Detailed Study of Low Density Salt and Pepper Noise Removal from Digital Color Images

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Abstract: Color digital images are greatly affected by salt and pepper noise, which negatively affects the clarity of the image and its characteristics. In this paper research we will investigate various filter used to deal with salt and pepper noise, a comparison will be done between these filters according to the calculated values of MSE and PSNR. An improvement procedure will be added to each filter to show how this improvement will enhance the values of MSE and PSNR and thus enhance the quality of the denoised image. Various noise densities will be experimented and it will be shown how median filter can be highly recommended to reduce the negative effects of salt and pepper noise.

Keywords: salt and pepper noise, noise density, convolution, median filter, average filter, MSE, PSNR.

Introduction

Colored digital images are one of the most common and widely used types of digital data, as they are used in many vital and important applications, which require improving them and removing noise from them, especially as they can be exposed to various types of noise that negatively affect the quality of the digital image[1-5].

Digital color image is composed of 3 2D matrixes, one 2D matrix for each color [6-12](red, green and blue) as shown in figure 1, the color pixel has value within the range 0 to 255, each color matrix (channel) can be affected by a noise, and this will lead to disturbed the image making it unclear [13-19].

Figure 1: Color image components

Salt and pepper noise is one of the additive types of noise present in the image during signal acquisition stage or due to the bit error in the transmission. In salt and pepper noise the corrupted pixels take the maximum (i.e. 255) value or the minimum (i.e. 0) value which leads to white and black **spots** in the image [41], [42].

Salt-and-pepper noise is a form of noise sometimes seen on images. This noise can be caused by sharp and sudden disturbances in the image signal. It presents itself as sparsely occurring white and black pixels. An effective noise reduction method for this type of noise is a median filter or a morphological filter [20-25].

Salt and pepper noise affect the quality of the color image by increasing the mean square error (MSE) between the original clear image and the noisy image, and at the same time will decrease the peak signal to noise ratio (PSNR) between the two images. MSE and PSNR can be calculated using equations 1 and 2 [32-40].

MSE of x channel

$$MSE_x = \frac{1}{N} \sum_{i=0}^{m-1} \sum_{j=0}^{n-1} [S(i, j) - R(i, j)]^2, N = m * n \quad (1)$$

Total MSE

$$MSE_t = MSE_R + MSE_G + MSE_B$$

Calculate PSNR

$$PSNR = 10 * \log_{10} \frac{(MAX_I)^2}{MSE_t} \quad (2)$$

Figure 2 shows the negative effects of salt and pepper noise, and how it negatively decreases the image clearance.

Figure 2: Negative effects of salt and pepper noise

The extent of the negative impact of salt and pepper noise on a digital color image depends on the noise density, which is measured by the number of affected pixels on the total number of pixels in the image. Increasing the noise density will decrease the value of PSNR and at the same time increase the value of MSE between the original and the noisy images. Figure 3 shows the effects of salt and pepper noise on the digital image using various noise densities [26-30].

Figure 3: Effects of various noise densities

Related Works

Multiple filters are used to reduce the effect of salt and pepper noise, and the extent of noise removal varies from one filter to another. Some filters give good results and others give bad results, and this is what we will discuss in this research paper.

Each filter apply convolution using the image matrix and the required filter mask (kernel) as shown in figure 4.

Figure 4: Matrix convolution process

The idea behind convolution is the use of image kernels. A kernel is a small matrix (usually of size 3 by 3) used to apply effect to an image (like sharpening, blurring...) [41], [42].

The core idea is that an image is just a bunch of numbers. Its representation in a computer is an array of size width by heights pixels, and each pixel is associated to three float values ranging from 0 to 1 (or integers going from 0 to 255). This three numbers represent the red, green and blue of said pixel, the combination of the three capturing its color. A fourth channel can be added to represent the transparency of the pixel but we won't focus on that.

If the image is black and white, a single value can be use per pixel, with 0 meaning black and 1 (or 255) meaning white. Let's begin with this for the explanation. The convolution of our image by a given kernel of a given size is obtained by putting the kernel in front of every area of the picture, like a sliding window, to then do the element-wise product of the numbers in our kernel by the ones in the picture it overlaps and summing all of these, figure 5 shows a convolution example:

Figure 5: Convolution example

The median filter is considered one of the anomalous filters that do not use the convolution process, but rather the values of the covered by the mask pixels are arranged in ascending order so that the value of the concerned pixel takes the value located in the middle, as shown in the figure 6:

Figure 6: Median filter operation

Figure 7 shows the filters and the associated mask, the filter operates by applying convolution using the image matrix and the associated mask, while figure 8 shows an example of implementing average filter [30-39].

