Fast Noise Level Estimation from a Single Image Degraded with Gaussian Noise

Takashi Suzuki[†] Keita Kobayashi[†] Hiroyuki Tsuji[†] and Tomoaki Kimura[†]
[†]Department of Information and Computer Science, Kanagawa Institute of Technology,
1030 Shimoogino, Atsugi-shi, Kanagawa, 243-0292 Japan

***Abstract*—Noise level estimation is essential for many image processing tasks, especially for denoising, because the estimated standard deviation (SD) of Gaussian noise is used for the restoration of degraded images. Two major methods are proposed for noise level estimation so far: one is based on the principal component analysis (PCA) and the other is based on the median absolute deviation (MAD). However, these methods have some problems, related to computing time or precision of the estimate. In this paper, we proposed a new noise level estimation for Gaussian noise that is achieved by extending the MAD-based method. In the proposed method, noise level is estimated by using a formula that is derived from linear regression. Experimental results show that the error of standard deviations estimated by the proposed method is smaller than that estimated by the conventional method.**

I. Introduction

Denoising algorithm from images degraded by Gaussian noise is very important process. Moreover, many denoising algorithms have been proposed,such as mean filter, weighted mean filter, and Wiener filter [1]. These denoising algorithms are based on the linear filtering technique, so the smoothing results are not necessarily surely good. One reason for this is the estimate of standard deviation of Gaussian noise is not accurate enough. Therefore, fast and accurate noise level estimation is crucial for improving such denoising algorithms [2-4].

Some estimation method of standard deviation for Gaussian noise has been proposed. In Ref. [5], this method based on the principal component analysis (PCA) is proposed. PCA method is a good result about Gaussian noise's estimate, however it needs many computing time for iteration process. Therefore PCA method is not suitable for Real-time processing. In Ref. [6], this method based on the median absolute deviation (MAD) is proposed. MAD method is little computing time, however it is not good estimate to image with many edges and details, and dark image. Therefore, a new method excellent in good noise's estimate and computing time is required.

In this paper, we proposed a new estimation method that extended MAD based method [6]. The new method solves two problems, that is, the image with many edges and details and the dark image. The new method proposed applications of correction factor to the image with many edges and details and application of elimination of 0 pixel value to the dark image.

Thus, these methods can improve two problems. In this paper, we compare the conventional method [6] and the proposed method using Gaussian noise images of 39 types. Finally, it is shown clearly that the proposed method is excellent to the conventional method.

II. Estimate the Standard Deviation of Gaussian Noise Based on the MAD

Eq. (1) is MAD based method on robust estimation, it is typical estimate method in standard deviation for Gaussian noise [7].

$$\hat{\sigma} = 1.483 \cdot med(|B_{\mathrm{i}} - med(B_i)|) \qquad (1)$$

Where med denote median process, $med(B_i)$ denote median process of local area B. In Ref. [7], Eq. (1) is applied to image whole, in this results, the standard deviation of Gaussian noise is estimated. However, this method is not good estimate accuracy in some cases. Because estimate accuracy of the MAD based method is dependent on the image quality. For example, estimate value of edges and details is calculated high. Because, in case of image in which edge and detail are contained, Eq. (1) is difficult to divide the noise and the high frequency component image. Therefore, as for Eq. (1) , it is applied only to the flat area.

Ref. [6] proposed a MAD based method which applied the sub-block consider to be flat area. The sub-block is image pixel of 16×16, it is estimated standard deviation of Gaussian noise by using Eq. (1). Therefore, it cannot be easily influenced to edge and detail. Specifically, estimate value of standard deviation for Gaussian noise are sorted sequentially from a top to all sub-block of image, and next, calculated the average value of 5% from minimum value of standard deviation. Fig. 1 shows the selected sub-blocks that are lighlighted with brighter pixel values.

In Ref. [6], the estimate results has the error of 20% from true noise levels ($\sigma = 10, 20, 30$). Fig. 2 shows estimate result by noise images ($\sigma = 10$). The value of estimate results within the range of 8 to 12. However, the estimate result of some images is large estimated error. Moreover, the estimate result of the image "couple" is small estimate value. Because the image "couple" is dark image and it is clipped in 0 by negative Gaussian noise. In this reason, distribution of Gaussian noise is set to asymmetry. As a result, the estimate result is set to small estimate valued. Moreover, the same is said about images of high brightness value. Therefore, the

Fig. 1 Selected sub-block (5% selected)

Fig. 3 Selected sub-block (30% selected)

