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Salt and pepper noise removal from images: An extensive analysis

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Abstract
In the process of image acquisition and transmission, the digital images are often corrupted with impulse noise. This is mainly because of the errors in the sensors or in the communication channel. It is highly imperative that this noise should be removed prior to its subjection for further processing, such as edge detection, image segmentation, object recognition, and pattern recognition. Various methods have been developed for salt and pepper noise removal from corrupted images. This paper analyses the various methods proposed for removal of salt and pepper noise from images.

Keywords: Salt and Pepper noise, B-spline, Cardinal B-spline

1. Introduction

In the process of image acquisition and transmission, the digital images are often corrupted with impulse noise. This is mainly because of the errors in the sensors or in the communication channel. It is highly imperative that this noise should be removed prior to its subjection for further processing, such as edge detection, image segmentation, object recognition, and pattern recognition. Various methods [1–15] have been developed for impulse noise removal from corrupted images. Median filters have been extensively used for the removal of impulse noise. They are simple yet very effective in the removal of salt and pepper type impulse noise. The limitation of median filters is that they modify good pixels too; therefore, impulse detection algorithms play a crucial role in noise removal. In [16], the progressive switching median (PSM) filter has been developed for removing impulse noise from highly corrupted images. It works by using an impulse detection algorithm and then iteratively detecting and filtering impulse noise, and hence, it performs heavy computation. In [17] an efficient detail-preserving adaptive median filter has been proposed for image denoising. In [18] Unser has elaborated the framework for using Splines in signal and image processing detection. In [19] B-spline wavelets are used for the noise removal. In [20] a method to work with salt and pepper noise using second generation wavelets had been discussed. Most of the algorithms used for the salt and pepper noise removal replace the original value with the median and lead to lot of distortion in the image. After the removal of the noise, the edges get jittered and the details of the image should be preserved so that the image is intact. When an image is corrupted by salt and pepper noise, the intensity values change to 0 and 255. In this synopsis, an analysis and application of cardinal B-splines, Cardinal Splines, Lifting Scheme, Adaptive Particle Swarm Optimization (APSO) and edge detail preservation using Cardinal Splines for image noise cancellation have been presented. To apply the cardinal B-splines to the various fields, one should analyze the different properties of the cardinal B-spline. Here we make use of the interpolation property and compact support of the cardinal B-splines [21]. Cardinal Splines have been an integral part of computer graphics for many years. It has been proposed that the noisy pixels have been identified and removed in the first phase and only these noisy pixels are involved in cardinal spline edge preservation process in the second phase. In the proposed Lifting Scheme Algorithm for image de-noising, using Split, Predict and Update steps, the salt and pepper noise from the image is removed. In the proposed APSO Algorithm, a new neighborhood average filter has been used in image noise removal by iterative process of searching. To test the effectiveness of proposed algorithm, the images corrupted up to 95% of salt and pepper noise are used. This paper analyzed different algorithms to cancel the salt and pepper noise from the image. Section II describes algorithmic analysis, section III tells about performance measurement, section IV describes results and discussions followed by conclusion in section V.

2. Algorithmic Analysis

Cardinal B-Splines being an integral part of Computer Graphics has been applied in the recent past for image processing applications. We have used the concept of Cardinal B-Splines for Interpolation of the noise free pixels. The main reason for using cardinal B-spline basis is that the interpolation is more proper, since the continuity condition is maintained throughout. Also, it is found that the reconstruction is smoother and continuous in the case of cubic cardinal B-splines of 4th order. We have developed our method based on cubic cardinal B-splines of 4th order only, so that the above properties are taken into consideration. Michael Unser [22] *et al*. have proved from their results that the cardinal B-spline of order 4 (cubic) guarantees the continuity of the function up to its second-order derivative, which seems to be sufficient for most practical applications. Also, it is proved that the image resolution quality is increased by increasing the order of the cardinal B-spline since the interpolation approximates more closely the ideal**.** The four control points p_0, p_1, p_2 and p_3 are used to set the boundary conditions for the cardinal B-spline.

P(0) = [p0 +4 p1 + p2]/6
P(1) = [p1 + 4 p2 + p3]/6
P'(0) = [p2- p0]/2
P'(1) = [p3- p1]/2

Where P(0) and P(1) are the B-Spline section end points and P'(0) and P'(1) are the slopes at those points.

$$P(u) = \sum_{k=0}^{3} p_k B_{k,3}(u)$$
$$= p_0 B_{0,3}(u) + p_1 B_{1,3}(u) + p_2 B_{2,3}(u) + p_3 B_{3,3}(u)$$

Where

$$B_{0,3}(u) = \frac{1}{6}(u)^3, 0 \le u < 1$$
$$B_{1,3}(u) = \frac{1}{6}\left(u^2(2-u) + u(3-u)(u-1) + (4-u)(u-1)^2\right), 1 \le u < 2$$
$$B_{2,3}(u) = \frac{1}{6}\left((4-u)^2(u-2) + (3-u)(4-u)(u-1) + u(3-u)^2\right), 2 \le u < 3$$
$$B_{3,3}(u) = \frac{1}{6}((4-u)^3), 3 \le u < 4$$

[31] elaborated the techniques of salt and pepper noise removal using cardinal B-splines. The steps are mentioned below.

Step1: Our aim is to first extract the surrounding pixels which are not corrupted by the noise. We require four pixel values for the interpolation of the corrupted pixel. The initial window size used is 3X3. The size of the window is modified according to the noise density.

