Thesis for the Degree of Master of Engineering

A Study on an Image Restoration in Mixed Noise Environment

by

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Pukyong National University

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A Study on an Image Restoration in Mixed Noise Environment

잡음환경하에서 영상복원에 관한 연구

Advisor: Prof. Nam-Ho Kim

by

Jin Bo

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Candidate for the degree of Master of Engineering and hereby certify that it is worthy of acceptance.

A dissertation

by

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February 26, 2008

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잡음환경하에서 영상복원에 관한 연구

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요 약

디지털 영상은 획득 및 저장 과정에서 다양한 채널을 통해 잡음에 의해 훼손되며, 이러한 잡음을 제거하기 위한 연구가 활발히 진행중이다.

또한, 영상에 첨가되는 잡음모델은 AWGN (additive white Gaussian noise)과 임펄스 잡음이 가장 대표적이다. 임펄스 잡음은 주로 신호를 전송하는 과정에서 첨가되며, 신호를 표현하기 위한 크기 범위 내에서 극단적인 형태로 발생한다. 이러한 임펄스 잡음을 제거하기 위한 대표적인 방법으로 메디안 필터가 있으며, 현재 에지보존 특성을 향상시키기 위한 변형된 메디안 필터에 대한 연구가 계속되고 있다[1]. 그리고 AWGN은 신호를 획득하고 처리하기 위한 과정에서 불규칙적이며, 연속적으로 발생한다. 이러한 AWGN을 제거하기 위해, 평균필터가 가장 일반적으로 사용되고 있다[3].

한편, 임펄스 잡음과 AWGN의 복합 잡음환경하에서 영상을 복원하기 위해 평균필터와 메디안 필터를 적용할 수 있으나, 영상에 중첩되는 임펄스 잡음의 밀도와 AWGN의 표준편차가 증가하게 될 경우, 처리된 결과영상은 시각적으로 매우 열화된다. 이와 같은 단점들을 개선하기 위해, Trilateral 필터가 제안되었다[4]. 그러나 영상에 중첩되는 임펄스 잡음의 밀도가 급격히 증가하는 경우에는 잡음제거성능이 저하하는 단점이 발생하였다.

본 논문에서는 마스크 내의 인접화소와 중심화소에 대한 차의 절대값을 임계값으로 설정하여 임펄스 잡음을 검출한 후, 그 결과로부터 영상에 중첩된 AWGN의 분산값을 추정하였다. 마스크 내의 화소들에 대한 공간 거리와 상대차값 등을 가중치 변수로 사용하여 복합적인 잡음성분을 제거하였다.

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.

Ⅱ. Conventional Image Restoration Methods

2.1 Spatial domain

The term spatial domain refers to the aggregate of pixels composing an image, and spatial-domain methods are procedures that operate directly on these pixels.

An image can be defined as a two-dimensional function, $y_{i,j}$, from which i, j are spatial coordinates. the value of y at any pair of coordinates (i,j) is defined as the intensity of the image at that point. The intensity of images is called gray level. An intensity image is a data matrix of which values have been scaled to represent intensities. When the elements of an intensity image are of class uint8, they have integer values in the range from 0 to 255.

A pixel p at coordinates (i,j) has four horizontal and vertical neighbors whose coordinates are given by $(i+1,j)$, $(i-1,j)$, $(i,j+1)$, $(i,j-1)$.

This set of pixels, called the 4-neighbors of p. It is noted that each of these pixels is a unit distance from (i,j) and also that some of the neighbors of p will be outside the digital image if (i,j) is on the border of the image.

The four diagonal neighbors of p have coordinates $(i+1,j+1)$, $(i+1,j-1)$, $(i-1,j+1)$, $(i-1,j-1)$.

These point, together with the 4-neighbors defined above, are called the 8-neighbors of p. As before, some of the points will be outside the image if (i,j) is on the border of the image, shown in Fig. 1.

An image may be continuous with respect to the i-coordinates and j-coordinates, and also in amplitude. Converting such an image to digital form requires that the coordinates, as well as the amplitude, be digitized. Digitizing the coordinate values is called sampling; Digitizing the amplitude values is called quantization. Thus, when i, j, and the amplitude values of y are all finite, descrete quantities, we call the image a digital image.

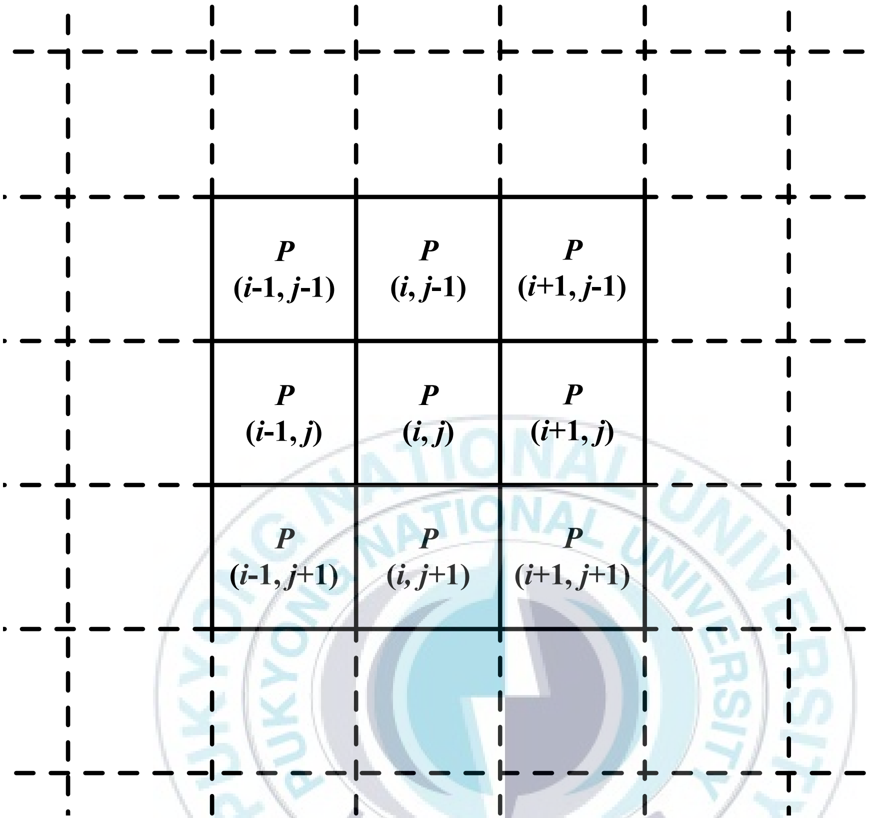

Fig. 1. Pixel (i, j) and its 3×3 neighbor pixels.

2.2 Spatial filtering

Spatial filtering is based on neighborhood operations. Linear spatial filtering is based on computing the sum of products, nonlinear spatial filtering is based, as the name implies, on nonlinear operations involving the pixels of a neighborhood. For example, letting the response at each center point be equal to the maximum pixel value in its neighborhood is a nonlinear filtering operation. Another basic difference is that the concept of a mask is not as prevalent in nonlinear processing. The idea of filtering carries over, but the "filter" should be visualized as a nonlinear function that operates on the pixels of a neighborhood, and whose response constitutes the response of the operation at the center pixel of the neighborhood. As shown in Fig.2, m(n) means the center pixel, and $m_1(n)$ to $m_8(n)$ are those neighboring pixels in 3 by 3 mask.