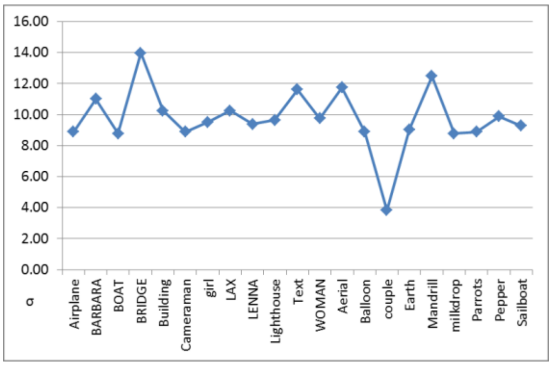

Fig.2 The estimation result of Gaussian noise image ($\sigma = 10$)

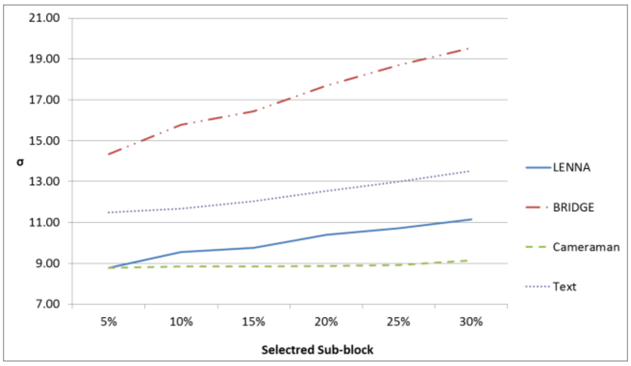

Fig. 4 The gradient of 4 type images

solution method of large estimate error and the partial image of brightness are required

III. Proposed Method

In this section, we proposed a new estimate value's method of Gaussian noise which used MAD based method. The proposed method has calculated the estimated value by applying the method of Ref. [6]. In Ref. [6], the flat area is searched by using MAD based method from sub-block of image. However, flat area may not exist in some images. Accordingly, the proposed method calculate the correction factor of the standard deviation's estimate value corresponding to image of edges and details.

Fig. 3 denotes selected sub-blocks from minimum to 30% by using Eq. (1). It seems the selected sub-blocks contained edges and details. Fig. 4 denotes the average value of standard deviation from 5% to 30% to images of LENNA, BRIDGE, Cameraman and Text. According to the Fig. 4, it seems the standard deviation's slop is linear. For example, the gradient of image (Cameraman) with much the flat area is small, and the gradient of image (BRIDGE) with much the edge and detail is large. Then, gradient of image can estimate the image quality, and the correction factor is calculable from the gradient by the proposed method.

The proposed method is 3 steps.

1) Division into sub-blocks and calculate standard deviation.
2) Elimination of the sub-block pixels in 0 brightness value of a certain number exists.
3) Calculate the correction factor and estimate standard deviation for Gaussian noise.

1) is Ref. [6]'s method, it gets standard deviation ($\hat{\sigma}$) for each sub-blocks by using equation (1).
2) is correspondence to the dark image. 3) estimate the image quality by standard deviation for each sub-blocks, it correct the standard deviation of Gaussian noise base on the image quality.

A. Division of the Sub-blocks and Calculate Standard Deviation

In Ref. [6], the image is divided to $n \times n$, and the standard deviation for Gaussian noise is estimated by using flat area of sub-blocks. The proposed method calculates a gradient by $n \times n$ sub-blocks from minimum to 30%. In this paper, sub-block size is $n = 16$. Moreover, the proposed method calculates a gradient to 5% sub-blocks standard deviation and a gradient to 30% sub-blocks standard deviation [9].

B. Elimination of the Influence to low Brightness Values's image

The standard deviation's value estimate of low brightness value's image is small. Fig. 5 shows the image "couple" distribution for brightness value, it seems there are many value of 0. Fig. 6 is the histogram of image "couple" with noise level ($\sigma = 10$) whose negative values caused by Gaussian noise are compensated. As it turns out from Fig. 6,, brightness values less than 0 should be considered to exist.in such cases. The proposed method eliminates and calculates 0 value pixels, when estimating for the standard deviation of each sub-block. Additionally, according to Eq. (2), when the number of 0 values in a sub-block exceeds *Th*, this sub-block is not used for noise level estimation.