Step 2: Let *X(i,j)* be the original image and *Y(i,j)* be the image corrupted by the salt and pepper noise. For every pixel of *Y(i,j)*, we start with the initial kernel *S(x,y)*∈*Y(i,j)*. An example of the window size 3X3 is shown below. Where z1 to z9 are the pixel intensities and (*) indicates noisy pixels. The above framework of *S(x,y)* is loaded from *Y(i,j)*.

Step 3: If *S(x,y)* contains the four pixels unaffected by the noise, then those pixel values are used to find the value of the center pixel on which window is centered. Let *L* be the number of noise free pixels in the *S(x,y)* and Z be a vector of 4 pixels unaffected by the noise. If *L* < 4, then the size of the *S(x,y)* is modified as given below:

Case1: If L = 3, the size of the initial window, is not increased but replicate the third value of the Z to get the fourth value and the value of corrupted pixel is interpolated using these four pixels.

Case 2: If L = 2, then the size of the S(x, y) is increased by adding two to its initial size since we need at least four noise-free pixels, i.e. two more noise free pixels and the interpolation on these pixels is repeated.

Case 3: If L = 1, then the size of window is increased by adding four to its initial size.

Case 4: If L = 0, then the size of the window is increased by adding six to its initial size.

3. Performance Measurement

The following parameters are used to check the quality of reconstructed images.

1. Peak Signal to Noise Ratio (PSNR)

The proposed algorithms have been tested for different levels of noise ranging from as low as 5% to as high as 95%. The experimental results have been gauged using the mean square error (MSE) and peak signal-to-noise ratio (PSNR) measures that have been given below.

$$MSE = \frac{1}{mn}\sum_{x=0}^{m-1}\sum_{y=0}^{n-1}(A(x,y) - R(x,y))^2$$

$$PSNR = 10\log_{10}\left(\frac{\max^2}{MSE}\right)$$

Where max is the maximum possible pixel value of the image and its value is 255 in the case of a grayscale image. A and R are the original and the restored images having a resolution of m × n.

2. Structural Similarity Index Measure – SSIM

The Structural Similarity Index Measure (SSIM) [23] is a full reference metric, in other words, the measuring of image quality based on an initial uncompressed or distortion-free image as reference. SSIM is designed to improve on traditional methods like peak signal to-noise ratio and mean-squared error, which have proved to be inconsistent with human eye perception. The measure of structural similarity compares local patterns of pixel intensities that have been normalized for luminance and contrast. In practice, a single overall index is sufficient enough to evaluate the overall image quality.

$$SSIM(x,y)=\frac{(2\mu_x\mu_y-C_1)(2\sigma_{xy}+C_2)}{(\mu_x^2+\mu_y^2+C_1)(\sigma_x^2+\sigma_y^2+C_2)}$$

$$MSSIM(x,y)=\frac{1}{M}\sum_{n=1}^{M}SSIM(x_n,y_n)$$

where M and N are total number of n samples

where μ_x is mean and σ_x is Standard Deviation of image x

and μ_y is mean and σ_y is Standard Deviation of image y

and σ_{xy} is covariance of x and y. C_1 and C_2 are constants given below

$$C_1=(k_1 L)^2=(0.01\times255)^2=6.5025$$

$$and\ C_2=(k_2 L)^2=(0.03\times255)^2=58.5225$$

$$\mu_x=\frac{1}{N}\sum_{i=1}^{N}x_i$$

$$\sigma_x=[\ \frac{1}{N-1}\sum_{i=1}^{N}(x_i-\mu_x)^2)\ ]^{1/2}$$

$$\sigma_{xy}=[\ \frac{1}{N-1}\sum_{i=1}^{N}(x_i-\mu_x)(y_i-\mu_y)\ ]^{1/2}$$

4. Results and Discussions

Fig 1: (a) Original Lena (b) Lena image with 30% noise (c) Restored Lena (PSNR=35.8962dB, MSSIM=0.9619).

Fig 2: (a) Lena image with 50% noise, (b) Restored Lena Image (PSNR = 31.6453 dB, MSSIM=0.9034).

Fig 3: (a) Lena image with 70% noise, (b) Restored Lena Image (PSNR = 28.4566 dB, MSSIM=0.8386).

Method	PSNR (dB)	MSSIM
Cardinal B-splines [31]	28.4566	0.8386
Adaptive median filter [30]	25.8	0.7446
ISM filter [30]	23.4	0.6532
MED filter [30]	23.2	0.6304
PSM filter [30]	19.5	0.4272
MSM filter [30]	19.0	0.3927
DDBSM filter [30]	17.5	0.2643

5. Conclusion

In this work, efficient algorithms for image de-noising along with edge detail preservation using Cardinal Splines, adaptive median filter, ISM filter, MED filter, PSM filter, MSM filter, DDBSM filter have been reviewed. From the presented results, it is clear that the algorithms work efficiently up to the 95% salt and pepper noise., it can be observed that the images corrupted with salt and pepper noise have better Peak Signal to Noise Ratio (PSNR) and Structural Similarity Index Measure (SSIM) values. In the cardinal B-Spline Algorithm, we could achieve 95% removal of salt and pepper noise with maximum PSNR of 23.2633 dB and maximum MSSIM of 0.6304 for Lena image. In future, I would like to explore the random valued impulse noise and its removal with the proposed methods developed.

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