A Study on an Image Restoration Algorithm in Universal Noise Environments

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Abstract—Images are often corrupted by noises during signal acquisition and transmission. Among those noises, additive white Gaussian noise (AWGN) and impulse noise are most representative. For different types of noise have different characters, how to remove them separately from degraded image is one of the most fundamental problems. Thus, a modified image restoration algorithm is proposed in this paper, which can not only remove impulse noise of random values, but also remove the AWGN selectively. The noise detection step is by calculating the intensity difference and the spatial distance between pixels in a mask. To divide two different noises, the method is based on three weighted parameters. And the weighted parameters in the filtering mask depend on spatial distances, positions of impulse noise and standard deviation of AWGN. We also use the peak signal-to-noise ratio (PSNR) to evaluate restoration performance, and simulation results demonstrate that the proposed method performs better than conventional median-type filters, in preserving edge details.

Index Terms—impulse noise, AWGN, image restoration

I. INTRODUCTION

For the extension of multimedia technology in recent years, digital image processing has been greatly progressed besides the development of interrelated theories and researches. Data transformation from analog to digital is very important, and digital images are often corrupted by impulse noise and additive white Gaussian noise (AWGN) during signal acquisition and transmission. The most fundamental problem in image processing is how preserving uncorrupted pixels when removing noisy pixels simultaneously. The noise removal algorithms are also applied differently, according to the types of noise. For AWGN and impulse noise are mostly representative in all noise models, a great many researches have been studied to remove them from degraded images.

Impulse noise is characterized by replacing original image's pixel values with extremely high or low values. Impulse noise is easily introduced into images during signal transmissions. The most fundamental algorithm for impulse noise removal is the median filter. Moreover, for good edge preserving performance, many algorithms based on median filter have been studied actively, and the adaptive switching median filter (ASM) not only removes impulse noise very well but also preserves detail information efficiently at the same time [1]-[3].

Generally, AWGN is systematically superposed into images during signal acquisition. Besides, AWGN is characterized by adding to each image pixel a value from a zero-mean Gaussian distribution during image acquisition. Ideally, removing AWGN would involve smoothing inside the distinct regions of an image without degrading the sharpness of their edges. And the mean filter, which is based on calculating the mean value of pixels in filtering mask as the output value to replace the centre pixel, is a representative method in removing AWGN [4].

Although images are usually corrupted by impulse noise and AWGN, there hasn't been much work carried out on building filters that can effectively remove them both. Though mean filter or median filter is applicable in complex noise environment, in case of impulse noise with large noise density and AWGN with large standard deviation, the removal image is badly degraded in feature. So the Trilateral filter was proposed in order to overcome this problem. According to more detailed calculation and separation of weight value parameters, the Trilateral filter method presents excellent noise removal characteristics. However, in regions of high local noise density corruption, the effectiveness of impulse noise still is deteriorated.

An image restoration algorithm using variety weighted parameters was proposed in this paper. We detected the impulse noise using a threshold value, earned by calculating the intensity differences between pixels nearby with each other in localized window, then used the result to estimate the variation value of AWGN. The proposed method removed complex noise with parameters of weight values by calculating the intensity difference and the spatial distance between pixels in filtering mask. We used a test image corrupted by AWGN as well as impulse noise with various densities for simulation, and also used PSNR to evaluate restoration performance.

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II. CONVENTIONAL METHODS NOISE

2.1 Mean filter

The mean filter is the most basic linear algorithm in mask-based filtering methods, which is defined as in equation (1). After calculating the mean value of pixels in filtering mask, the mean filter substituted the mean value for the center pixel [4].

$$\tilde{u}_{i,j} = \frac{1}{w \times w} \sum u_{k,l}, \qquad (k,l) \in \Omega_{k,l}^{w} \tag{1}$$

From equation (1), $u_{k,l}$, $\tilde{u}_{i,j}$, (i,j), and (k,l) are denote as input pixel value, output pixel value and spatial coordinates of center pixel and adjoined pixels in mask respectively. The mask size $w \times w$ is an odd integer not smaller than 3. And the region of the pixels within the mask is represented as $\Omega_{k,l}^{w}$ in equation (2).

$$\Omega_{k,l}^{w} = \left\{ k,l \;\middle|\; \begin{array}{l} i-(w-1)/2 \le k \le i+(w-1)/2, \\ j-(w-1)/2 \le l \le j+(w-1)/2 \end{array} \right\} \tag{2}$$

B. Median filter

One of the most popular nonlinear filter is the standard median (SM) filter, which exploits the rank-order information of pixel intensities within a filtering window and replaces the center pixel with the median value [1]. Due to its effectiveness in image restoration and simplicity in implementation, various modifications of the SM filter have been introduced [2]-[6].