$$B_0 \geq Th \qquad (2)$$

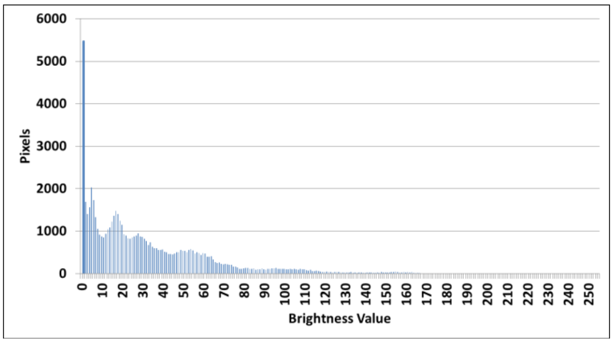

Fig. 5 Histogram of brightness value of the image couple

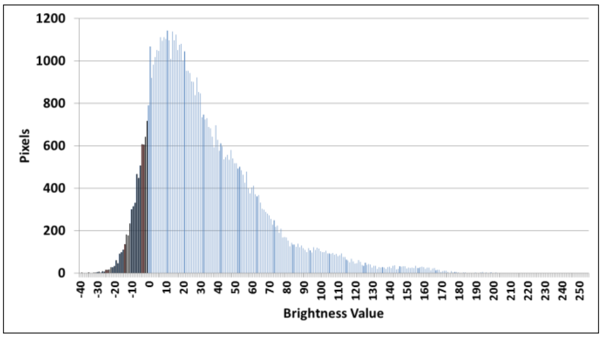

Fig. 6 Histogram of brightness value of superimposed Gaussian noise

Fig. 7 The image eliminate the pixel of brightness value 0

where B_0 is the number of pixels 0 brightness values in the sub-blocks, Th is threshold. By the way, threshold is $h = 36$, it is a good result of the experiment [8]. The white block of Fig. 7 shows that it is eliminated the sub-blocks with much 0 in image "couple".

C. Application and Derivation of the Correction Factor

In Ref. [6], estimate value of MAD based method is dependent on the image quality. The proposed method add the correction factor α, as shown in Eq. (3).

$$\hat{\sigma}^* = \alpha \cdot \frac{\sum_{i=0}^{N} 1.483 \cdot med(|B_i - med(B_i)|)}{N} \quad (3)$$

where N is number of sub-blocks of $n \times n$. The correction factor α needs to change with the image quality. Therefore, the proposed method can eliminate the dependence of image.

In Eq. (3), the correction factor α have to be change by the image quality. In case of flat area, the correction factor α close to 1. Moreover, in case of edges and details area, the correction factor α smaller than 1. Therefore, the correction factor α is calculated according to rate of edges and detail area. Hence, the correction factor α is given by Eq. (4). Where, Eq. (4) is liner equation, and m is the image quality parameter shown by Eq. (5).

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

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

Where σ_5 is average of standard deviation's estimate value of the sub-blocks from the minimum to 5%, σ_{30} is average of standard deviation's estimate value of the sub-blocks from the minimum to 30%. The value of image quality parameters m shows the rate of edge and detail in image.

Eq. (4) has to be control the factor a_1, a_0 by Gaussian noise. However, original value of Gaussian noise is unknown. Accordingly, the factor a_1, a_0 defined by as

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

Where $\hat{\sigma}$ is standard deviation's estimate value in Ref. [6]'s method. Finally, the standard deviation's estimate value for Gaussian noise can be estimate by using Eq. (1) - (6).

Fig. 8 21 type standard images

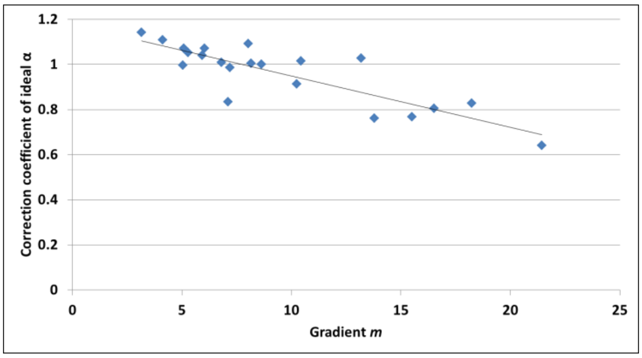

Fig. 9 Approximate equation of the ideal of correction factor

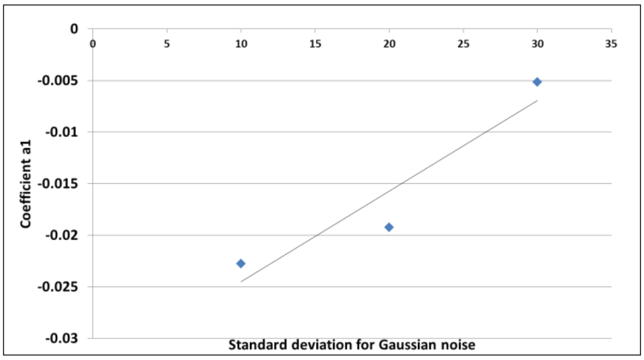

Fig. 10 Approximate equation of a_1

IV. Experimental Results

In this section, the value of factor b_{00} to b_{11} is set up by Eq. (6). Moreover, we compare the conventional method (literature [6] method) and the proposed method by using the Gaussian noise images ($\sigma = 5, 10, 20, 30$).

