An Estimation of Standard Deviation of Gaussian Noise Using the Image Variation Components and the Denoising Filter

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Abstract— **There are methods based on PCA using iterative processing and MAD as methods to estimate the standard deviation σ of Gaussian noise in the Gaussian noise image. These methods can be estimated accurately if the Gaussian noise is large. However, in the case of low Gaussian noise with σ less than 10, its estimation accuracy is not good. In this paper, we extend the method based on denoising filter and MAD, and propose a estimation method of low Gaussian noise by using the difference. In this paper, it is clarified that the error can be reduced by 12% in the low Gaussian noise image compared with the conventional method using MAD.**

I. Introduction

Methods to estimate the standard deviation of Gaussian noise from an image on which Gaussian noise is superimposed have been proposed method based on PCA by Liu[1] and methods based on the author's change in the image [2]. Liu's method [1] uses iterative processing, so its estimation accuracy is good. However, that method has the problem that the amount of calculation is large. Our proposed method [2] divides the image into blocks and then estimates the standard deviation of Gaussian noise of the block that is considered to be flat using the MAD (Median Absolute Deviation) based method used in robust estimation. Authors also apply the method of Ref B to the Wiener filter, and propose a method to demonstrate the performance improvement of the noise removal filter [3]. Data-dependent filters including Wiener filters, SURE method [4], etc. are based on the assumption that the standard deviation of Gaussian noise superimposed on an image is known. Therefore, accurate estimation of the noise to be superimposed on the image is necessary to obtain appropriate filter coefficients. The method of reference [2] can accurately estimate noise when the standard deviation of Gaussian noise superimposed on an image is 10 or more. However, in this method, if the Gaussian noise being superimposed is less than 10, the accuracy may not be preferable depending on the type of image. The reason for this is that the image is a set of the nonstationary signals, and in the method of reference [2], edges and detail signals are present in blocks considered to be flat. Therefore, we think that it may be caused by the inability to separate the image component and the noise component. Thus, a method that can estimate noise accurately and quickly even if the standard deviation of Gaussian noise is less than 10 is desired.

In this paper, we extend the method of Ref. [2] and propose a method to estimate noise more accurately than Ref. [2] even if the standard deviation of Gaussian noise is less than 10. Specifically, we propose a method to estimate noise by applying a noise removal filter to the noisy image and minimizing the effects of edge and detail signals.

In the proposed method, a noise reduction filter is applied to the Gaussian noise affected image, and then the standard deviation is estimated by the method of reference [2].

This standard deviation is assumed to be the standard deviation that includes the edge and detail signals of the image itself. The standard deviation of the image on which Gaussian noise is affected is also estimated by the method of reference [2], and it is considered that the standard deviation of the Gaussian noise affected on the image can be calculated by taking these differences. In this paper, the effectiveness of the proposed method is clarified by applying and comparing the method of the reference [2] (the conventional method) and the proposed method to an image on which low Gaussian noise$\sigma = 5$ Gaussian noise is affected.

II. Gaussian Noise Estimation by the Conventional Method

There is a method using MAD (Median Absolute Deviation) based on robust estimation as a method to estimate the standard deviation of Gaussian noise from an image on which Gaussian noise is affected[1].

$$\hat{\sigma} = 1.483 \cdot med(|B_i - med(B_i)|) \qquad (2)$$

In Eq.(1), med denotes median processing, and $med(B_i)$ denotes the median value of the processing point and its neighboring area B.

In Ref[6], the image is divided into 16 × 16 subblocks, and Eq.(1) is applied to each subblock. Then, the standard deviation of all subblocks is rearranged in ascending order, and 5% of the number of all subblocks is selected from the minimum value. Furthermore, by calculating the mean of the standard deviation of the selected sub-blocks, the standard deviation of Gaussian noise affected on the entire image is obtained. By these, it is possible to estimate the standard deviation of Gaussian noise from the sub-block that seems to be the flat part of the image.

$$\sigma_n = \frac{1}{M_n} \sum_{i=1}^{M_n} \sigma_x (B_i) \qquad (2)$$

In Eq.(2) , $\sigma_x(B_i)$is the result of applying Eq.(1) to each subblock B_i sorted in ascending order, and M_n is n% of the total number of all subblocks Represents. In Ref[6], subblocks from the minimum value to 5% are selected, and in Eq.(2), n = 5 and the estimated value can be expressed as σ_5.

In Ref[2], the result of Eq.(2) is multiplied by a correction value controlled by the amount of edge and detail signals contained in the image. Thereby, solves the problem that the accuracy of noise estimation in Ref[6] depends on the type and nature of the image.

$$\hat{\sigma}^* = \alpha \cdot \frac{1}{M_n}\sum_{i=1}^{M_n}\sigma_x(B_i) \quad (3)$$

The correction factor α in Eq.(3) is controlled by the content of edge and detail signal in the image. The correction factor is basically close to 1 when the image contains many flat parts, and is basically less than 1 when the image contains many edge and detail signals. Therefore, the value of α is determined according to the proportion of edge and detail signals in the image. In Ref[2], the correction coefficient α is given by the linear expression of the image property parameter m which quantifies the property of the image.

$$\alpha = a_1 m + a_0 \quad (4)$$

Then, the image property parameter m is defined by the following equation.

$$m = \frac{\sigma_{30}-\sigma_5}{0.3-0.05} \quad (5)$$

In Eq.(5), σ_5 is the value of using Eq.(2) to calculate the average of the standard deviation of subblocks from the minimum value to 5%. Also, σ_{30} is the value of using Eq.(2) to calculate the average of the standard deviation of subblocks from the minimum value to 30%. The gradient connecting the plots of σ_5 and σ_{30} gives the proportion of edge and detail signals contained in the image. This gradient corresponds to m defined in Eq.(5).

In Eq.(4), the coefficients a_1 and a_0 need to be controlled by the standard deviation of Gaussian noise affected on the image. However, since the standard deviation of true Gaussian noise is unknown, in the Ref[2], the coefficients a_1 and a_0 are defined as follows using the Gaussian noise estimated value σ_5 estimated by the Ref[6].

$$a_i = b_{i1}\sigma_5 + b_{i0} \qquad (i = 0,1) \quad (6)$$

In Ref [2], the coefficients b_i0 and b_i1 are calculated experimentally using 21 types's of images in Eq.(6). The coefficients were calculated as $b_{00} = 1.222976$, $b_{01} = -0.001872$, $b_{10} = -0.03331$, $b_{11} = 0.00088$.

The above is the standard deviation estimation method of the Gaussian noise affected on the image of the conventional method according to the Ref[2]. The method of Ref[2] can be estimated accurately if the Gaussian noise is more than σ = 10. However, if σ is less than 10, the estimation accuracy is not good. For example, Figure 1 shows the result of applying the conventional method to an image on which low Gaussian noise (σ = 5) is affected. In the estimation of the standard deviation of the low Gaussian noise affected image by the conventional method, it is possible to estimate a value close to the true valueσ = 5 for an image containing many flat parts. However, the standard deviation of Gaussian noise tends to be overestimated in images with few flat parts and many edge and detail signals. In low Gaussian noise affected images with few flat parts, the effects of components such as edges and detail signals of the original image are larger than noise components, so that the estimation accuracy varies depending on the type of image. In the conventional method, the estimation error will be large unless the image has a flat part. Therefore, it is necessary to have a method to stably estimate Gaussian noise even in images without flat parts.

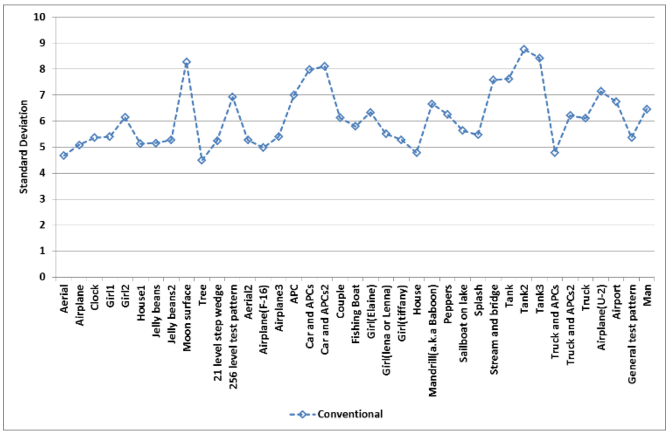

Fig. 1 Result of Gaussian noise estimation by conventional method(σ = 5)

III. PROPOSED METHOD USING DENOISING FILTER

Assuming that the variance of the original image on which the Gaussian noise is not affected is I_{var}, the variance of the Gaussian noise to be affected is N_{var}, and the variance of the Gaussian noise affected image is X_{var}, the following relation can be expressed.

$$X_{var} = I_{var} + N_{var} \quad (7)$$

N_{var} becomes close to 0 when applying denoising filter to Gaussian noise affected image, Therefore, if the variance of the image to which the noise removal filter is applied is X'_{var}, then X'_{var} is close to I_{var}. Accordingly, the estimated value N_{var} of the variance of Gaussian noise can be expressed by the following equation.

$$N_{var} = X_{var} - X'_{var} \quad (8)$$

At this time, X_{var} is the variance of the image on which Gaussian noise is affected, it can be expressed as $\hat{\sigma}^{*}{}_{n}{}^{2}$ by applying Eq.(3).In addition, X'_{var} is an image after denoising filter, it can be expressed as $\hat{\sigma}^{*}{}_{n}{}'^{2}$ by applying Eq.(3). Based on these relationships, the proposed method estimates the standard deviation of Gaussian noise in the following three steps.

1. A denoising filter is applied to the low Gaussian noise affected image.

2. The Gaussian noise is estimated by Ref[2] for each of the low Gaussian noise affected image and the image to which the noise reduction filter is applied.

3. Calculate the difference between the variance $\hat{\sigma}^{*}{}_{5}{}^{2}$ of the low Gaussian noise affected image estimated in step 2 and the variance $\hat{\sigma}^{*}{}_{5}{}'^{2}$ of the image to which the noise reduction filter

is applied. From this difference, we estimate the variance $\hat{N}_{var}$ of the Gaussian noise affected on the image. In this case, n = 5 is set to select a subblock of 5% from the minimum value.

$$\hat{N}_{var} = \hat{\sigma}^*{}_5{}^2 - \hat{\sigma}^*{}_5{}'^2 \tag{9}$$

When using noise reduction filter such as winner filter or data dependent filter in step 1, use the standard deviation of Gaussian noise affected on the image as a parameter. Thus, it is considered inappropriate to adopt to estimate Gaussian noise to be affected on an image. Therefore, we use Gaussian filter as a simple filter with low computational cost and with some edge and detail signal preservation. The Gaussian filter's kernel uses the values shown below.

$$K = \frac{1}{16}\begin{bmatrix} 1 & 2 & 1 \\ 2 & 4 & 2 \\ 1 & 2 & 1 \end{bmatrix} \tag{10}$$

In step 2, The method of [2] basically estimates the standard deviation of Gaussian noise from the flat part contained in the image. In the case of an image in which the flat part is sufficiently included, the variance X'_{var} after applying the noise reduction filter is almost 0, so it is considered that Gaussian noise is rarely underestimated by taking the difference in step 3. In contrast, in the case of an image that includes edge and detail signals, the variance X'_{var} after applying the noise reduction filter is calculated as an estimated value of the cause of excessive noise evaluation in the conventional method [2].Therefore, the Gaussian noise estimated value is less overestimated by taking each difference in step 3.

IV. APPLICATION EXAMPLE

In this chapter, the conventional method (the method of reference [2]) and the proposed method using a noise reduction filter are applied to various images on which Gaussian noise is affected, and then comparison and examination are made. In the conventional method, the estimation accuracy of Gaussian noise with $\sigma = 5$ was not good. Therefore, in this paper, we use 39 images (Figs. 2, 3 and 4) with Gaussian noise of $\sigma = 5$ affected. Figure 5 shows the results of applying the conventional method and the proposed method to an image on which Gaussian noise with $\sigma = 5$ is affected. In addition, Fig. 6 shows the average error of the estimation results of 39 types of images of the conventional method and the proposed method.

In Fig. 6, the estimated value of Gaussian noise of the proposed method is smaller than that of the conventional method. In particular, noise overestimation is suppressed for images (Moon surface, 256 level test pattern, APC, Car and APCs, Car and APCs2, Mandrill(a.k.a Baboon), Stream and bridge, Tank, Tank2, Tank3, Airplane(U-2), Airport) with many edges and detail signals. In the conventional method, the standard deviation was overestimated by about 2 to 4, but in the proposed method, it was possible to reduce the standard deviation by about 1 to 2 from the conventional method. However, there are images (Aerial, Tree, Aerial2, Airplane (F-16), House, Truck and APCs) in which noise is underestimated by the proposed method.

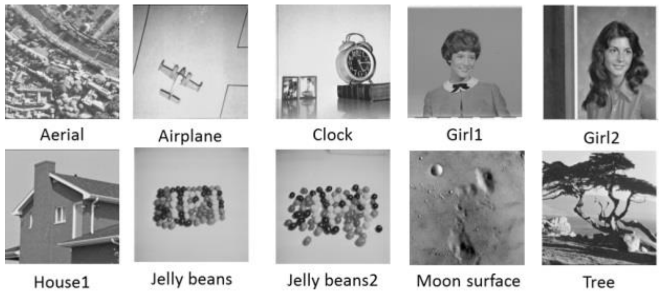

Fig. 2 39 type images 1 (256×256)

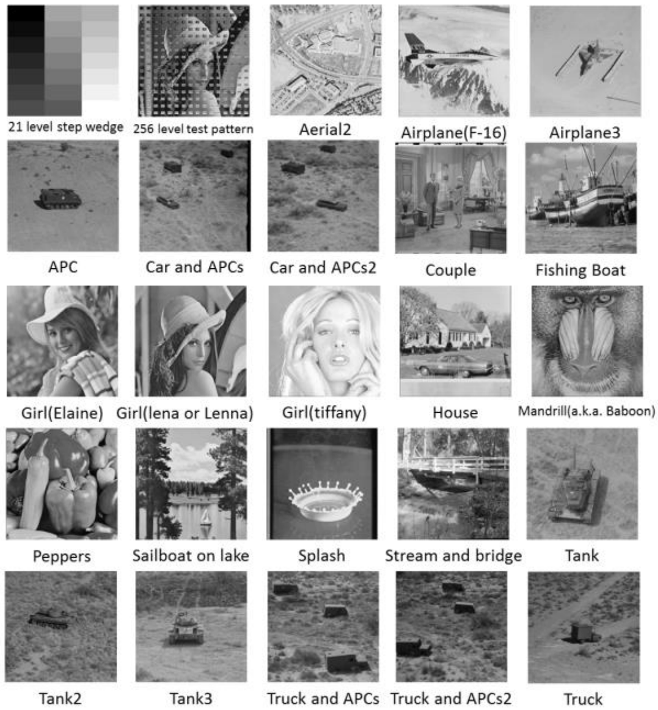

Fig. 3 39 type images 2 (512×512)

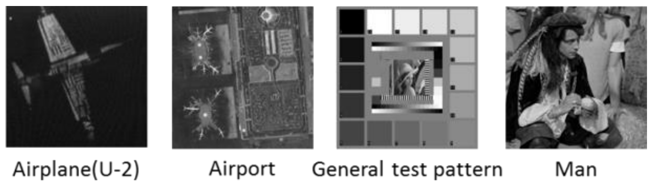

Fig. 4 39 type images 3 (1024×1024)

These were images with sufficient estimation accuracy in the conventional method. In the conventional method, a value close to the true value $\sigma = 5$ was estimated, but in the proposed method, the noise was underestimated by about 1 as a standard deviation. The reason is that the noise reduction filter by the proposed method can not remove all noise, so the remaining noise component is affected by the estimated standard deviation. As a result, when taking the difference from the estimated value of Gaussian noise in Eq.(9), the noise is underestimated due to the remaining noise component.

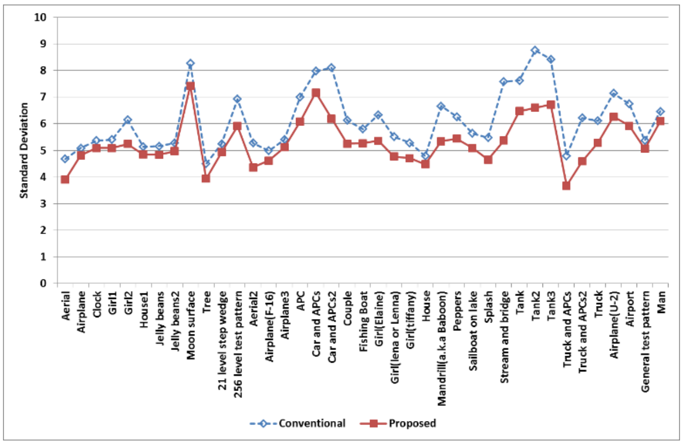

Fig. 5 Compare the conventional and proposed

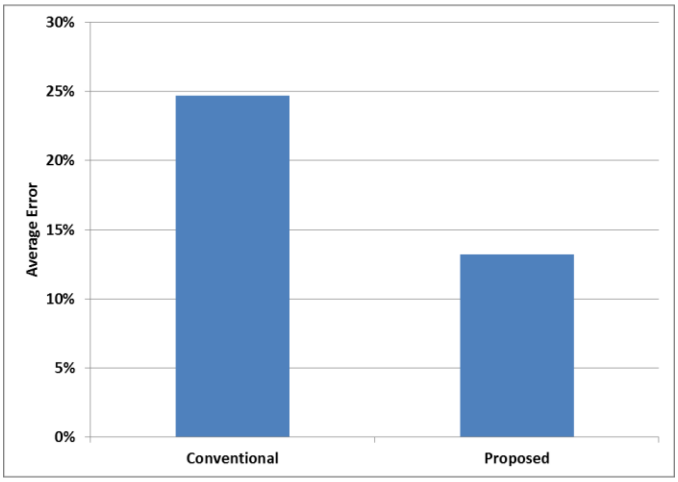

Fig. 6 39 type images error

Therefore, in this paper, the Gaussian filter is used, however we think that this problem may well solved by changing to the non-liner filter with higher noise removal performance[7][8].

According to figure 5, in the conventional method, an image having many flat portions is estimated to have a value close to $\sigma = 5$, which is the true value, and the noise is overestimated as the ratio of edge and detail signals increases. There are 5 to 9 variations depending on the image as an estimate of the standard deviation of Gaussian noise. In constrast, in the proposed method, compared to the conventional method, the noise of the image with few edge and detail signals and many flat parts is underestimated. However, in the proposed method, the variation in estimation accuracy due to the type of image is suppressed compared to the conventional method, and it is 4 to 7 as the estimated value of the standard deviation of Gaussian noise. In Fig. 6, the error of the estimation accuracy of Gaussian noise of the whole image in the proposed method is reduced by about 12% compared to the conventional method.

V. CONCLUSION

In this paper, we proposed a method to estimate the standard deviation from an image degraded by low Gaussian noise. In the proposed method, the noise reduction filter is applied to the image degraded by low Gaussian noise and the standard deviation of the edge and detail signal of the image is calculated, and the cause of the noise being overestimated can be removed. The proposed method achieves a reduction of estimation error of about 12% in the low Gaussian noise ($\sigma = 5$) image compared to the conventional method. We were able to solve the problem that the noise was overestimated, especially for images with few flat parts and many edge and detail signals.

However, the standard deviation estimate of Gaussian noise in some images was underestimated by about 1 compared to conventional method.

As a future subject, it is necessary to verify whether the estimation accuracy of noise is improved by changing to a filter having higher noise removal performance than the Gaussian filter.

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