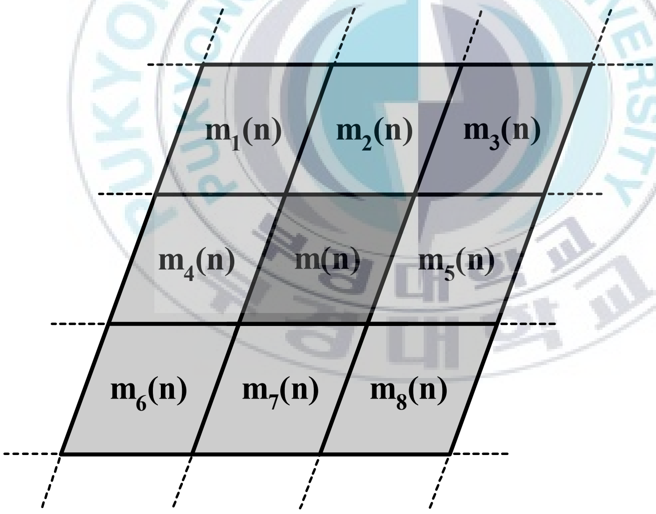

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Fig. 2. Mask for image processing.

2.2.1 Mean filter

Mean filter is a straightforward spatial-domain technique for image restoration. The procedure is to generate a smoothed image whose gray level at every point (i, j) is obtained by averaging the gray-level values of the pixels in the mask, which contained in a predefined neighborhood of (i, j).

Mean filter is the most basic linear type method for removing AWGN, denoted as (1). The method replaces center pixel value by calculating mean value as output value [3].

$$y_{i,j} = \frac{1}{w \times w} \sum x_{k,l}, \qquad (k,l) \in \Omega^{w}_{k,l} \tag{1}$$

Where, $x_{k,l}$, $y_{i,j}$, (i, j), and (k, l) are denoted as input value, output value and spatial coordinates of center pixel and adjacent pixels in filtering mask. Besides $w \times w$ and $\Omega^{w}_{k,l}$ are represented as the mask size and the region of the pixels within the mask in (2).

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

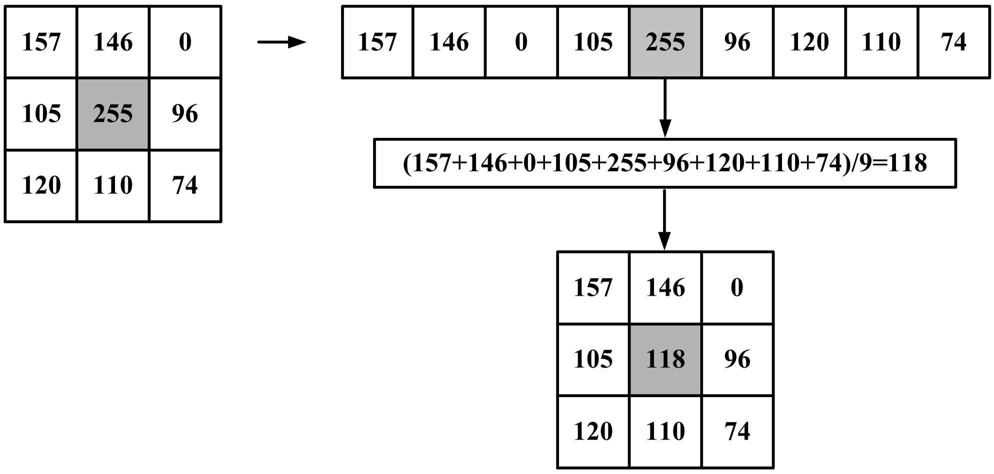


Fig. 3. Demonstrating an example of mean filter.

2.2.2 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]. This method is particularly effective when the noise pattern consists of strong, spikelike components, and where the characteristic to be preserved is edge sharpness.

In order to perform median filtering in a neighborhood of a pixel we first sort the values of the pixel and its neighbors, determine the median, and assign this value to the pixel. For example, in a 3×3 neighborhood the median is the 5th largest value, in a 5×5 neighborhood the 13th largest value, and so on. The principal function of median filtering is to force points with very distinct intensities to be more like their neighbors, thus actually eliminating intensity spikes that appear isolated in the are of the filter mask.

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].

$$y_{i,j} = \text{median}\{x_{k,l}\}, \qquad (k,l) \in \Omega^{w}_{k,l} \tag{3}$$

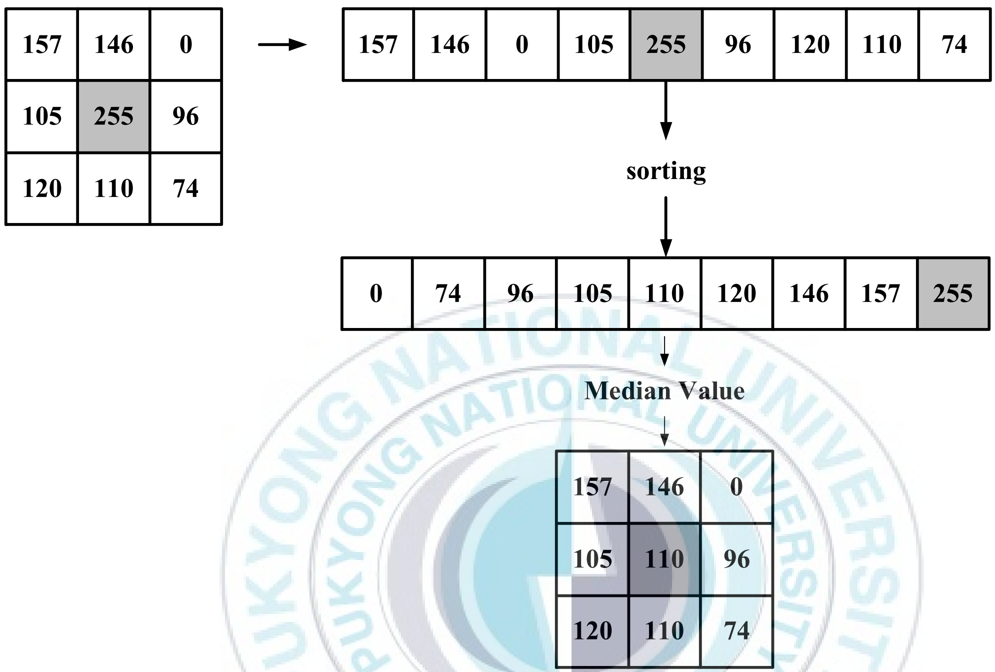


Fig. 4. Demonstrating an example of mean filter.

2.2.3 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].

$$y_{i,j} = \begin{cases} m_{i,j}, & \text{if} \quad f_{i,j} = 1,\ M > (w \times w)/2 \\ x_{i,j}, & \text{otherwise} \end{cases} \tag{4}$$

Where, $f_{i,j} = 1$ means the current pixel is a impulse noise while $f_{i,j} = 0$ means it is an uncorrupted pixel. And $m_{i,j}$ and M are represented as the median value and the number of uncorrupted pixels in the mask.

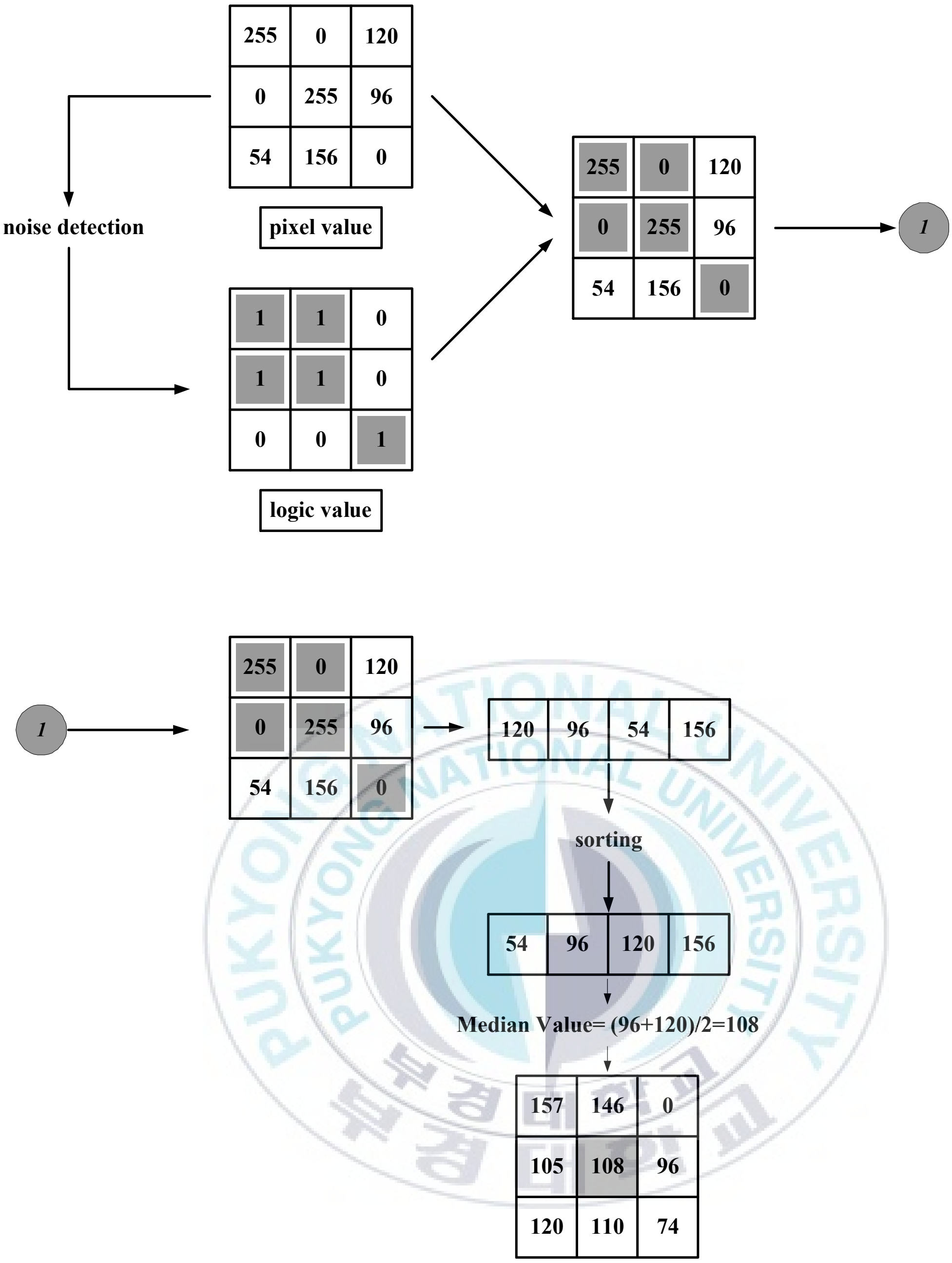


Fig. 5. Demonstrating an example of ASM filter.
(In the case when the number of noise pixels is odd)

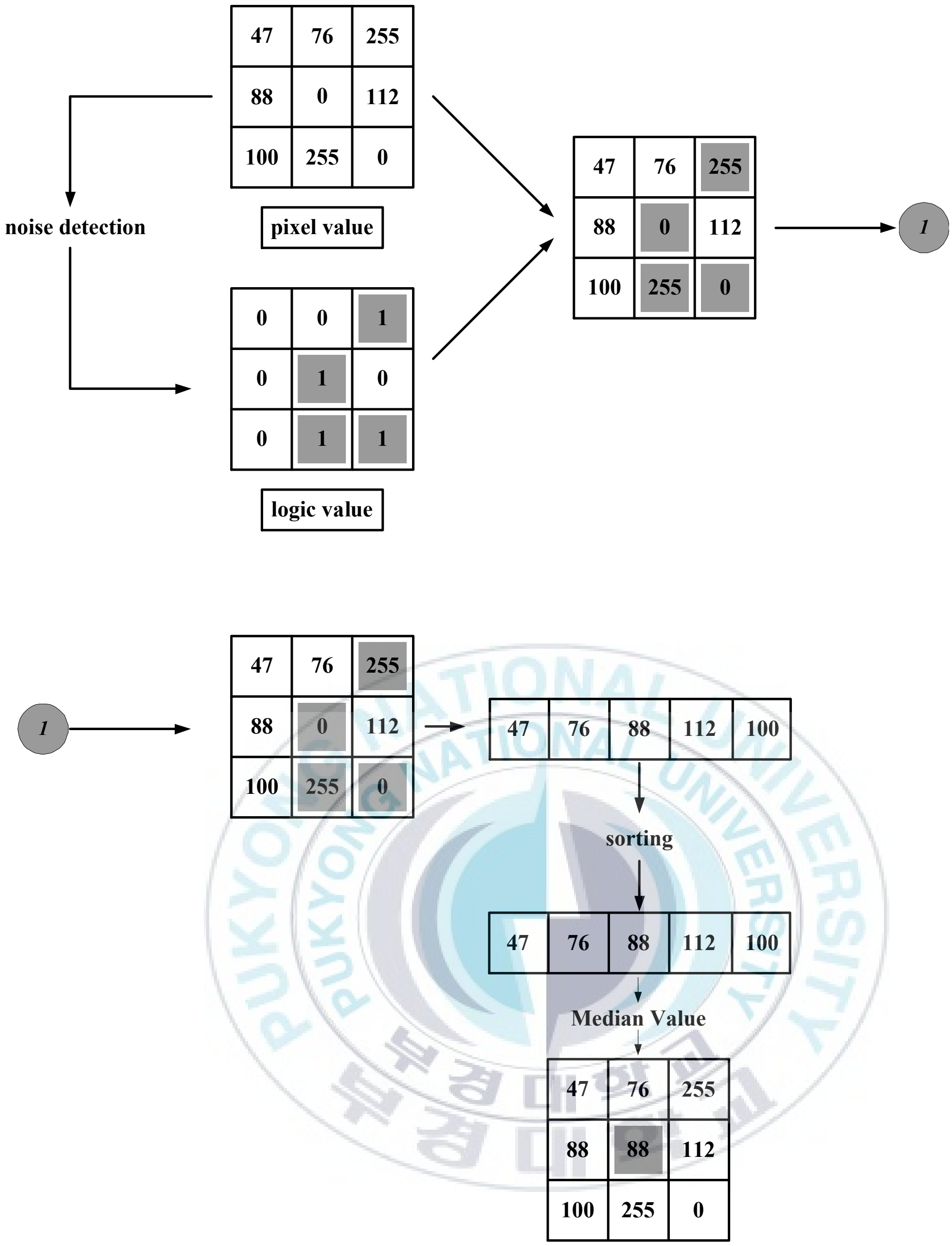


Fig. 6. Demonstrating an example of ASM filter.
(In the case when the number of noise pixels is even)

Ⅲ. Proposed Algorithm

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

3.1 Impulse noise detection

In case that the location of impulse noise would be exactly detect from noisy image, an more improved noise removal result can be earned through noise filtering step. So, in this paper, after ascending pixels in mask region, the difference value between sorted pixels is used to detect the location of impulse noise.

The noisy image corrupted by both impulse noise and AWGN is denoted in equation (5).

$$x_{i,j} = \begin{cases} 0, & \text{with probability} \quad p \\ 255, & \text{with probability} \quad p \\ x^0_{i,j} + n_{i,j}, & \text{with probability} \quad 1-2p \end{cases} \tag{5}$$

From above, (i,j), $x^0_{i,j}$, $x_{i,j}$, $n_{i,j}$, and p are expressed as the space coordinates, the value of original pixel, the value of noisy pixel, the amplitude of AWGN, and the probability of the impulse noise respectively. By making the pixels in the mask in an ascending order, the sequence $\hat{x}$ is established as equation (6).

$$\hat{x} = \{X[1], X[2], \cdots, X[N]\}, \quad (N = w \times w) \tag{6}$$

Where, $X[n]$ represents as n-th biggest pixel in sequence $\hat{x}$ and the intensity difference between each pair of adjacent pixels in $\hat{x}$ is expressed as equation (7).

$$D[n] = X[n+1] - X[n], \quad (1 \le n \le N-1) \tag{7}$$

To figure out the boundaries by finding the maximum intensity differences in two clusters divided by median value are defined as in equation (8).

$$\begin{aligned} b_1 &= \max\{D[n_1]\}, \quad (1 \le n_1 \le (N-1)/2) \\ b_2 &= \max\{D[n_2]\}, \quad ((N+1)/2 \le n_2 \le N-1) \end{aligned} \tag{8}$$

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

3.2 Noise filtering

The proposed method, using the standard deviation estimated in the region without impulse noise pixels, removed complex noise, the combination of the impulse weight value, the AWGN weight value and the spatial distance weight value.

Other pixels except for impulse noise are regarded as AWGN in the noisy image, and the standard of AWGN is expressed as (9).

$$\hat{\sigma}_G = \sqrt{\frac{\pi}{2}} \frac{\sum_{i,j=1}^{m,n} |(u * L)_{i,j}| \, W_I(x_{i,j})}{\sum_{i,j=1}^{m,n} W_I(x_{i,j})} , \tag{9}$$

$$\text{where} \quad L = \begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix}$$

Where, L is the Laplacian filter, $*$ represents the convolution, and (m,n) is the size of whole image. Besides, $W_I(x_{i,j})$ is the impulse weight value corresponding to the spatial coordinates (i,j) of image. In case that $f_{i,j}=1$, the impulse weight value would be $W_I(x_{i,j})=0$, else it would be $W_I(x_{i,j})=1$.

From (9), $2\hat{\sigma}_G$ is denoted as the threshold value about AWGN and the AWGN weight value $W_G(x_{i,j}, x_{k,l})$ between center pixel and its neighboring pixels is defined as (10).

$$W_G(x_{i,j}, x_{k,l}) = \exp\left(-\frac{|x_{i,j} - x_{k,l}|}{2\left(2\hat{\sigma}_G\right)^2}\right) \tag{10}$$

And the spatial distance weight value $W_S(x_{i,j}, x_{k,l})$ between center pixel and its neighboring pixels in mask is denoted as (11).

$$W_S(x_{i,j}, x_{k,l}) = \exp\left(-\frac{(i-k)^2 + (j-l)^2}{2\sigma_S^2}\right) \tag{11}$$

Where σ_S is the threshold about spatial distance. And $\sigma_S = 0.5$ when current pixel is an impulse noise as $f_{i,j} = 1$, else $\sigma_S = 5$.

In this paper, by the spatial distance weight value W_S, the impulse weight value W_I and the AWGN weight value W_G, the total weight value W applied between the center pixel and its neighboring pixels was proposed as in (12).

$$W(x_{i,j}, x_{k,l}) = W_S(x_{i,j}, x_{k,l})\, W_G(x_{i,j}, x_{k,l})\, W_I(x_{i,j}) \qquad (12)$$

Where, different weight value was applied to different pixel in the mask, by the spatial distance between pixels and the type of noise superposed on the center pixel and its neighboring pixels. Which means, the weight value is being decreased while the spatial distance between pixels increases, large weight value is applied to AWGN while small weight value is applied to impulse noise.

At last, the image would be restored in both impulse noise and AWGN environment by using equation (13).

$$y_{i,j} = \frac{\sum_{k,l \in \Omega^w_{k,l}} W(x_{i,j}, x_{k,l})\, x_{k,l}}{\sum_{k,l \in \Omega^w_{k,l}} W(x_{i,j}, x_{k,l})} \qquad (13)$$

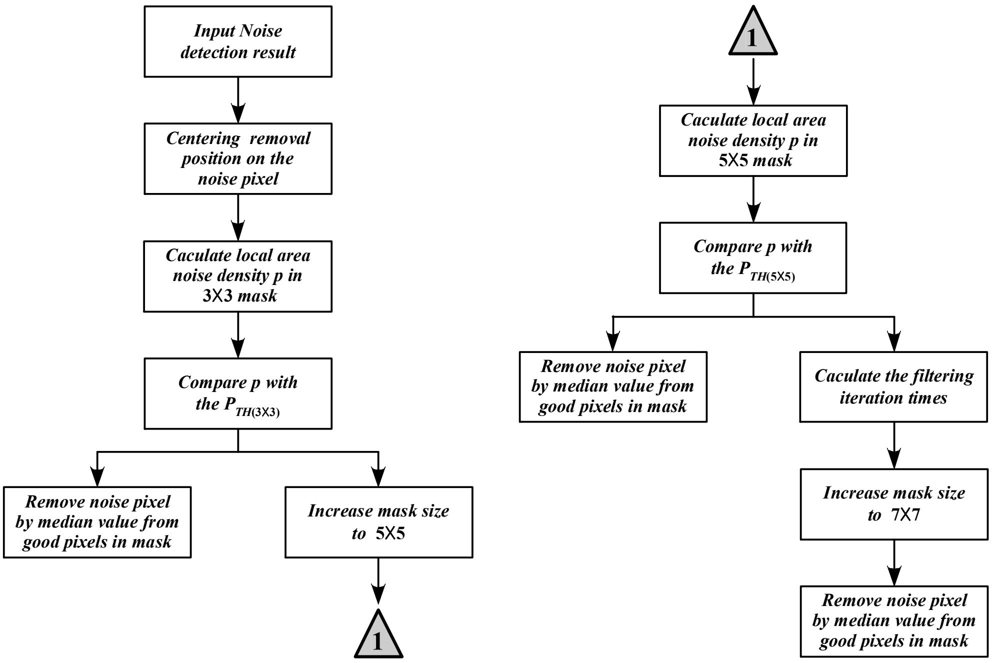


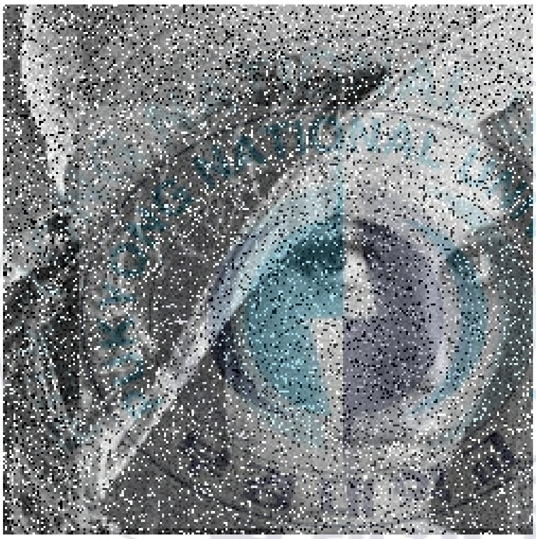
Fig. 7. Block diagram of proposed algorithm.

Ⅳ. Simulation & Results

We used the 512×512 "Lena", "Peppers", "Barbara", "Cameraman" images, corrupted complexly by impulse noise with density of 20% and AWGN with the standard deviation of 10 for the simulation. Besides, the peak signal to noise ratio (PSNR) is also provided to evaluate restoration performance. The proposed method was compared with conventional algorithms. Moreover, parts of enlarging restoration images were represented to confirm the noise removal effect visually.

The test images of simulation and the restoration result of images are shown in Fig. 8 to Fig. 19. Where are the original image while the corrupted image by impulse noise with the density of 20% and AWGN with the standard deviation of 10. And the restoration results by the median filter, the mean filter, the ASM filter and the proposed method respectively. Furthermore, we used the four times of difference images, which means the pixels of restoration image versus orignal image to illustrate the result. From the figures, the blurring phenomenon occurs in edge region because conventional methods did not remove AWGN and impulse noise separately. On the other hand, the proposed method showed a excellent visual result, by removing the noise separately while preserving the edge region of image simultaneously. And Fig. 20 to Fig. 23 are to compare the noise removal results by changing the impulse noise density with 10% to 60% while fixing the standard deviation of AWGN with 20. The proposed method shows better PSNR performance than other methods in any noisy standard deviation.

(a) Original image



(b) Noisy image
(impulse noise $p=20\%$, AWGN $\sigma=10$)

Fig. 8. Test image (Lena 512×512).

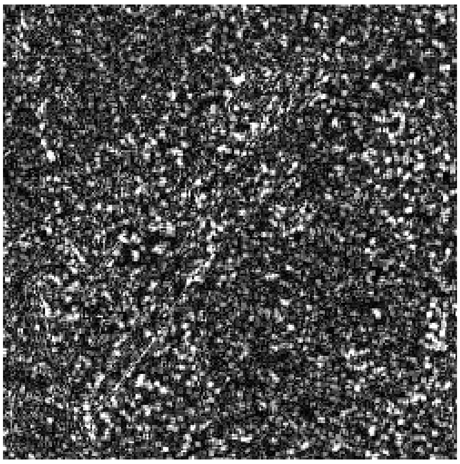
(a) Mean filter

(b) Median filter

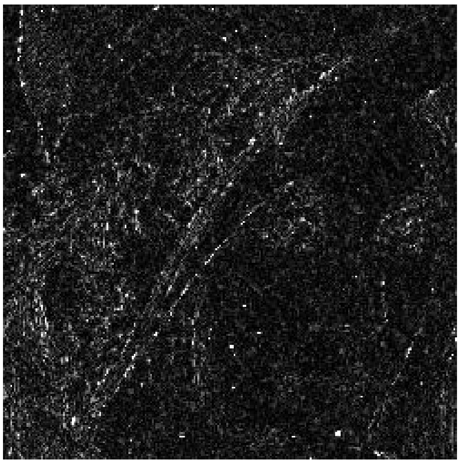
(c) ASM filter

(d) Proposed method

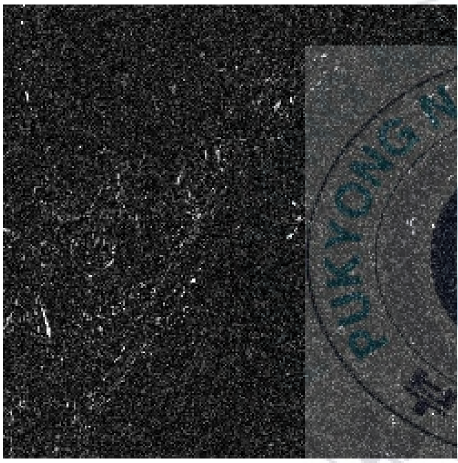
Fig. 9. Denoising result (Lena 512×512).



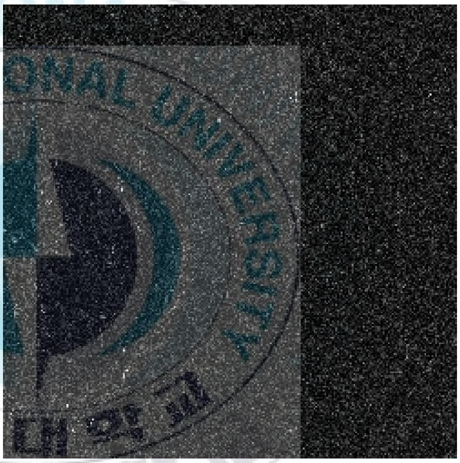
(a) Difference image×4
(Mean filter)



(b) Difference image×4
(Median filter)



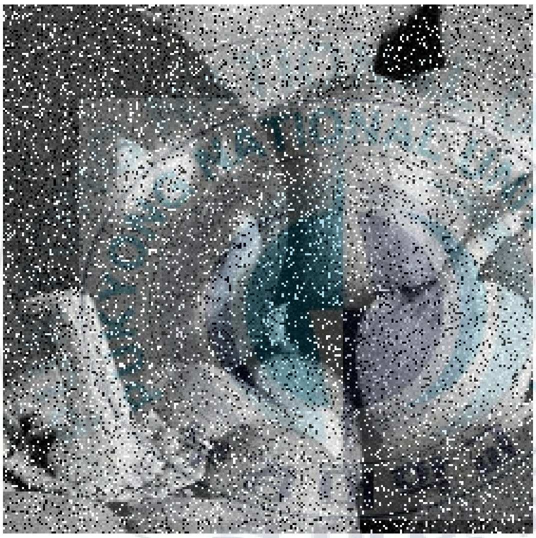
(c) Difference image×4
(ASM filter)



(d) Difference image×4
(Proposed method)

Fig. 10. Difference images (Lena 512×512).

(a) Original image



(b) Noisy image
(impulse noise $p=20\%$, AWGN $\sigma=10$)

Fig. 11. Test image (Peppers 512×512).