A. Derivation of the Correction Factors

The four factors are calculated experimentally by using 21 images in Fig. 8. The Gaussian noise ($\sigma = 10, 20, 30$) are added to these images. Moreover, the ideal correction factor α is calculated from these images by using the estimation value $\hat{\sigma}$ in Eq. (3). After that, the ideal correction factor α and the image quality parameter m are calculated from 21 images by the approximation formula of linear expression. The gradient and intercept of linear expression corresponds to a_1, a_0 in equation (4). Fig. 9 denotes an example of $\sigma = 10$. In this result, as for the proposed method, the linear expression is considered to be approximate by Fig. 9. The correction factor a_1, a_0 is dependent on the Gaussian noise in image. Therefore, the factor a_1, a_0 of Eq. (4) is calculated about each Gaussian noise images ($\sigma = 10, 20, 30$). Fig. 10 shows calculation results of factor a_1 calculated by Gaussian noise images ($\sigma = 10, 20, 30$). The relation between the standard deviation σ and the factor a_1 is straight-line approximation. Moreover, the gradient and intercept of this straight-line can show the parameter b_{11} and b_{10} in equation (6). Similarly, the relationship between the standard deviation σ and factor a_0 can calculate by parameter b_{01} and b_{00}. As a result, each parameters of the proposed method are $b_{00} = 1.222976$, $b_{01} = -0.001872$, $b_{10} = -0.03331$, $b_{11} = 0.00088$. The

Fig. 11 39 type images 1 (256×256)

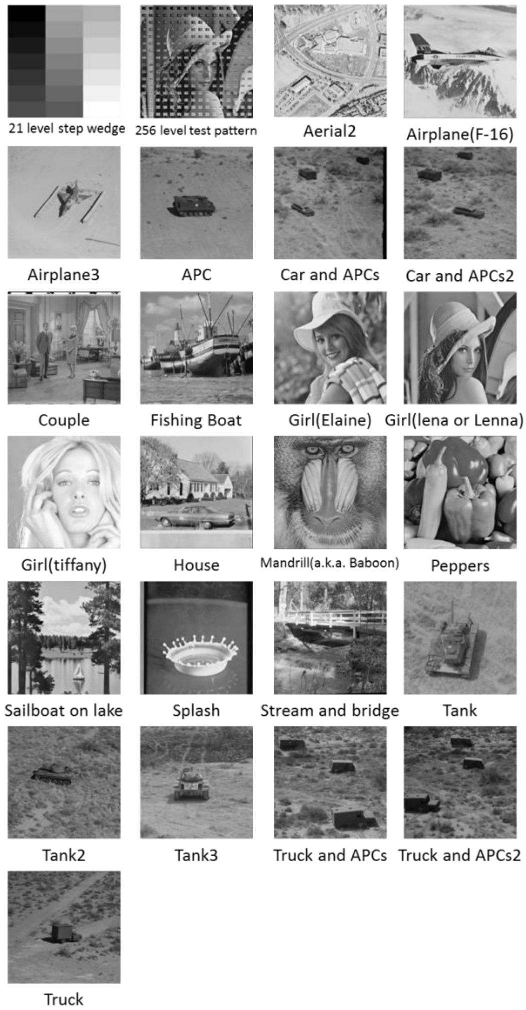

Fig. 12 39 type images 2 (512×512)

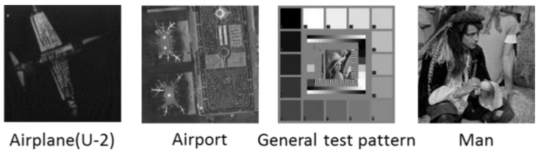

Fig. 13 39 type images 3 (1024×1024)

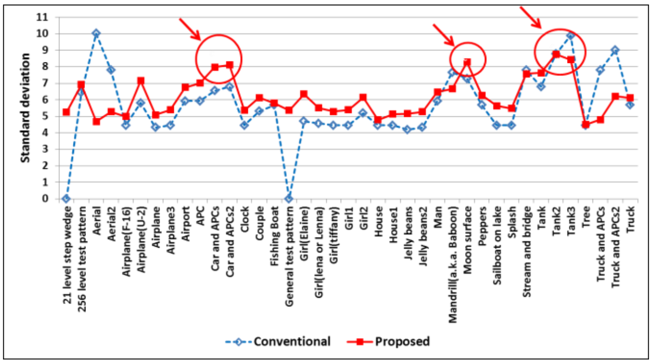

Fig. 14 Compare the conventional and proposed ($\sigma = 5$)