Sobel			Prewitt			Laplacian		
1	2	1	1	1	1	0.1667	0.6667	0.1667
0	0	0	0	0	0	0.6667	-3.3333	0.6667
-1	-2	-1	-1	-1	-1	0.1667	0.6667	0.1667
Unsharp			Log			Gaussian		
-0.1667	-0.6667	-0.1667	0.0448	0.0468	0.0564	0.0113	0.0838	0.0113
-0.6667	4.3333	-0.6667	0.0468	0.3167	0.7146	0.0838	0.6193	0.0838
-0.1667	-0.6667	-0.1667	0.0564	0.7146	-4.9048	0.0113	0.0838	0.0113
			0.0468	0.3167	0.7146			
			0.0448	0.0468	0.0564			
			Average					
			0.1111	0.1111	0.1111			
			0.1111	0.1111	0.1111			
			0.1111	0.1111	0.1111			

Figure 7: Filters masks

Figure 8: Average filter implementation

The Proposed Method

The proposed method provides an improvement to each filter, this improvement will enhance the values of MSE and PSNR and enhance the quality of the de-noised image. Salt and pepper noise adds pixels with values zero or 255, so the values rather than these values must be kept without change and move from the noisy image to the denoised image, pixels with values equal 0 or 255 are considered as noises, so the filter must be applied only for these pixels.

The following is an algorithm of applying each of the above mentioned filters:

Input:

Noisy image;

Filter mask;

Output:

Denoised image;

Operations:

Extract each color matrix

For each pixel in the noisy color matrix do the following:

- Check the pixel value.
- If the pixel value not equal 0 or the pixel value not equal 255 move the pixel value from the noisy image to the denoised image and move to the next pixel.
- Apply the filter and update the pixel value, then move it to the denoised image, and move to the next pixel.

Merge the denoised matrices to form the denoised color image.

Implementation and experimental results

The above mentioned filters were implemented using various images corrupted with salt and pepper noises with various densities, the improved versions of the filters were also implemented to show the enhancements of the quality parameters MSE and PSNR. Figures 9 and 10 show an example output of one of the implementations.

Figure 9: Sample outputs

Figure 10: Output images histograms

Table 1 thru table 8 show the obtained experimental results

Table 1: Median filter results

Noise density %	Median filter		Improved median filter	
	MSE	PSNR	MSE	PSNR
1	56.9898	70.3965	1.4500	107.1828
3	59.3083	69.9978	3.4585	98.4170
5	62.0971	69.5383	5.6932	93.4325
8	67.6349	68.6840	9.8248	87.9761
10	71.9704	68.0627	13.1848	85.0347
13	80.7437	66.9125	19.1437	81.3055
15	90.2794	65.7962	25.7466	78.3422
18	108.6068	63.9479	38.0231	74.4433
20	128.5357	62.2632	51.4042	71.4281
Average	80.6851	67.2888	18.6588	86.3958

Table 2: Average filter results

Noise density %	Average filter		Improved Average filter	
	MSE	PSNR	MSE	PSNR
1	97.1103	65.0668	5.1974	94.3436
3	147.4226	60.8922	15.9483	83.1317
5	200.2774	57.8282	29.0650	77.1299
8	284.0527	54.3337	53.8427	70.9646
10	344.1505	52.4145	74.0619	67.7763
13	439.0586	49.9789	109.8739	63.8319
15	507.1974	48.5363	138.4380	61.5210
18	610.2805	46.6861	185.5121	58.5941
20	685.8278	45.5190	222.0270	56.7973
Average	368.3753	53.4729	92.6629	70.4545

Table 3: Unsharp filter results

Noise density %	Unsharp filter		Improved Unsharp filter	
	MSE	PSNR	MSE	PSNR
1	913.7673	42.6495	204.4832	57.6204
3	1.6016e+003	37.0375	611.9911	46.6581
5	2.2583e+003	33.6015	1.0202e+003	41.5479
8	3.1956e+003	30.1300	1.6333e+003	36.8415
10	3.7968e+003	28.4062	2.0421e+003	34.6080
13	4.6497e+003	26.3798	2.6531e+003	31.9906
15	5.1884e+003	25.2834	3.0570e+003	30.5733
18	5.9657e+003	23.8875	3.6663e+003	28.7559
20	6.4764e+003	23.0661	4.0853e+003	27.6738
Average	3782.9	30	2108.2	37.4

Table 4:Sobel filter results

Noise density %	Sobel filter		Improved Sobel filter	
	MSE	PSNR	MSE	PSNR
1	1.1413e+004	17.4003	223.2434	56.7426
3	1.1637e+004	17.2061	475.5319	49.1809
5	1.1855e+004	17.0203	735.4162	44.8209
8	1.2192e+004	16.7398	1.1383e+003	40.4521
10	1.2416e+004	16.5575	1.4141e+003	38.2825
13	1.2743e+004	16.2983	1.8498e+003	35.5970
15	1.2960e+004	16.1290	2.1390e+003	34.1446
18	1.3289e+004	15.8783	2.6004e+003	32.1909
20	1.3484e+004	15.7329	2.9041e+003	31.0865
Average	12443	17	1498	40