A delegated nonlinear filter which is named as median filter, can be denoted in equation (3). All pixels in the mask are arranged into ascending order, then median value is chosen as the output value [1].

$$\tilde{u}_{i,j} = \text{median}\{u_{k,l}\}, \qquad (k,l) \in \Omega_{k,l}^{w} \tag{3}$$

Where, $\text{median}\{\cdot\}$ means the median operation.

C. ASM filter

For those modified median filters are implemented uniformly across the image, they also tend to modify undisturbed good pixels. The so-called adaptive switching median filter, which has the noise detection step before the noise filtering step, was developed and the detection results are used to determine whether a pixel should be modified [7]-[11]. Though having variable window size for removal of impulse noise, the adaptive switching median filter also has a weakness for ignoring the local area situation in determination of the mask size [12]-[16].

The adaptive switching median (ASM) filter, after estimating by the noise detection step only removes noisy pixels, and filtering mask size can be adaptively changeable. The method can decrease the degradation phenomenon by remaining uncorrupted pixels [2].

$$f_{i,j} = \begin{cases} 0, & \text{if } u_{i,j} \text{ is not a noise} \\ 1, & \text{otherwise} \end{cases} \tag{4}$$

In equation (4), $f_{i,j}$ represents the noise detection result, where $f_{i,j} = 1$ means the current pixel is a noise and $f_{i,j} = 0$ means it is an uncorrupted pixel.

$$\tilde{u}_{i,j} = \begin{cases} m_{i,j}, & \text{if } f_{i,j} = 1,\ M > (w \times w)/2 \\ u_{i,j}, & \text{otherwise} \end{cases} \tag{5}$$

In equation (5), $m_{i,j}$ and M represent as the median value and the number of uncorrupted pixels in the mask respectively.

III. PROPESED METHOD

Since different noise has different characteristics, the remaining noise or the degradation phenomenon occurs in complex noise environment while using the same weight value. Therefore, in this paper, the location of impulse noise in image was confirmed exactly through the noise detection step, and complex noise was removed by adding different weight values to each pixel in the filtering mask during the noise filtering step.

A. Impulse noise detection

From noisy image, in case that the location of impulse noise exactly, in the process into that step of that th of filtering, an improved noise removal result can be obtained. Hence, in this paper, to detect the location of impulse noise, after ascending pixels in mask region, the difference value between sorted pixels is used.

The noisy image superposed by both AWGN and salt-and-pepper noise is express ed as equation (6).

$$u_{i,j} = \begin{cases} 0, & \text{with probability } p \\ 255, & \text{with probability } p \\ u_{i,j}^{0} + n_{i,j}, & \text{with probability } 1-2p \end{cases} \tag{6}$$

Where (i,j), $u_{i,j}^{0}$, $u_{i,j}$, $n_{i,j}$, p are denoted as the space coordinates, the value of original pixel, the value of noisy image, the amplitude of AWGN, and the probability of the impulse noise respectively.

To make the pixels in the mask in an ascending order, the value sequence $\hat{u}$ is expressed as equation (7).

$$\hat{u} = \{U[1], U[2], \cdots, U[N]\}, \qquad (N = w \times w) \tag{7}$$

Where, $U[n]$ means nth biggest pixel in sequence $\hat{u}$ and $m_{i,j}$ defined as the median value in equation (8).

$$m_{i,j} = \text{median}\left\{ \hat{u}_x \,\middle|\, x \in \Omega_{k,l}^{w} \right\}, \quad \left(U[1] < m_{i,j} < U[N]\right) \tag{8}$$

And the intensity difference between each pair of adjacent pixels in $\hat{u}_x$ is established as equation (9).

$$D[n] = U[n+1] - U[n], \quad (1 \le n \le N-1) \tag{9}$$

To identify for the boundaries by finding the maximum intensity differences in two clusters which are divided by median value are defined as equation (10).

$$\begin{aligned} b_1 &= \max\{D[n_1]\}, \quad (1 \le n_1 \le (N-1)/2) \\ b_2 &= \max\{D[n_2]\}, \quad ((N+1)/2 \le n_2 \le N-1) \end{aligned} \tag{10}$$

From above equation, b_1 is the maximum difference value smaller than the median value while b_2 is the maximum difference value larger than the median value. If the current pixel belongs to the cluster $b_1 \le u_{i,j} < b_2$, it would be considered as uncorrupted pixel. When it belongs in either of this two clusters $0 \le u_{i,j} < b_1$ or $b_2 \le u_{i,j} \le 255$, it would be considered as noise candidate.

And the output value $f_{i,j}$ of impulse noise detection is defined as equation (11).

$$f_{i,j} = \begin{cases} 0, & \text{if } b_1 \le u_{i,j} < b_2 \\ 1, & \text{otherwise} \end{cases} \tag{11}$$

Where, $f_{i,j} = 0$ means the current pixel isn't an impulse noise while $f_{i,j} = 1$ means it is an impulse noise

B. Noise filtering

In this paper, using the standard deviation estimated in the region except the impulse noise pixel, complex noise is removed by the combination of the impulse weight value, the AWGN weight value and the spatial distance weight value.

After taking the absolute difference of the center value with its neighboring pixels in to ascending order $D_{k,l}$, $ROAD_{i,j}$, which represents as the sum of smallest $D_{k,l}$ with the number of $\{(w \times w) + 1\}/2$, is expressed as following equations.

$$D_{k,l} = \left| \, u_{i,j} - u_{k,l} \, \right| \tag{12}$$

$$ROAD_{i,j} = \sum_{m=1}^{\{(w \times w)+1\}/2} \min(D_{k,l}) \tag{13}$$

From the noisy image, other pixels expect impulse noise can be regarded as AWGN, and the standard of AWGN is defined as equation (14).

$$\hat{\sigma}_G = \sqrt{\frac{\pi}{2}} \frac{1}{\sum_{i,j=1}^{m,n} W_I(i,j)} \sum_{i,j=1}^{m,n} \left| (u * L)_{i,j} \right| W_I(i,j), \quad \text{if} \quad f_{i,j} = 0 \quad \text{where } L = \begin{pmatrix} 1 & -2 & 1 \\ -2 & 4 & -2 \\ 1 & -2 & 1 \end{pmatrix} \tag{14}$$

From equation, L is the Laplacian filter and (m,n) is the size of whole image. And $W_I(u_{i,j})$, which is the impulse weight value corresponding to the spatial coordinates (i, j) of image, is defined as (15).

$$W_I(u_{i,j}) = e^{-\frac{ROAD^2_{i,j}}{2\sigma_I^2}} \tag{15}$$

Where, as a threshold value about impulse noise, σ_I should never be out the range of [25, 55].

From above equation (14), $2\hat{\sigma}_G$ is established as the threshold value about AWGN and the AWGN weight value $W_G(u_{i,j}, u_{k,l})$ between center pixel and its neighboring pixels is defined as equation (16).

$$W_G(u_{i,j}, u_{k,l}) = e^{-\frac{\left| u_{i,j} - u_{k,l} \right|}{2(2\hat{\sigma}_G)^2}} \tag{16}$$

Moreover, the spatial distance weight value $W_S(u_{i,j}, u_{k,l})$ between center pixel and its neighboring pixels in the mask is expressed as (17).

$$W_S(u_{i,j}, u_{k,l}) = e^{-\frac{(i-k)^2 + (j-l)^2}{2\sigma_S^2}} \tag{17}$$

According to the noise type, as the threshold about spatial distance, σ_S is applied as equation (18).

$$\sigma_S = \begin{cases} 0.5, & \text{if } f_{i,j} = 1 \\ 5, & \text{otherwise} \end{cases} \tag{18}$$

In this paper, by the spatial distance weight value W_S, the weight impulse value W_I and the AWGN weight value W_G, a total weight value W applied between the center pixel and its neighboring pixels was proposed as following equation (19).