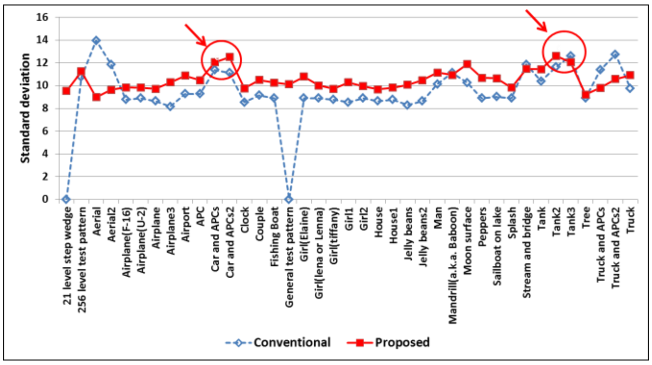

Fig. 15 Compare the conventional and proposed ($\sigma = 10$)

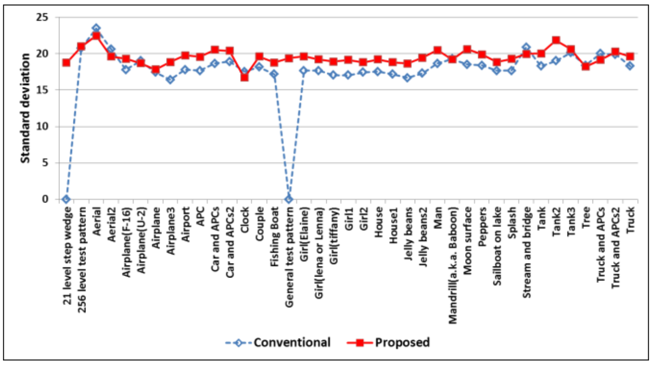

Fig. 16 Compare the conventional and proposed ($\sigma = 20$)

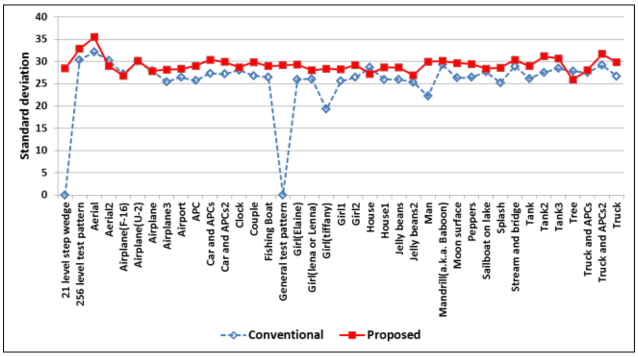

Fig. 17 Compare the conventional and proposed ($\sigma = 30$)

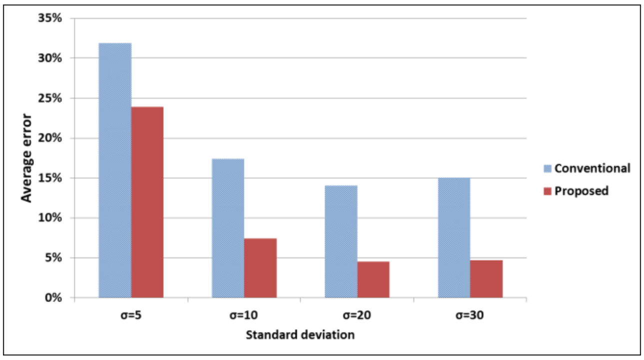

Fig. 18 39 type images error

factor a_0 and a_1 are calculated by above parameters, as a result, the correction factor α is calculated by these parameters. In this paper, the proposed method use these parameters.

B. Comparison of the Proposed Method and the Conventional Method

Fig. 11, 12, 13 are 39 type images of different sizes. Fig. 14, 15, 16, 17 shows the estimation results of the proposed method and the conventional method which added Gaussian noise ($\sigma = 5, 10, 20, 30$) to these images. Moreover, Fig. 18 shows average estimate error for 39 type images.

From Fig. 18, the proposed method shows the estimate result between to the conventional method. The estimation error of proposed method is smaller than the conventional method and about the ratio of estimate result, $\sigma = 5$ is 8% error, $\sigma = 10$ is 10% error, $\sigma = 20$ is 10% error and$\sigma = 30$ is 10% error. