A Mask-based Gaussian Noise Removal Algorithm in Spatial Space

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Abstract—According to the development and wide use of broad band internet etc., diverse application technologies using large capacity data such as images have been progressed and in these systems, for accurate acquisition and precise applications of an original signal, the degradation phenomenon generated in the transmission process etc. should be removed. Noises have become known as the main cause of the degradation phenomenon and especially Gaussian noise represents characteristics occurring dependently in image signals and degrades detail information such as edge. In this paper, we removed Gaussian noise using a subdivided nonlinear function according to a threshold value and analyzed the histogram acquired from an edge image to establish a threshold value adaptively, and strengthened detail information of image by using the postprocessing. In simulation results, the proposed method represented excellent performance from comparison of MSE with existing methods.

Index Terms—Degradation phenomenon, Gaussian noise removal, histogram, threshold value

I. INTRODUCTION

Owing to wide use and the development of portable terminal and internet, diverse applications using massive data like as image have been progressed and researches related to these areas have been being processed. In the process of transmission and storage of image, the degradation phenomenon is generated at a raw signal by a variety of causes.

The degradation phenomenon interferes with accurate acquisition and precise application of the raw signal and noise has known as a representative cause. Especially, the Gaussian noise represents the characteristics generating at signals dependently during the image transmission and is modeled as statistical form with the normal distribution and is superposed on the original image with smaller amplitude than different types of noises.

As methods to remove the Gaussian noise, there are linear spatial filters [1]-[5]. Since linear spatial filters generally represent simple characteristics mathematically, it excels in process speed and does not need domain transform for noise removal. Mean filter is representative in linear spatial methods. It substitutes the average value of pixels in mask region as a new pixel and uses a method which decreases the difference value of degraded pixels by noises. Therefore, it shows good noise removal ability in regions representing small amplitude variance relatively while the result image is blurred due to not reflecting detail information.

Moreover, to reflect original characteristics of image, methods which judge operation of pixels in filtering mask using threshold value have been proposed [6]-[16]. Generally, these methods analyze features of images by threshold value established with absolute difference value of central pixel and neighboring pixels. If absolute difference value is smaller than threshold, the central pixel would be outputted according to judgment that the central pixel represents the similar to the characteristics of neighboring pixels. On the other hand, if the absolute difference is larger than threshold, it would be judged as high-frequency characteristics representing large brightness difference and processes as detail information such as edges. However, in case that the establishment of threshold value is not proper or characteristics of images could not be reflected due to fixed threshold value, a weak point which could not have excellent noise removal ability is generated.

In this paper, we present a mask-based noise removal algorithm in spatial space. Since the proposed method processes inputted image by using a nonlinear function and threshold established in this paper, image characteristics could be reflected in detail. In order to establish adaptive threshold, after calculating the histogram of edge image of result processed by a nonlinear function, we analyze the mean value and standard deviation of the histogram. Through postprocessing, we could strengthen detail information of images using the difference value of central pixel and neighboring pixels. Moreover, in order to evaluate the performance of proposed algorithm, we use mean square error (MSE) and prove Gaussian noise removal ability of proposed method through the comparison with other methods.

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II. EXISTING NOISE REMOVAL METHODS

There are mean filter, linear technique, and threshold permutation weighted median (TPWM) filter as existing Gaussian noise removal methods used in this paper for comparison with the proposed algorithm. These methods utilize pixels in mask like as Fig. 1. And then a 3×3 mask is used and a central pixel $m(n)$ is calculated as an output value through computations with neighboring pixels in the mask.

2.1 Mean filter

Mean filter is a representative linear spatial filter which has the weighted value of 1 and processes the sum of each pixel divided by the total pixel number of mask [1]. That is, image is smoothed by using the mean value of pixels corresponding to mask region and Gaussian noise is removed.

Therefore, it has excellent characteristics in low frequency region representing the slightly varied gray level. However, in high frequency region which has the features of sharply varied gray level, a weak point not reflecting the details of images is generated. Equation (1) defines the mean filter with a 3×3 mask.

$$y_{mean}(n) = \frac{1}{9}\left(\sum_{i=1}^{8} m_i(n) + m(n)\right) \tag{1}$$

2.2 The linear technique

The linear technique is a Gaussian noise removal algorithm which uses the output of difference between central pixel and its neighboring pixels to reflect features of images. It is defined as (2) [3]-[4].

$$y_{linear}(n) = m(n) + \mu(4m(n) - m_2(n) - m_4(n) - m_5(n) - m_7(n)) \tag{2}$$

From above the equation, μ is an establishment parameter and should be larger than 0. The second term of this equation makes the roll of high frequency pass filter and it is a method applying neighboring image information in mask.

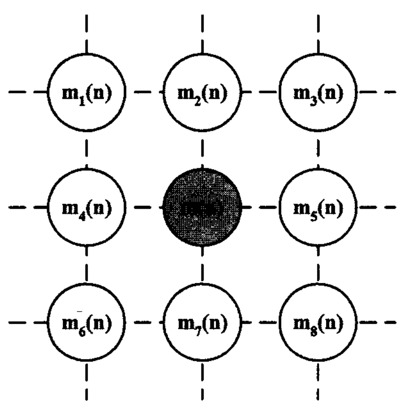


Fig. 1 Mask for filtering.

2.3 TPWM filter

TPWM filter is based on order statistics [6]. This filter arranges pixels in ascending order of magnitude and is a Gaussian noise cancellation method using threshold value according to magnitude ranking. The preprocessing of this method is defined as (3).

$$y_{PWM}(n) = \begin{cases} m(n) + \tau \cdot m_{(th_{PWM+1})}(n) - \tau \cdot b(n), & rc \le th_{PWM} \\ (1+\tau) \cdot m(n) - \tau \cdot b(n), & th_{PWM} < rc \le N - th_{PWM} \\ m(n) + \tau \cdot m_{(N-th_{PWM})}(n) - \tau \cdot b(n), & rc > N - th_{PWM} \end{cases} \tag{3}$$

where, τ is a weight parameter and $m_{(1)}, m_{(2)}, \cdots, m_{(N)}$ are pixels ranked in filtering mask after ascending pixels. rc is the magnitude ranking of the central pixel and N is total number of pixels in mask. Moreover, $b(n)$ is defined as equation (4).

$$b(n) = (m_{(1)}(n) + m_{(N)}(n))/2 \tag{4}$$

Equation (4) means the mean value between minimum value and maximum value in mask after ascending. And when pixels in mask are ascended, th_{PWM} is applied as the threshold value for rc, and this output value is calculated into three sections. And then, by (5), final output is acquired and where, T_{TPWM} is a threshold value separating the difference value of $m_{(N)}(n)$ and $m_{(1)}(n)$ after ascending pixels in mask.

$$y_{TPWM}(n) = \begin{cases} y_{PWM}(n), & m_{(N)}(n) - m_{(1)}(n) > T_{TPWM} \\ m(n), & m_{(N)}(n) - m_{(1)}(n) \le T_{TPWM} \end{cases} \tag{5}$$

III. PROPOSED ALGORITHM

In this paper, we calculate the difference value between central pixel and neighboring pixels by using 3×3 filtering mask to remove Gaussian noise. Eight difference values are obtained in one mask region, and then, after these values are divided into seven sections by the established threshold value, they are processed by a nonlinear function. In this process, Gaussian noise is removed and in order to establish adaptive threshold value, we calculate and analyze the histogram of edge image which is sensitive to noise. To strengthen detail information of the result image processed by a proper threshold value, postprocessing is applied after calculating the difference value.

The first step of proposed algorithm is an operation by a nonlinear function, $E(d)$ established in this paper and $E(d)$ is defined as (6).

$$E(d)=\begin{cases} MAX\{-5(5th_p+d), L-1\}, & d<-5th_p \\ -(3th_p+d), & -5th_p \le d < -3th_p \\ -\frac{1}{4}(4th_p+d), & -th_p \le d < th_p \\ d, & -th_p \le d < th_p \\ \frac{1}{4}(4th_p-d), & th_p \le d < 3th_p \\ 3th_p-d, & 3th_p \le d < 5th_p \\ MIN\{5(5th_p-d), -L+1\}, & d \ge 5th_p \end{cases} \quad (6)$$

Where, d means difference values between central pixel and neighboring pixels and is defined as (7). L is the quantization number of the inputted image, and th_p is a threshold value established in this paper. From (6), if d is not a large value, its output value would be similar with neighboring pixels by making smaller difference. If d is a large value, the probability with existence of details such as edge in images is high relatively and so, a larger absolute value would be inserted into for calculation as detail characteristics of image.

$$d = m_i(n) - m(n) \quad (7)$$

From (6) and (7), eight values are calculated by th_p in $E(d)$, in case of one mask operation. And then, after the mean value of these values is calculated, the sum of this average value and central pixel, and $L-1$ are compared as (8).

$$y(n) = MIN\left\{m(n) + \frac{1}{8}\sum_{i=1}^{8} E(d),\ L-1\right\} \quad (8)$$

The Gaussian noise removal work is implemented by a threshold value th_p through the process of (6) to (8). In order to establish the threshold value of the proposed method adaptively, we can get the edge image of output by (9).

$$y_e(n) = 2MAX\{|y(n)-y_2(n)|,\ |y(n)-y_4(n)|\} \quad (9)$$

As (9) is the equation which reacts sensitively to edge and noise, and a proper threshold value is estimated using this edge image.

If the threshold value is not proper, not only edge but also noise is distributed in the output image. On the other hand, if noises are removed excellently by a proper threshold value, only edge is represented in the output image.

And then, in order to establish the proper threshold value, we analyze a histogram using the distribution of the edge image. Where, $H(l)\ (0 \le l \le L-1)$ defines the histogram of the edge image. We establish a threshold value using calculation of the mean value and the standard deviation of $H(l)$. The mean value and standard deviation are defined as (10) and (11) respectively. If th_p is a small value, the histogram represents a smoothed shape. If th_p is a large value, the distribution of histogram is concentrated at the location of low gray level. During the process of the Gaussian noise removal, because the probability increasing total number of $l=0$ and $l=255$ is artificially high, these values are excepted from the calculation of histogram.

$$H_m = \frac{\sum_{l=1}^{L-2} lH(l)}{\sum_{l=1}^{L-2} H(l)} \quad (10)$$

$$H_{std}^2 = \frac{\sum_{l=1}^{L-2} (l-H_m)^2 H(l)}{\sum_{l=1}^{L-2} H(l)} \quad (11)$$

Using the mean value and standard deviation of histogram calculated by (10) and (11), we can get a parameter, Q to obtain a proper th_p as (12).

$$Q = \frac{H_{std}^2}{H_m} \quad (12)$$

The th_p is obtained by the output of (12). And if H_m is a large value, this processed result raises the probability passing the original pixel. So, the image would be sharp and the performance of noise removal would be inefficient.

If H_m is a small value, the blurring phenomenon occurs in images and noise is removed efficiently while there is a weak point incurring the loss of details of images. Therefore, by the relation of (12), in case that Q is the maximum, the most proper th_p is chosen. Therefore, before applying proposed algorithm, we set the optional section of threshold value. And then, we chosen the filtering result of maximum Q. Detail information of image passing through the noise removal process by a proper th_p

is made more sharp as (13).

$$y(n) = m(n) - \underset{i=1\sim8}{MIN}\{D(m(n),\ m_i(n))\} + \underset{i=1\sim8}{MIN}\{D(m_i(n),\ m(n))\} \quad (13)$$

where, $D(a, b)$ is defined as (14).

$$D(a, b) = \begin{cases} a-b, & 0 < a-b \le L-1 \\ 0, & a-b \le 0 \end{cases} \quad (14)$$

By (13) and (14), the edge parts of images are more sharp and the blurring phenomenon generated in the Gaussian noise removal process is decreased.

IV. EXPERIMENTAL RESULTS

In order to simulate the proposed algorithm in this paper, as test image with 256×256, "Man" and "Einstein" image were used. We superposed AWGN of diverse variances on original images and used MSE as the judgment to evaluate the noise removal performance of the proposed method. Mean filter, the linear technique and TPWM filter were used for the performance comparison. A 3×3 mask was used in this paper. And $\mu = 1.2$ was used in the linear technique and $th_{TPWM} = 2$, $\tau = 2.5$, and $T_{TPWM} = 50$ were used in TPWM filter. In the proposed method, we set an optional section of threshold as 10 to 50.

Fig.2 and Fig. 3 represent images for simulation. (a) is an original image of "Man" and "Einstein" respectively. (b) is the degraded image by Gaussian noise with variance $\sigma^2 = 50$.

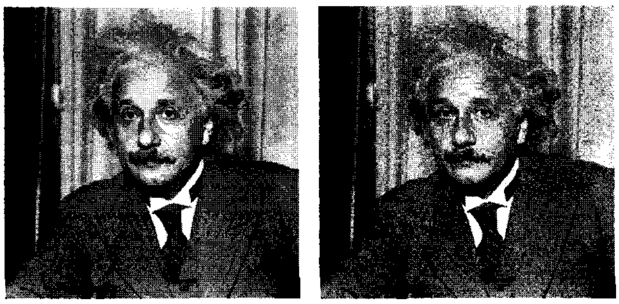
Fig. 3 shows filtering result images and difference images by each method. In this figure, (a), (c), (e), and (g) represent result images by mean filter, linear technique, TPWM filter, and the proposed method respectively. From the results, the result by mean filter has good noise removal ability while blurring phenomenon was generated in hair and edge of objects. Since linear technology reflects image characteristics, its filtering result preserved detail information clearly while error was generated in the process of noise removal. TPWM filter preserved detail information of degraded image and has excellent noise removal performance. However, since some error occurred in the result image, degradation phenomenon remains. Since the proposed method reflects image features by analyzing the histogram of edge image, it showed a excellent noise removal ability. Due to postprocessing to strengthen detail information, it preserved edge of image for example the watch. (b), (d), (f), and (h) represent the difference images by mean filter, linear technology, TPWM filter and the proposed method. Since in difference images by each method, the proposed method showed the smallest difference with the original image, the proposed algorithm represents the best noise removal ability.

Fig. 5 represents filtering results and difference images about "Einstein" image by mean filter, linear technology, TPWM filter and a proposed algorithm. These figures represents similar results with "Man" image ones. Mean filter showed blurring phenomenon and especially in necktie etc. Linear technology generates error during noise removal step in "Einstein" image, too. TPWM filter cleared edges such as suit but occurred error. The result by the proposed method removed Gaussian noise efficiently and preserved edges such as eyebrows and a necktie by using the histogram of edge image. Difference images by each method represented similar results with one of "Man" image. In difference images, the proposed algorithm showed the most approached filtering result with the original image.

Table 1 represents MSE results about "Man" and "Einstein" image. Mean filter showed low MSE relatively according to removing Gaussian noise by smoothing image. Linear technique represented largest MSE values in the results by each method since error was generated in the process of noise removal. TPWM filter showed better MSE in low variance regions while increased MSE gradually according to high variances. In the MSE by the proposed algorithm, best MSE was shown because Gaussian noise removed well and preserved detail information through postprocessing.

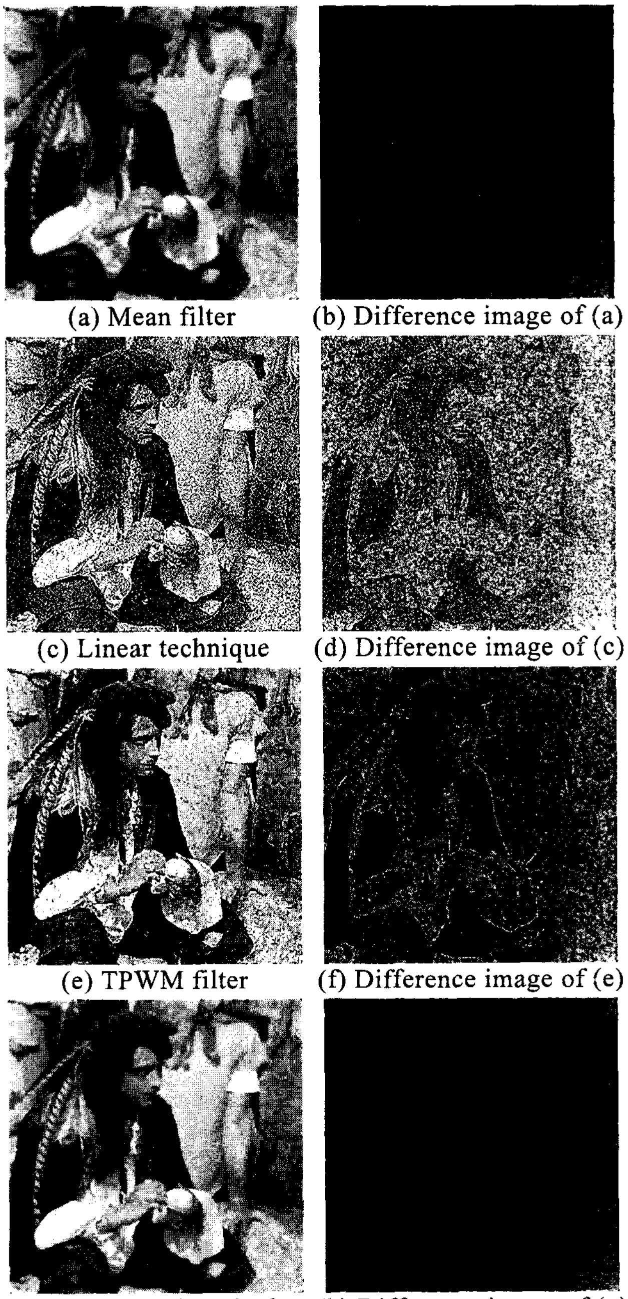
(a) Original image (b) Degraded image

Fig. 2 "Man" images for simulation.



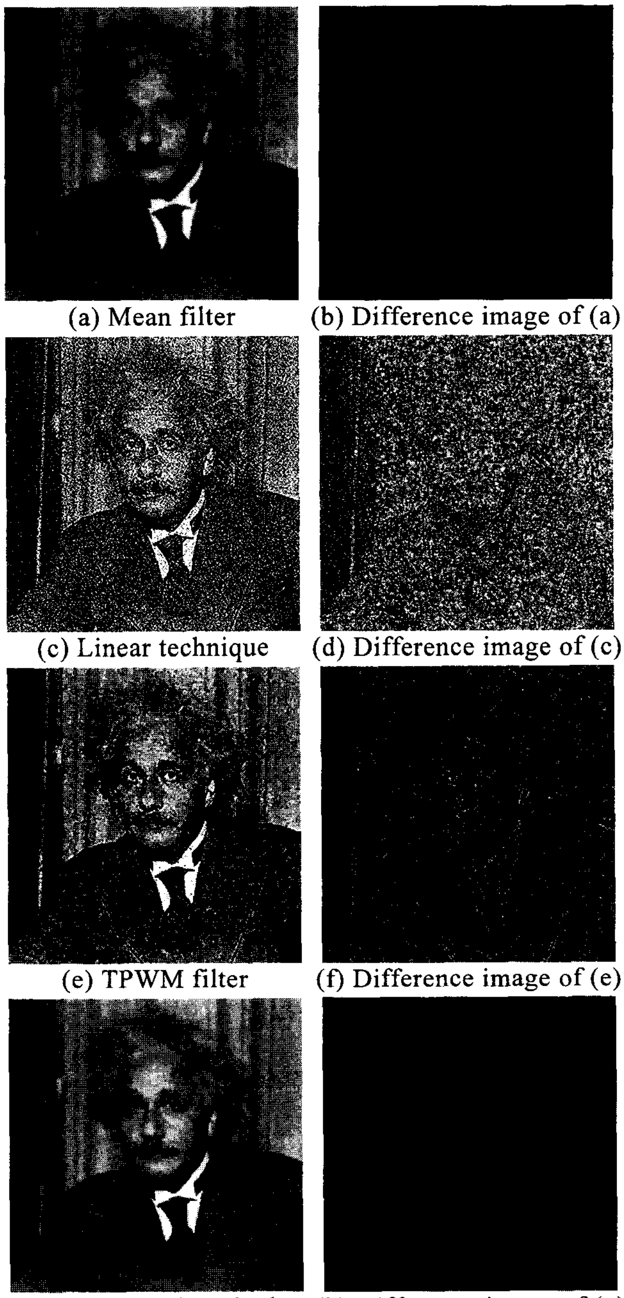
(a) Original image (b) Degraded image

Fig. 3 "Einstein" images for simulation.



(a) Mean filter (b) Difference image of (a)
(c) Linear technique (d) Difference image of (c)
(e) TPWM filter (f) Difference image of (e)
(g) Proposed method (h) Difference image of (g)

Fig. 4 Filtering results about "Man" image.



(a) Mean filter (b) Difference image of (a)
(c) Linear technique (d) Difference image of (c)
(e) TPWM filter (f) Difference image of (e)
(g) Proposed method (h) Difference image of (g)

Fig. 5 Filtering results about "Einstein" image.

Table 1 The comparison of MSE

σ^2	Man				Einstein			
	Mean	Linear	TPWM	Proposed	Mean	Linear	TPWM	Proposed
10	64.809	195.21	82.51	39.71	44.33	198.18	59.57	34.49
20	67.879	202.55	108.49	47.03	47.90	207.19	90.16	40.29
30	71.284	207.23	128.28	55.45	51.93	211.80	114.11	45.31
40	74.059	208.98	143.28	61.26	55.89	215.04	133.26	52.27
50	77.578	212.13	156.07	65.44	59.15	217.52	150.14	55.25
60	80.901	212.87	165.52	69.54	63.35	219.39	161.71	60.13
70	83.709	214.66	172.92	75.15	65.96	220.56	172.36	62.93
80	85.883	215.10	179.86	77.79	70.10	221.54	180.28	67.12
90	88.953	216.27	186.95	81.94	72.66	222.30	186.98	70.98
100	91.462	217.19	189.52	85.82	75.82	223.14	192.43	74.59

V. CONCLUSION

We presented a mask-based Gaussian noise removal algorithm in spatial space in this paper. In order to remove Gaussian noise, pixels in mask are processed by dividing seven sections using a nonlinear function and threshold. Moreover, to establish a proper threshold value adaptively, the edge image, which is sensitive to noise and edge, is acquired after pixels in mask are processed by a threshold value. And then, using the mean value and standard deviation of the histogram about edge image, a proper threshold value can be acquired adaptively. Finally, detail information of the image is strengthened efficiently through postprocessing step.

In simulations, the proposed algorithm was compared with existing methods. From filtering results, the proposed method removed Gaussian noise well and preserved detail information such as edges. Moreover, through MSE comparison in simulation, the proposed method showed the best MSE values and was proven Gaussian noise removal characteristics. Therefore, it is thought that the proposed method would be applied widely for the part such as the noise cancellation step of systems utilizing images.

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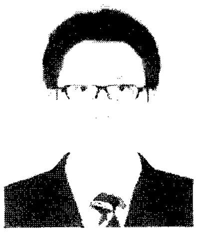

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