$$W(u_{i,j},u_{k,l}) = \begin{cases} W_S(u_{i,j},u_{k,l})\, W_G(u_{i,j},u_{k,l}), & \text{if } f_{i,j} = 0 \\ W_S(u_{i,j},u_{k,l})\, W_I(u_{i,j},u_{k,l}), & \text{otherwise} \end{cases} \qquad (19)$$

By above equation (19), according to the spatial distance between pixels and the type of noise superposed on the center pixel and its neighboring pixels, different weight value was applied to different pixel in the mask. That is, the weight value is being decreased as long as the spatial distance between pixels increase, large weight value is applied to AWGN while small weight value is applied to impulse noise.

Finally, using following equation (20), the image would be restored in complex noise environment.

$$\tilde{u}_{i,j} = \frac{\sum_{k,l\in\Omega^{w}_{k,l}} W(u_{i,j},u_{k,l})\, u_{k,l}}{\sum_{k,l\in\Omega^{w}_{k,l}} W(u_{i,j},u_{k,l})} \qquad (20)$$

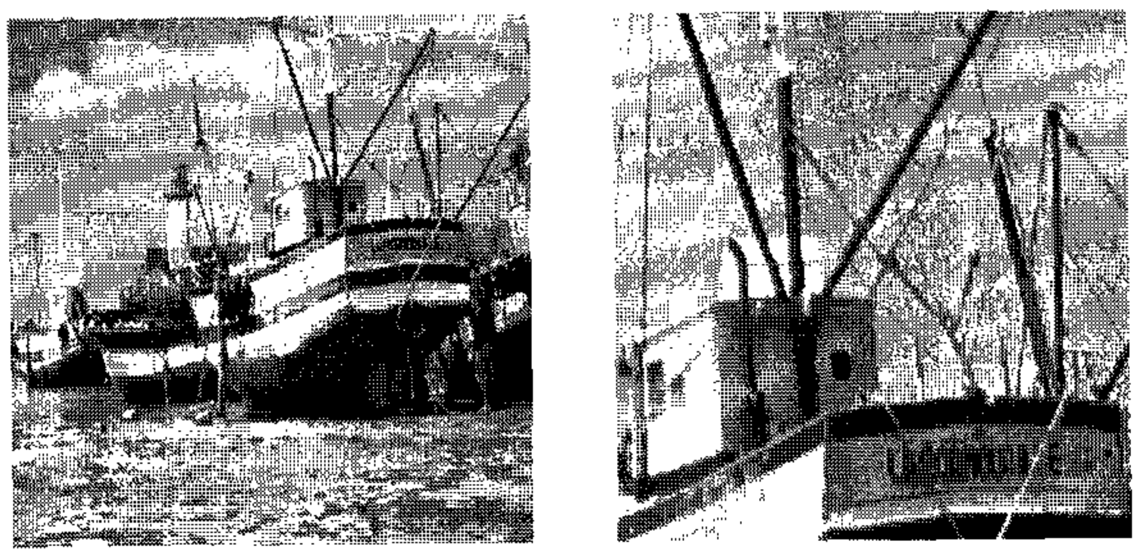
IV. SIMULATION RESULTS

For the simulation, we used the original "Boat" image with the size of 512x512, superposing by salt & pepper noise with density of 20% and AWGN with the standard deviation of 10 complexly. And we also provided the PSNR to evaluate restoration performance. The proposed method was compared with conventional noise removal algorithms. Moreover, in order to visually confirm the noise removal effect, part of enlarging restoration images were represented.

The Impulse noise detection results are shown in table 1. Miss detection means detection result considered Impulse noise as AWGN, while error alarm means detection result considered AWGN as Impulse noise. Using the threshold method and the proposed method under the condition of the Impulse noise ratios from 20% to 60% while fixing the standard deviation of AWGN with 10 [4].

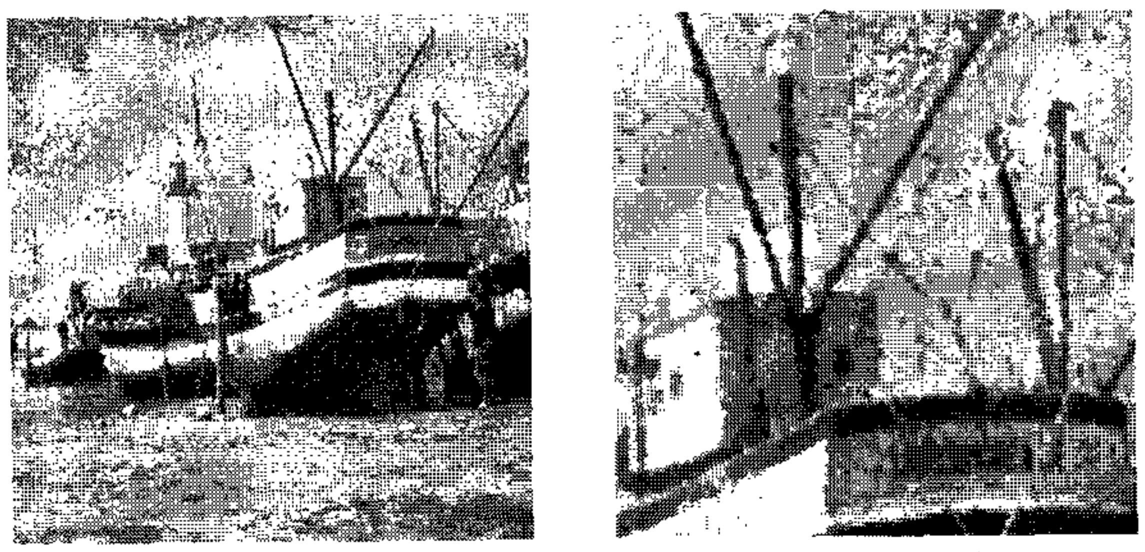
Moreover the table 2 shows the simulation results of four test images with PSNR, which include the proposed method and other conventional methods, with the impulse noise density in 20% and fixing the standard deviation of AWGN with 10 for "Lena", "Brab", "Baboon", and "Peppers" image. The Proposed method showed a better performance than others.

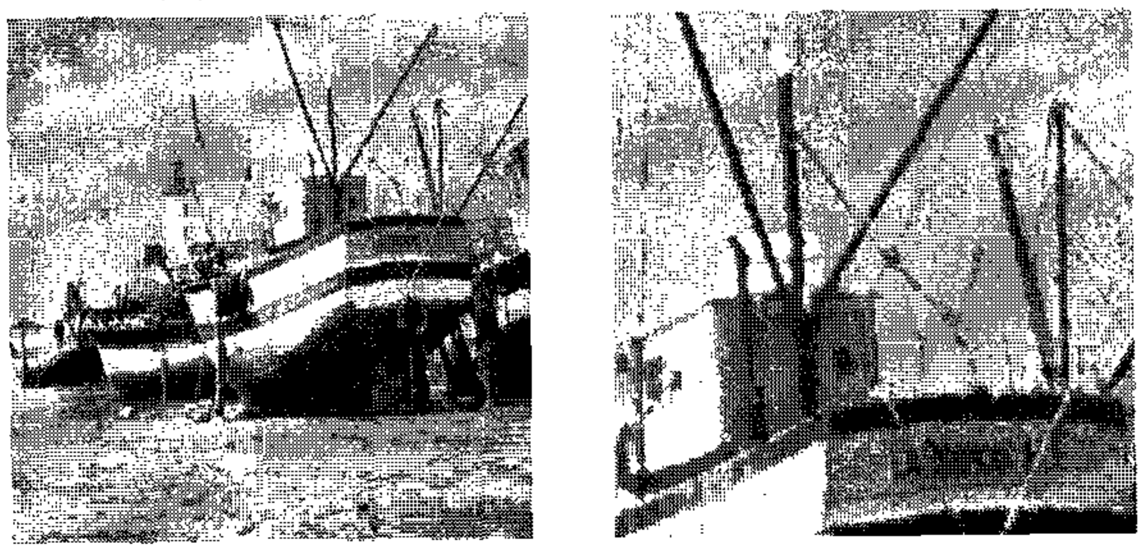
Fig. 1 shows the restoration result of "Boat" image. Fig. 1(a) is the original image while (b) is the corrupted image by salt & pepper noise with the density of 20% and AWGN with the standard deviation of 10. And (c) to (f) are the restoration results by the median filter, the mean filter, the ASM filter and the proposed method respectively. From the figure, for conventional methods did not remove AWGN and impulse noise separately, the blurring phenomenon occurs in edge region. On the other hand, since the proposed method removed the noise separately while preserved the edge region of image simultaneously, it showed a excellent visual result.


(a) Original image


(b) Noisy image (p=20%, σ=10)


(c) Mean filter (5x5, PSNR=22.08)


(d) Median filter (5x5, PSNR=26.60)


(e) ASM filter (5x5, PSNR=27.26)

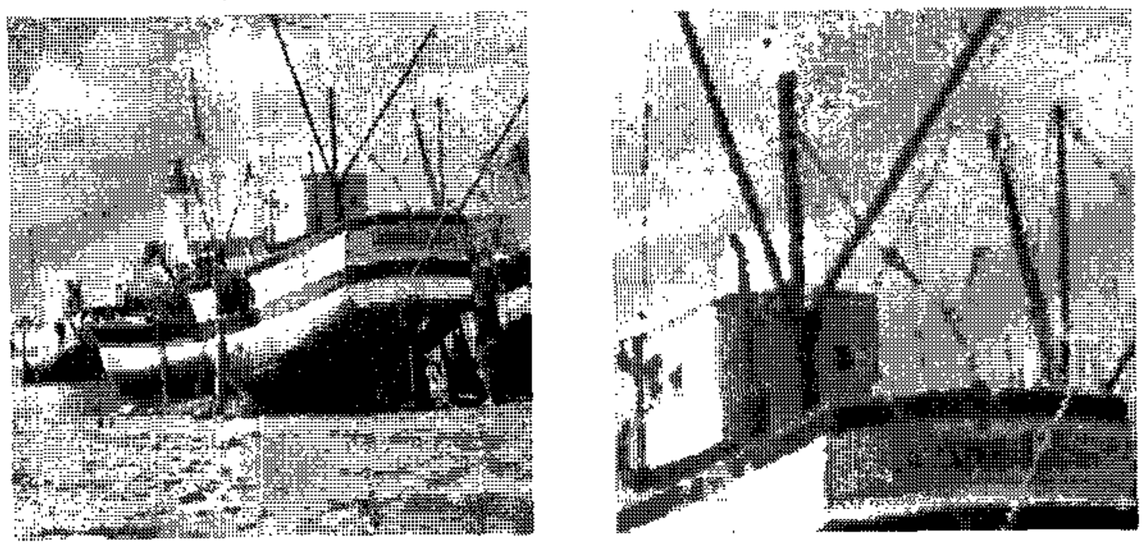

(f) Proposed filter (5x5, PSNR=28.68)

Fig. 1. Restoration results.

Fig. 2 is to compare the noise removal results by changing the standard deviation of AWGN with 10 to 60 while fixing the Impulse noise density with 20%. The figure demonstrate that the proposed method separated and removed noise component from complex corrupted image and shows better PSNR performance than other methods in any noisy standard deviation.

Fig. 3 is to compare the noise removal results by changing the impulse noise density with 10% to 60% while fixing the standard deviation of AWGN with 10. The proposed method also shows better PSNR performance than other methods in any Impulse noise density.

Table 1. Results of impulse noise detection (Boat 512x512 image, AWGN σ=10)

Impulse Noise Density	Threshold Method		Proposed Method	
	Miss Detection	Error Alarm	Miss Detection	Error Alarm
20%	2569	2040	0	984
30%	3152	1969	0	989
40%	3762	1842	0	898
50%	4238	1950	0	783
60%	4588	2055	0	756

Table 2. PSNR with Various test images (p=20%, σ=10)

Method	Images with PSNR [dB]			
	Lena	Brab	Baboon	Peppers
Before Restoration	12.10	12.12	11.95	12.15
Mean filter	23.02	21.7	19.14	20.08
SM	28.01	24.19	23.93	27.49
ASM	27.84	24.53	23.82	27.71
Proposed	30.82	26.2	25.01	30.33

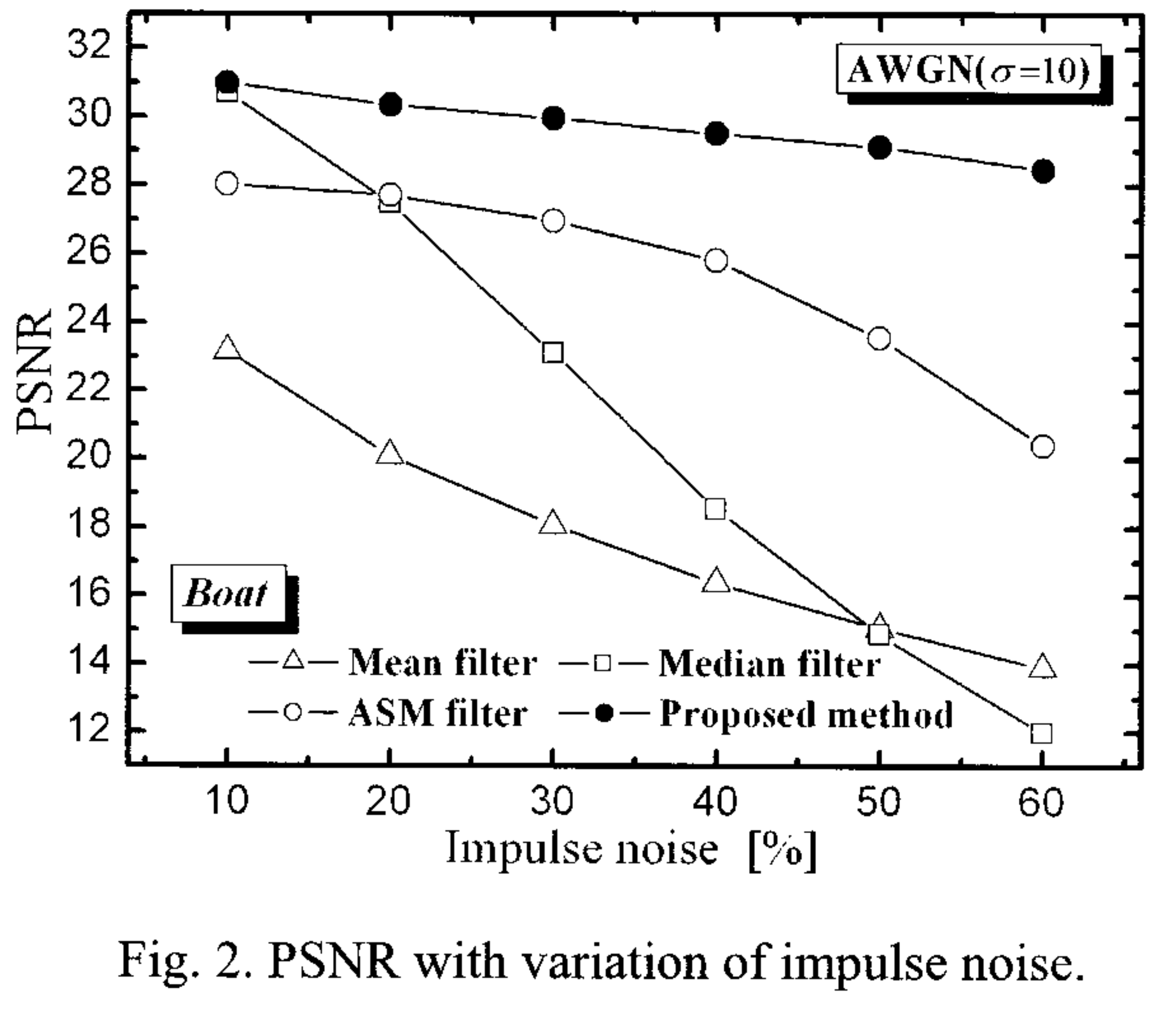


Fig. 2. PSNR with variation of impulse noise.

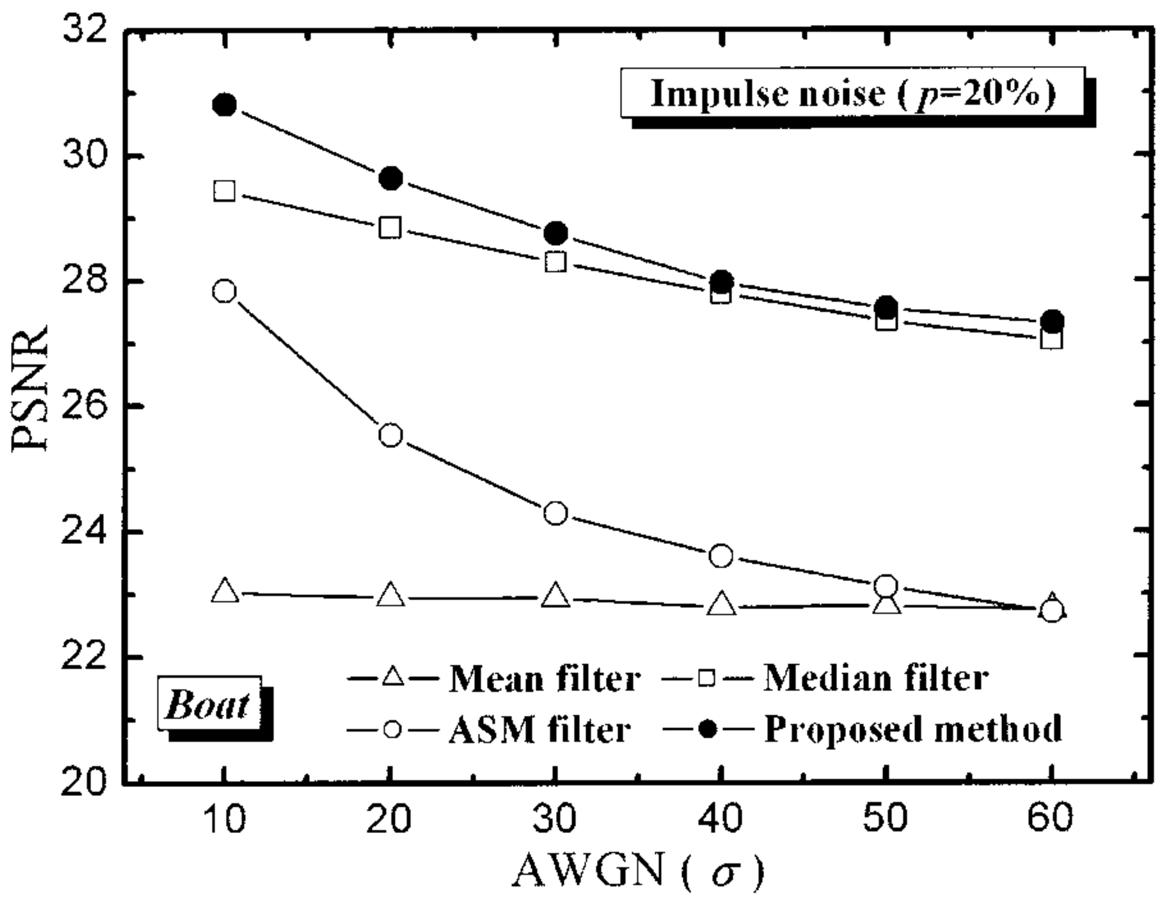


Fig. 3. PSNR with variation of AWGN standard deviation.

V. CONCLUSIONS

In this paper, to restore the corrupted image in complex noise environment, since the noise detection step is added before the filtering step, the proposed method detects the spatial location of impulse noise and calculates the standard deviation of AWGN. From the noise detection result, the weight value of pixels in mask is established more exactly, the proposed method has the characteristic for separating and removing AWGN and impulse noise.

Before the noise filtering step, we added the impulse noise detection step to calculate the location of different noise types. In the noise detection algorithm, it classifies the pixels of a localized window, centering on the current pixel, in an ascending order, then uses the median value to divide the pixels into two groups, then classifies by the intensity difference among adjacent pixels. The mask size is changable by the local noise density in the filtering mask comparing with the threshold value to the mask. And weighted parameters in the filtering mask are based on spatial distances, positions of impulse noise, and standard deviation of AWGN.

From simulation results, conventional methods remained impulse noise partially or occurred the blurring phenomenon. However, the proposed method separated and removed impulse noise as well as AWGN while preserved edge regions simultaneously, and showed a better MSE result. Furthermore, it is believed that the proposed method would be widely used in a variety of image processing fields.

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