distributed.

The probability density function p of a Gaussian random variable z is given by:

$$p_G(z) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(z-\mu)^2}{2\sigma^2}}$$

Where z represents the grey level, μ the mean value and σ the standard deviation.

A special case is white Gaussian noise, in which the values at any pair of times are identically distributed and statistically independent (and hence uncorrelated). In communication channel testing and modelling, Gaussian noise is used as additive white noise to generate additive white Gaussian noise. Principal sources of Gaussian noise in digital images arise during acquisition eg. sensor noise caused by poor illumination and/or high temperature, and/or transmission eg. electronic circuit noise. In digital image processing Gaussian noise can be reduced using a spatial filter, though when smoothing an image, an undesirable outcome may result in the blurring of fine-scaled image edges and details because they also correspond to blocked high frequencies. Conventional spatial filtering techniques for noise removalinclude: mean (convolution) filtering, median filtering and Gaussian smoothing.

Impulse noise is characterized by replacing a portion of an image pixel with noise values, leaving the remainder unchanged. When an image is corrupted by impulse noise, only a portion of the pixels are changed.

To be precise, let $x_{i,j}$ and $y_{i,j}$ be the pixel values at location (i,j) in the original and noisy images, respectively, and $[n_{min}, n_{max}]$ be the dynamic range of the allowed pixel values.

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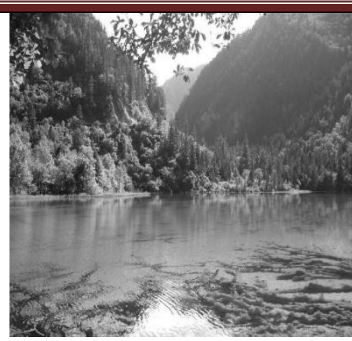
		
Fig: 1.	**Fig: 2.**	**Fig: 3.**

There are two cases of noise distributions for impulse noise, namely, fixed valued (also called salt-and-pepper) impulse noise and random valued impulse noise. For fixed-valued impulse noise, the values of the corrupted pixels are equal to nmin or nmax with equal probability. For random-valued impulse noise, however, the corrupted pixels are uniformly distributed between nmin and nmax. For gray-level images with 8 bits per pixel (i.e.,n_{min}=0 and $n_{max=}$255), the noise value $n_{i,j}$ of the first case corresponds to a fixed value of 0 or 255 with equal probability, whereas that of the second case corresponds to a random value uniformly distributed between 0 and 255. Cleaning random valued impulse noise is far more difficult than removing fixed valued noise because, in the latter case, the differences of the pixel values between a noisy pixel and its noise-free neighbours are often significant.

Image Processing

Image processing is a method to convert an image into digital form and perform some operations on it, in order to get an enhanced image or to extract some useful information from it. It is a type of signal dispensation in which input is image, like video frame or photograph and output may be image or characteristics associated with that image. Usually Image Processing system includes treating images as two dimensional signals while applying already set signal processing methods to them.

Image processing focuses on two major tasks that are improvement of pictorial information for human interpretation and processing of image data for storage, transmission and representation for autonomous machine perception

Image processing refers to processing of a 2D picture by a computer. Basic definitions:

An image defined in the “real world” is considered to be a function of two real variables, for example, a(x,y) with a as the amplitude (e.g. brightness) of the image at the real coordinate position (x,y).

Modern digital technology has made it possible to manipulate multi-dimensional signals with systems that range from simple digital circuits to advanced parallel computers. The goal of this manipulation can be divided into three categories:

- Image Processing (image in -> image out)
- Image Analysis (image in -> measurements out)
- Image Understanding (image in -> high-level description out)

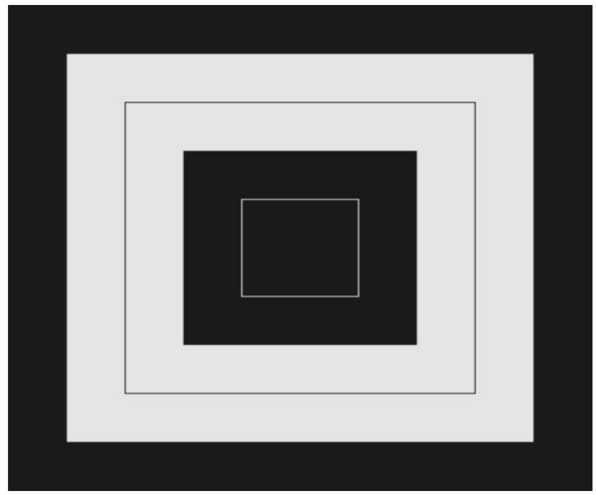


Fig: 2. Without Noise

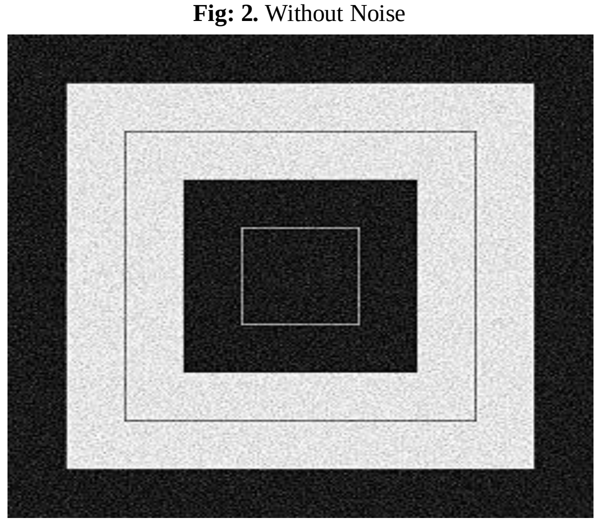


Fig: 3. With Gaussian Noise

An image may be considered to contain sub-images sometimes referred to as regions-of-interest, ROIs, or simply regions. This concept reflects the fact that images frequently contain collections of objects each of which can be the basis for a region. In a sophisticated image processing system it should be possible to apply specific image processing operations to selected regions. Thus one part of an image (region) might be processed to suppress motion blur while another part might be processed to improve color rendition. Sequence of image processing:

Most usually, image processing systems require that the images be available in digitized form, that is, arrays of finite length binary words. For digitization, the given Image is sampled on a discrete grid and each sample or pixel is quantized using a finite number of bits. The digitized image is processed by a computer. To display a digital image, it is first converted into analog signal, which is scanned onto a display.

Closely related to image processing are computer graphics and computer vision. In computer graphics, images are manually *made* from physical models of objects, environments, and lighting, instead of being acquired (via imaging devices such as cameras) from *natural* scenes, as in most animated movies. Computer vision, on the other hand, is often considered *high-level* image processing out of which a machine/computer/software intends to decipher the physical contents of an image or a sequence of images (e.g., videos or 3D full-body magnetic resonance scans).

In modern sciences and technologies, images also gain much broader scopes due to the ever growing importance of scientific visualization (of often large-scale complex scientific/experimental data). Examples include microarray data in genetic research, or real-time multi-asset portfolio trading in finance.

Before going to processing an image, it is converted into a digital form. Digitization includes sampling of image and quantization of sampled values. After converting the image into bit information, processing is performed. This processing technique may be Image enhancement, Image restoration, and Image compression.

Image Enhancement

It refers to accentuation, or sharpening, of image features such as boundaries, or contrast to make a graphic display more useful for display & analysis. This process does not increase the inherent information content in data. It includes gray level & contrast manipulation, noise reduction, edge crispening and sharpening, filtering, interpolation and magnification, pseudo coloring, and so on.

Image Restoration

It is concerned with filtering the observed image to minimize the effect of degradations. Effectiveness of image restoration depends on the extent and accuracy of the knowledge of degradation process as well as on filter design. Image restoration differs from image enhancement in that the latter is concerned with more extraction or accentuation of image features.

Image Compression

It is concerned with minimizing the number of bits required to represent an image. Application of compression are in broadcast TV, remote sensing via satellite, military communication via aircraft, radar, teleconferencing, facsimile transmission, for educational & business documents, medical images that arise in computer tomography, magnetic resonance imaging and digital radiology, motion, pictures, satellite images, weather maps, geological surveys and so on.

- Text compression – CCITT GROUP3 & GROUP4
- Still image compression – JPEG
- Video image compression - MPEG

The purpose of image processing is divided into 5 groups. They are:

Visualization: Observe the objects that are not visible. Visualization is any technique for creating images, diagrams, or animations to communicate a message. Visualization through visual imagery has been an effective way to communicate both abstract and concrete ideas since the dawn of man.

Image Sharpening: To create a better image.Image sharpening is a powerful tool for emphasizing texture and drawing viewer focus. It's also required of any digital photo at some point — whether you're aware it's been applied or not. Digital camera sensors and lenses always blur an image to some degree, for example, and this requires correction.

Image Restoration: Image Restoration is the removal of noise (sensor noise, motion blur, etc.) from images. The simplest possible approach for noise removal is various types of filters such as low-pass filters or median filters. More sophisticated methods assume a model of how the local image structures look like, a model which distinguishes them from the noise. By first analysing the image data in terms of the local image structures, such as lines or edges, and then controlling the filtering based on local information from the analysis step, a better level of noise removal is usually obtained compared to the simpler approaches.

Image Retrieval: Seek for the image of interest. An image retrieval system is a computer system for browsing, searching and retrieving images from a large database of digital images. Most traditional and common methods of image retrieval utilize some method of adding metadata such as captioning, keywords, or descriptions to the images so that retrieval can be performed over the annotation words.

Image Recognition: The identification of objects in an image. This process would probably start with image processing techniques such as noise removal, followed by (low-level) feature extraction to locate lines, regions and possibly areas with certain textures.

Filter (Median Filter)

Nonlinear filters have been developed for removing impulse noise. Among them, one of the most popular and robust nonlinear filters is the median filter. In median filtering a window size is selected and the centre pixel value is replaced with the median of the intensity values in the neighborhood of that pixel. The various advantages of median filter are that it has a good de-noising power, simple implementation, and high computational efficiency. Also there is no reduction in contrast across steps, since output values available consist only of those present in the neighborhood. Disadvantage of the median filter is that, in many cases, it removes desirable details: sometimes it alters the clean pixels as well and in certain cases the edges get blurred after median filtering. This is particularly a problem when the noise density is high. Also a median filter is more expensive than a smoothening filter.

To obtain improved performance, various generalized and modified median-based filters have been proposed. Nevertheless, they are still uniformly implemented across the image without considering whether the current pixel is noise free or not. As a result, this would inevitably alter the intensities and remove the image details contributed from uncorrupted pixels and cause image quality degradation. To deal with this problem, one solution is to introduce a noise-detection mechanism, prior to filtering, to identify the corrupted pixels and, meanwhile, leaving the uncorrupted pixels unaltered.

Algorithm: Introduce Salt & Pepper Noise to the given grayscale image. The procedure for filtering is carried out in two stages:

- Coarse
- Fine

Coarse Filtering

- A [5x5] window is taken into consideration and the median (med) is calculated.
- The median calculated above is used to compute the Median absolute deviation(MAD) and the Normalized Median absolute deviation(MADN) as follows:-
  MAD=Med {|y-Med(y)|}
  MADN=MAD(y)/0.6457
- Using the above MADN value, the ROR(Robust Outlyingness Ratio) is calculated as follows:-
  ROR ($y_{i,j}$)=|($y_{i,j}$- Med(y))/ MADN(y)|
- Using the ROR values, the pixels are divided into four clusters. The four clusters are the most like cluster
  ROR>3;
  The second like cluster 2<ROR<=3;
  The third like cluster 1<ROR<=2;
  and the fourth like cluster 0<=ROR<=1.
- If the ROR value is greater than 1, then calculate the absolute deviation (dev) between the current pixel and the median of its local window. Then compare the deviation with the Threshold (provided for different noise levels) (tc1, tc2, tc3) according to the ROR values.
- If the deviation is greater than the threshold, replace it with the median of the local window
- Repeat steps from (1) to (6) for a particular number of iterations (mc) that is specified for a given noise level.

Fine Filtering

- Repeat steps (1) to (4) of coarse filtering.
- Calculate the absolute deviation between the current pixel and the median of its local window. Then compare the deviation with the Threshold (provided for different noise levels) (tc1, tc2, tc3, tc4) according to the ROR values.
- If the deviation is greater than the threshold, replace it with the median of the local window.
- Repeat steps from (1) to (3) for a particular number of iterations (mc) that is specified for a given noise level.

Procedure

Robust Outlyingness Ratio (ROR)

To solve the problems associated with the prior techniques of image noise filtering a new detection mechanism for universal noise detection and a universal noise-filtering framework has been proposed. A new detector based on new statistics called Robust Outlyingness Ratio (ROR), is used to measure how much a pixel looks like an impulse noise.

The operation is carried out in two stages, i.e., detection followed by filtering. Several experiments have proved that mean and standard deviation (SD) are not very reliable estimates for finding the centre of data outlier present. To avoid the problems associated with these statistics this method uses more robust statistics which are variations of the older methods. The sample median and the normalized median absolute deviation (MADN) are robust versions of mean and SD, respectively:

MADN(y) = MAD(y)/0.6457
MAD(y) = Med {|y-Med(y)|}
Med(y) = Median (y1, y2, y3……yn)

The ROR value is calculated as

ROR($y_{i,j}$) = |($y_{i,j}$-Med(y))/MADN(y)|

ROR of each pixel in an image is calculated as follows. Let $y_{i,j}$=(i,j) be the location of the pixel under consideration, and let

Ωy(N)={$y_{i+k,j+l}$:-N<=l, k<=N}

be the set of points in a (2N+1)*(2N+1) neighbourhood centred at $y_{i,j}$ for some positive integer N.

Med(Ωy(N)) is the median value of all pixels in Ωy(N), i.e.,

Med (Ωy(N))=Median(Ωy(N))

Then, calculate median absolute deviations MAD (Ωy(N))and MADN (Ωy(N)) are:

MAD (Ωy(N)) =Med{ (Ωy(N))- Med (Ωy(N))}
MADN (Ωy(N))=MAD(Ωy(N))/0.6457

Finally, the ROR of the pixel $y_{i,j}$ can be obtained as

ROR ($y_{i,j}$)=|($y_{i,j}$ -Med(Ωy(N)))/MADN(Ωy(N))|

For detection, first, the Robust Outlyingness Ratio (ROR) is calculated and then all the pixels are divided into four clusters according to the ROR values. ROR measures the outlyingness of the pixels, i.e., how impulse like a pixel is. Based on this value all pixels are divided into four levels (clusters). The four clusters are: the most like cluster ROR>3; the second like cluster 2<ROR<=3; the third like cluster 1<ROR<=2; and the fourth like cluster 0<=ROR<=1. The lower the ROR, the lower impulse the pixel is.

Table: 1.

Noise Ratio	The most like level ($ROR > 3$)	The second level ($2 < ROR \le 3$)	The third level ($1 < ROR \le 2$)	The fourth level ($0 \le ROR \le 1$)
Noise-free	2045	10059	41688	208352
10%	21305	7868	34056	198915
20%	39238	7093	26451	189362
30%	54517	8254	21260	178113
40%	62540	11590	20443	167571

3. Number of the Pixels in Each Level of Lena with Different. Noise Ratios About Random-Valued Impulse Noise

Coarse and Fine Strategy

Second, different decision rules are used to detect the impulse noise. In order to make the detection results more accurate and more robust, the from-coarse-to-fine strategy and the iterative framework are used. For the sake of detecting the impulse noise, the absolute difference between the processed pixel and the median of its neighbours is calculated. Then, the difference is compared with a pre-given threshold to judge the impulse noise. Since the pixels have different degrees of the impulse like, different thresholds are adopted in different clusters. After each iteration, the median- based output of the input is obtained according to the detection result, and this restored image is used as an input for the next iteration. The first input image of the fine stage is the final output image of the coarse stage

Coarse Stage

Step: 1. Choose the algorithm parameters, i.e., coarse thresholds T1, T2, T3 and window size N(the actual size is((2N + 1) X (2N+1)); iterations mC; and initial j=1.
Step: 2. Initialize the detection flag matrix map as zeroes, where “0s” and “1s” represent good and noisy pixels, respectively.
Step 3. Calculate the ROR of the current pixel. If the ROR is in the fourth level, treat it as a good pixel, or calculate the absolute deviation d between the current pixel and the median of its local window. Then, compare d with threshold T_k according to its ROR value. If d is larger than T_k, it is a noisy pixel, or it is a good pixel. Update the flag Map according to the result.
Step: 4. Get the median-based restored image I according to the detection result. If the flag is 1, represent the pixel with the median of its local window, or do not change.
Step: 5. If J<=m_c, j=j+1, then go to step 2), or the coarse stage is completed.

5.2.2 Fine stage

Step: 1. Choose the algorithm parameters, i.e., fine thresholds T1,T2 ,T3 and T4 ; window size N(the actual size is (2N + 1) X (2N+1)); iterations mf; and initial j=1.
Step: 2. Initialize the detection flag matrix MAP as zeros, where “0s” and “1s” represent good and noisy pixels, respectively.
Step: 3. Calculate the ROR of the current pixel and the absolute deviation d between the current pixel and the median of its local window. Then, compare d with threshold T_k according to its ROR value. If d is larger than T_k, it is a noisy pixel, or it is a good pixel. Update the flag Map according to the result.
Step: 4. Get the median-based restored image I with the detection result. If the flag is 1, represent the pixel with the median of its local window, or do not change.
Step: 5. If j<=m_f, j=j+1, then go to step 2), or the fine stage is completed.

These thresholds T_1, T_2, T_3 and T_4 are very critical in the detection process. If the thresholds are too large, the “false hit” term is small and the “miss” term is large. In contrast, if the thresholds are too small, the “false-hit” term is large and the “miss” term is small.

In order to keep a good balance between the “false-hit” and “miss” terms, the from-coarse-to-fine ideal is used, and the detection procedure is divided into two stages, i.e., the coarse stage followed by the fine stage. In the coarse stage, the relatively larger thresholds are adopted. Then, the “false hit” term is small and the “miss” term is large. In the coarse stage, the purpose is to detect the most impulse like pixels and keep the “false-hit” term as low as possible, and then in the fine stage, the purpose is to detect the most impulse like noise while keeping a good trade-off between the “false-hit” and “miss” terms. Therefore, the thresholds of the coarse stage are relatively larger, and the thresholds of the fine stage are smaller.

Through extensive experiments, the following suitable parameters are obtained:
For the window size N=2, i.e., 5 X 5; the coarse threshold is [40, 50, 60] for tc1, tc2, and tc3, respectively; the fine threshold is [30, 30, 40, 50] for tf1, tf2, tf3 and tf4 respectively.

Number of Iterations

The number of the iterations is very important to the quality of the output because iterative filtering has to be stopped before it starts to severely destroy image details.

Table: 2.

Noise type	Noise ratio (p)	The number of Coarse iterations	The number of Fine iterations
Random-valued impulse noise	[0,30%]	[3,5]	[1,2]
	(30%,60%]	[5,7]	[3,5]
	(60%,70%]	[8,10]	[6,8]
Fixed-valued impulse noise	[0,25%]	[3,4]	[2,4]
	(25%,60%]	[5,7]	[5,7]
	(60%,90%]	[8,10]	[8,10]

Suitable Number Of Iterations For Random-Valued Impulse Noise And Fixed-Valued Impulse Noise

4. Characteristics of the method

4.1 Hierarchical

The pixels in the image are divided into four clusters based on the value ROR, and they independently detect impulse noise in every cluster.