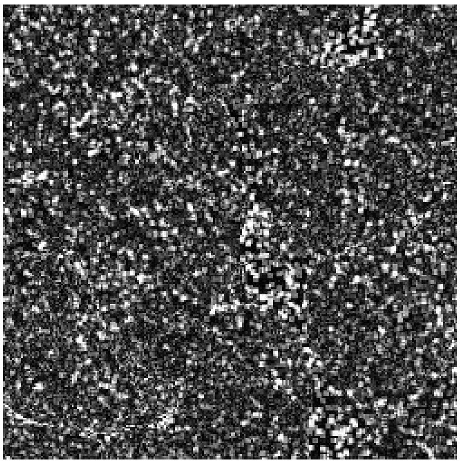
(a) Mean filter

(b) Median filter

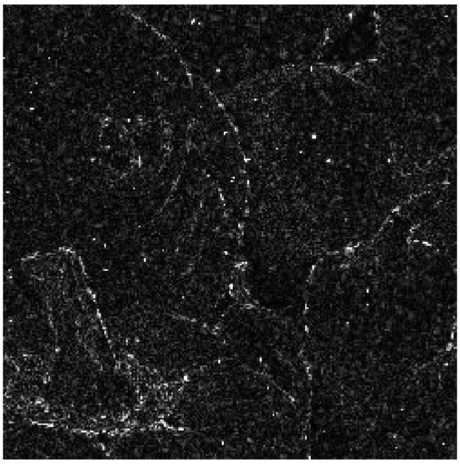
(c) ASM filter

(d) Proposed method

Fig. 12. Denoising result (Peppers 512×512).

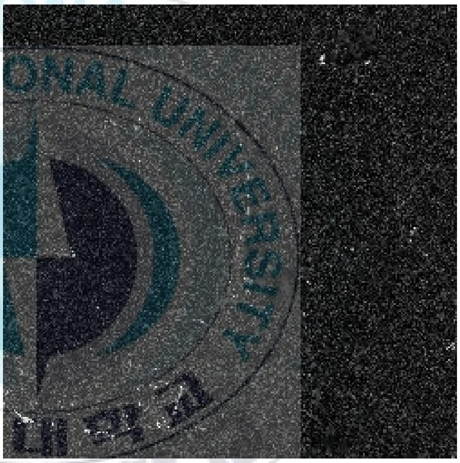


(a) Difference image×4
(Mean filter)



(b) Difference image×4
(Median filter)

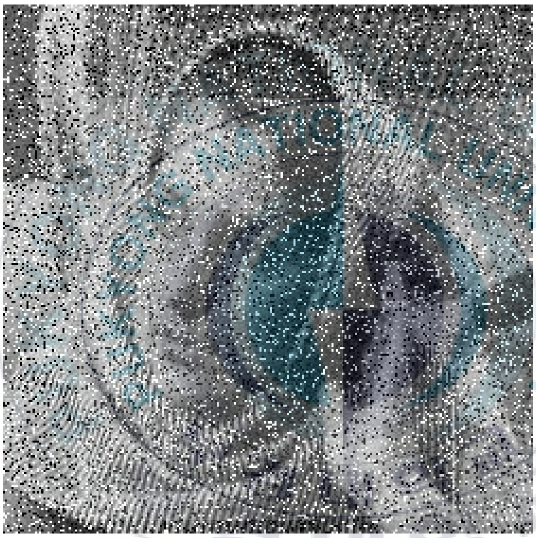
(c) Difference image×4
(ASM filter)



(d) Difference image×4
(Proposed method)

Fig. 13. Difference images (Peppers 512×512).

(a) Original image



(b) Noisy image
(impulse noise $p=20\%$, AWGN $\sigma=10$)

Fig. 14. Test image (Barbara 512×512).

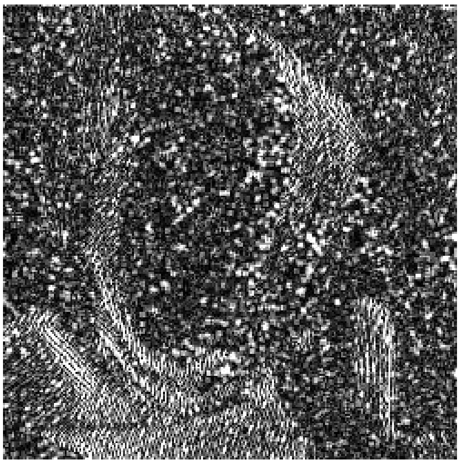
(a) Mean filter

(b) Median filter

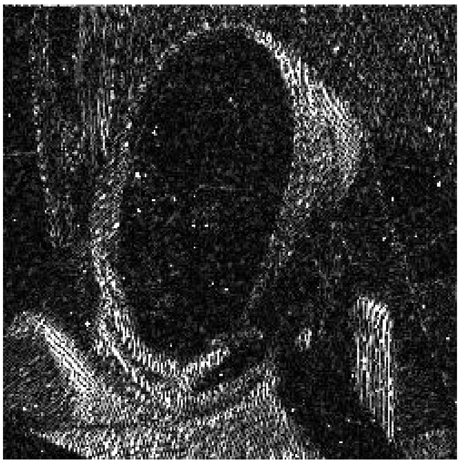
(c) ASM filter

(d) Proposed method

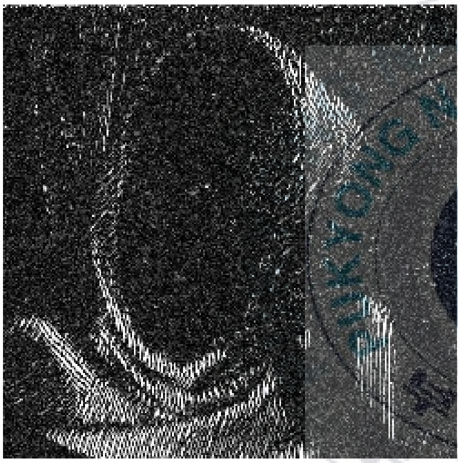
Fig. 15. Denoising result (Barbara 512×512).



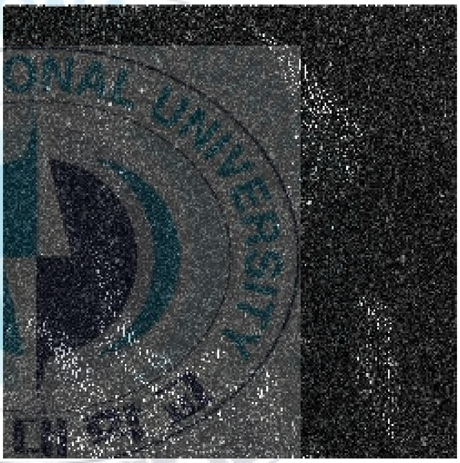
(a) Difference image×4
(Mean filter)



(b) Difference image×4
(Median filter)



(c) Difference image×4
(ASM filter)



(d) Difference image×4
(Proposed method)

Fig. 16. Difference images (Barbara 512×512).

(a) Original image

(b) Noisy image
(impulse noise $p = 20\%$, AWGN $\sigma = 10$)

Fig. 17. Test image (Cameraman 512×512).

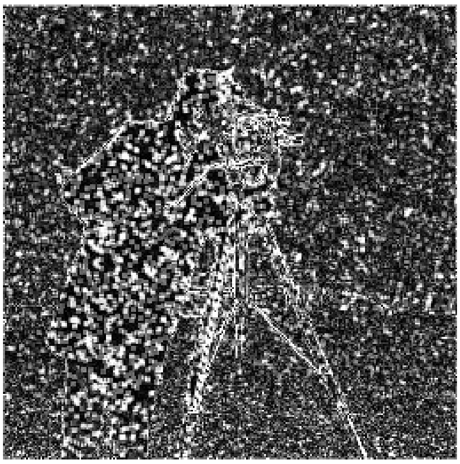
(a) Mean filter

(b) Median filter

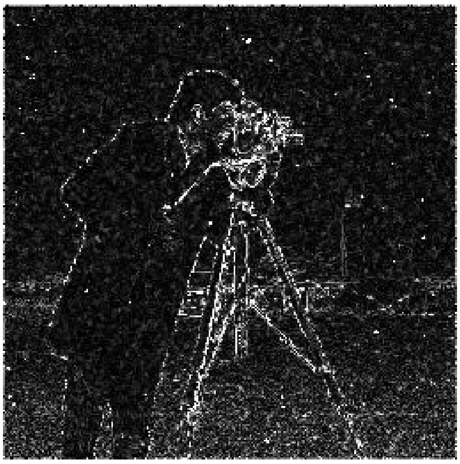
(c) ASM filter

(d) Proposed method

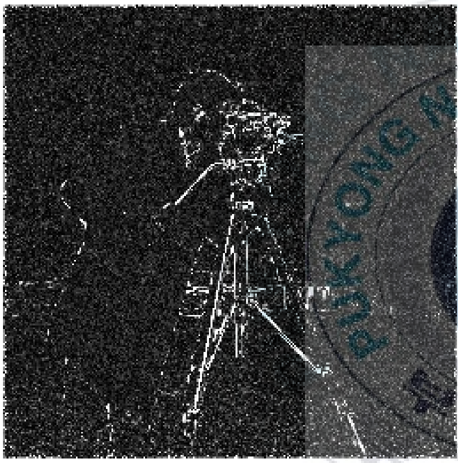
Fig. 18. Denoising result (Cameraman 512×512).



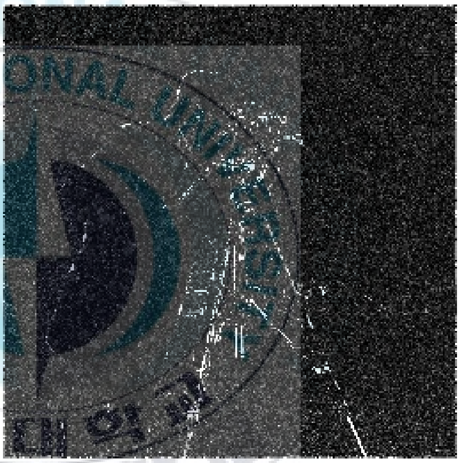
(a) Difference image×4
(Mean filter)



(b) Difference image×4
(Median filter)

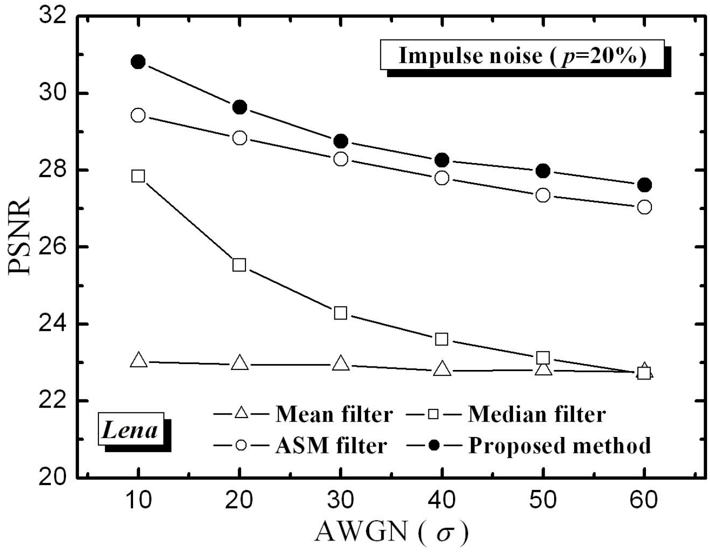


(c) Difference image×4
(ASM filter)

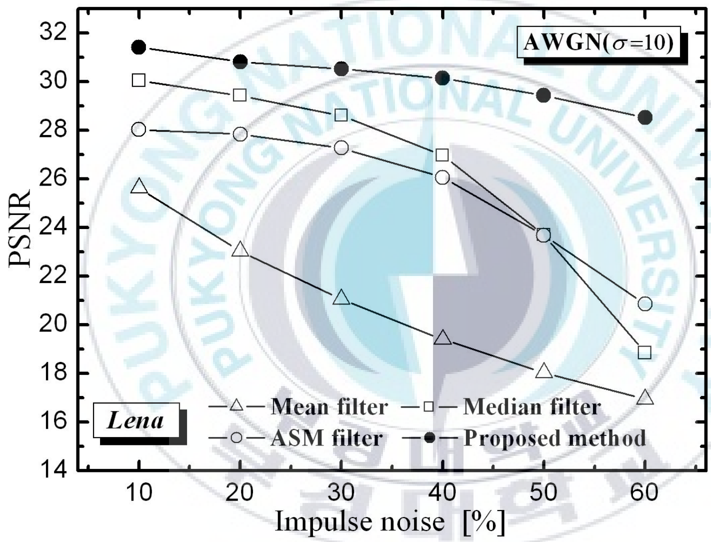


(d) Difference image×4
(Proposed method)

Fig. 19. Difference images (Cameraman 512×512).

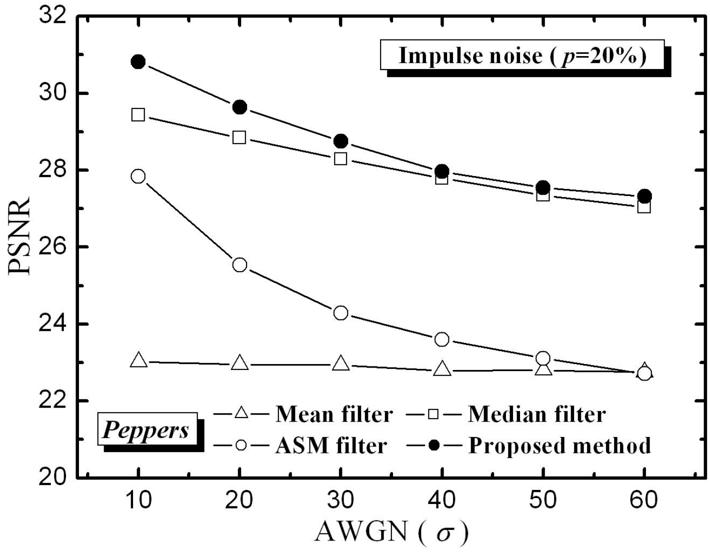


(a) PSNR with variation of AWGN

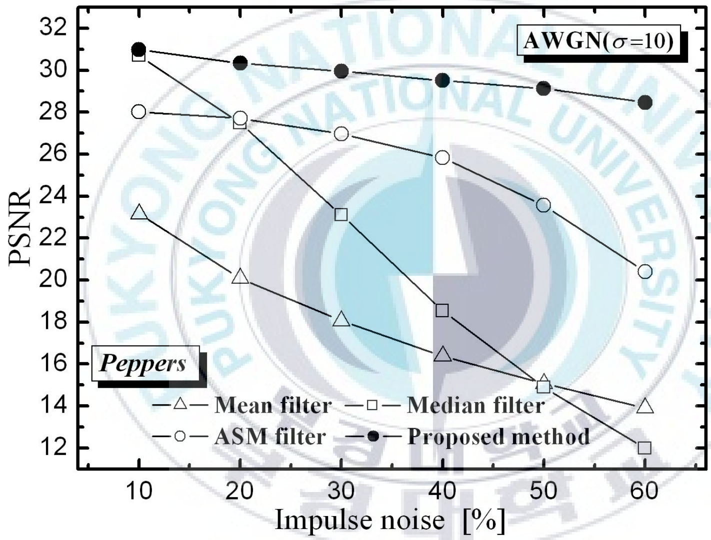


(b) PSNR with variation of impulse noise

Fig. 20. PSNR of Lena Image.