Table 5: Prewitt filter results

Noise density %	Prewitt filter		Improved Prewitt filter	
	MSE	PSNR	MSE	PSNR
1	1.1534e+004	17.2946	221.4087	56.8252
3	1.1572e+004	17.2622	473.8675	49.2160
5	1.1652e+004	17.1927	723.0956	44.9899
8	1.1784e+004	17.0803	1.1046e+003	40.7526
10	1.1906e+004	16.9776	1.3627e+003	38.6528
13	1.2104e+004	16.8127	1.7565e+003	36.1146
15	1.2240e+004	16.7008	2.0222e+003	34.7057
18	1.2471e+004	16.5140	2.4425e+003	32.8176
20	1.2623e+004	16.3924	2.7290e+003	31.7083
Average	11987	17	1426	41

Table 6: Laplacian filter results

Noise density %	Laplacian filter		Improved Laplacian filter	
	MSE	PSNR	MSE	PSNR
1	1.2595e+004	16.4147	263.6186	55.0802
3	1.2616e+004	16.3981	579.7735	47.1989
5	1.2684e+004	16.3444	899.2709	42.8094
8	1.2855e+004	16.2105	1.3912e+003	38.4457
10	1.3012e+004	16.0890	1.7221e+003	36.3123
13	1.3282e+004	15.8838	2.2276e+003	33.7387
15	1.3491e+004	15.7272	2.5746e+003	32.2908
18	1.3845e+004	15.4687	3.0961e+003	30.4463
20	1.4094e+004	15.2903	3.4568e+003	29.3444
Average	13164	16	1801	38

Table 7: Gaussian filter results

Noise density %	Gaussian filter		Improved Gaussian filter	
	MSE	PSNR	MSE	PSNR
1	94.4735	65.3421	79.3750	67.0834
3	265.9765	54.9912	239.5998	56.0356
5	439.9350	49.9590	402.3530	50.8520
8	702.5263	45.2784	648.6431	46.0764
10	880.2011	43.0238	815.6887	43.7849
13	1.1513e+003	40.3384	1.0711e+003	41.0608
15	1.3298e+003	38.8973	1.2398e+003	39.5986
18	1.6152e+003	36.9530	1.5102e+003	37.6254
20	1.7981e+003	35.8807	1.6839e+003	36.5364
Average	919.7236	45.6293	854.5177	46.5171

Table 8: Log filter results

Noise density %	Log filter		Improved Log filter	
	MSE	PSNR	MSE	PSNR
1	1.2345e+004	16.6149	303.0505	53.6863
3	1.2539e+004	16.4594	670.1544	45.7502
5	1.2796e+004	16.2564	1.0405e+003	41.3511
8	1.3254e+004	15.9047	1.6126e+003	36.9695
10	1.3624e+004	15.6292	2.0001e+003	34.8157
13	1.4208e+004	15.2094	2.5897e+003	32.2321
15	1.4606e+004	14.9337	2.9846e+003	30.8131
18	1.5248e+004	14.5034	3.5929e+003	28.9580
20	1.5655e+004	14.2398	3.9925e+003	27.9035
Average	13808	16	2087	37

From the results obtained and shown in the above tables, it was found that the median and average filters give the best results through the values of the quality parameters MSE and PSNR, the maximize the value o PSNR and minimize the value of MSE making the denoised image more clear and closed to the source clean image, other filters gave worse results as shown in figure 11, so we can highly recommend median filter, then average filter to reduce the effects of salt and pepper noise from a color image.

From table 1 we can see that applying the filter improvement will enhance the values of MSE and PSNR for any value of the noise density, from table 1 we can see that the average value of PSNR using the improved procedure will be increased from 67.2888 to 86.3958, while the MSE value will be decreased from 80.6851 to 18.6588, which are an excellent enhancement as shown in figure 12.

Figure 11: PSNR values for various filters

Figure 12: Enhancing PSNR values using improved median filter

The median filter is superior to the average filter by eliminating salt and pepper noise and to a greater degree of noise elimination, median filter is highly recommended to be used to deal with this noise, using an improved version of median filter will minimize the negative effects of salt and pepper noise as shown in figure 13.

Figure 13: Comparisons between median and average filters

Conclusion

Different filter were investigated to reduce the effects of salt and pepper noise with various density values. The obtained experimental results showed that the best results were obtained using median filter, this filter will maximize the PSNR values and at the same time minimize the values of MSE, An improvement procedure was added to each filter, these procedure enhanced the ability of each filter by increasing the PSNR value and decreasing MSE value keeping median filter the best.

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