4.2 Progressive

The from-coarse-to-fine strategy is adopted, and the detection mechanism contains two stages, i.e., the coarse and fine stages. The detection results become more and more accurate.

4.3 Iterative

The iterative framework is adopted by our method.

4.4 Anisotropic

The decision rule with different thresholds is used in different clusters.

5. Results

Simulations are carried out to verify the noise-removing capability of the ROR-NLM filter, and the results are compared with existing median filters. Our method produces results superior to those of most methods in both visual image quality and quantitative measures. Simulations are made on several 512 X 512 8-bit grayscale standard test images with salt-and-pepper impulse noise, random-valued impulse noise, and mixed noise.

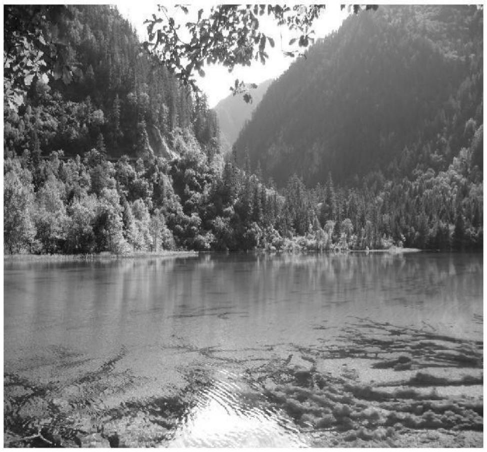


Fig: 4. Original image (I)

Noise level=0.15

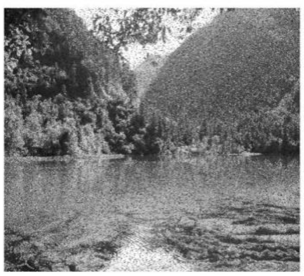


Fig: 5a. Noised Image

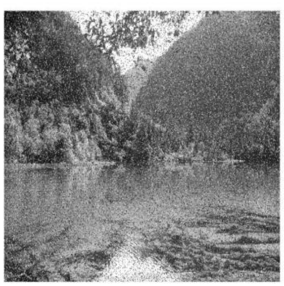
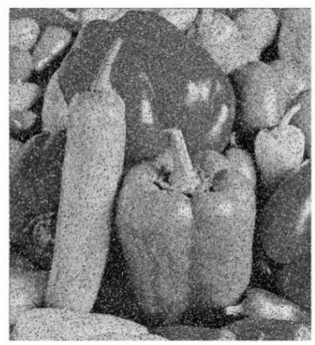


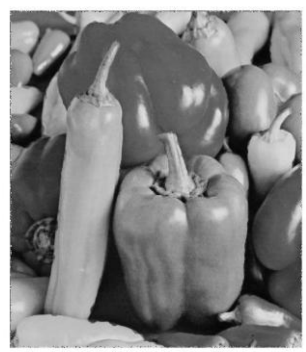
Fig: 5b. After Median Filtering

Fig: 5c. After ROR Filtering

Original Image (III)

Fig: 6.





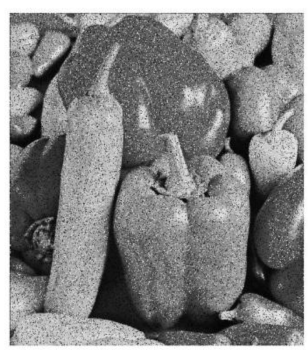


Fig: 7.

6. Conclusion

The main contribution of this paper can be summarized as follows: introduce new statistics ROR for describing the outlyingness of the pixels and propose a new detection mechanism. The proposed approach can be adapted to various models such as salt-and-pepper impulse noise and random-valued impulse noise by modifying some parameters in the algorithm.

Extensive simulations reveal that the performance of the proposed algorithm is impressive as compared to the previously used median filter.

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