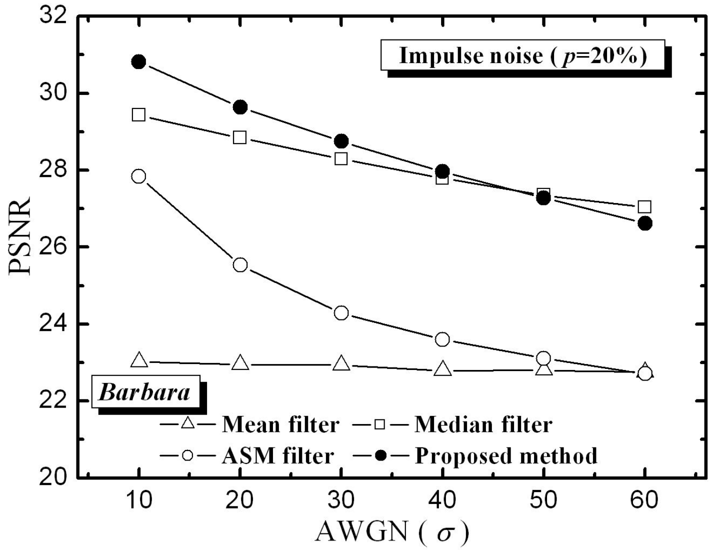


(a) PSNR with variation of AWGN

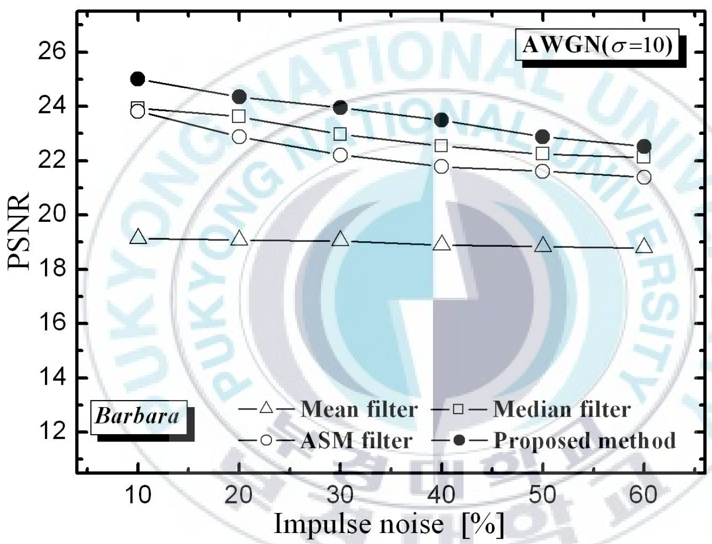


(b) PSNR with variation of impulse noise

Fig. 21. PSNR of Peppers Image.

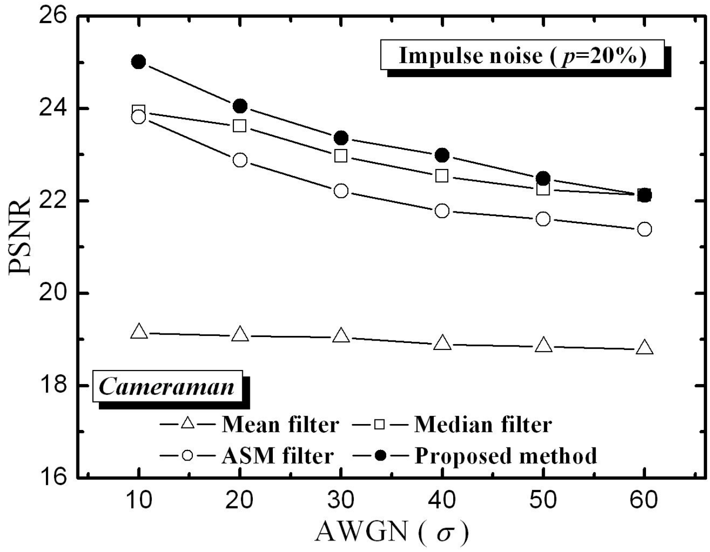


(a) PSNR with variation of AWGN

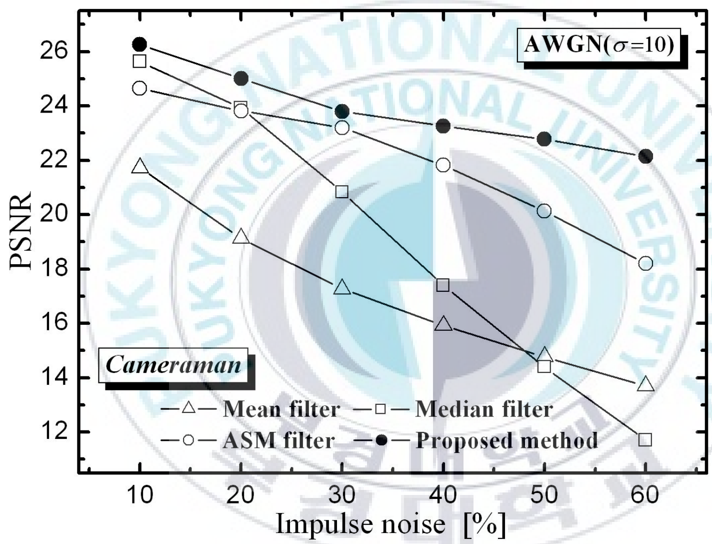


(b) PSNR with variation of impulse noise

Fig. 22. PSNR of Barbara Image.



(a) PSNR with variation of AWGN



(b) PSNR with variation of impulse noise

Fig. 23. PSNR of Cameraman Image.

V. Conclusion

An image restoration method for separating and removing AWGN and impulse noise was proposed in this paper. 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. Weighted values in mask are established more exactly by detecting the spatial location of impulse noise and calculating the standard deviation of AWGN.

From the simulation result, the proposed method separated and removed impulse noise as well as AWGN while preserving edge regions simultaneously, and also showed a better PSNR result. It is believed that the proposed method would be widely used in many image processing fields.

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감사의 글

본 논문이 완성되기까지 부족함이 많은 저에게 학문에 대한 의미를 부여해 주시고, 북경의 집을 떠나 부산으로 유학생활하는 것에 어려움은 없는지, 항상 세심하게 챙겨주시고, 아낌없는 사랑과 가르침으로 보살펴 주신 김남호 교수님께 고개 숙여 감사드립니다. 교수님의 은혜와 배려를 마음속 깊이 간직하겠습니다. 그리고, 바쁘신 와중에도 보잘 것 없는 제 논문에 많은 신경을 써주시고 지도와 조언을 해주신 변기식 교수님, 황용연 교수님께도 감사의 마음을 전합니다. 지금까지 수준 높은 수업으로 저의 시야를 넓혀주셨고, 아낌없는 마음으로 이끌어 주신 이형기 교수님, 최연욱 교수님, 김만고 교수님, 안영주 교수님, 이경창 교수님께 감사드립니다.

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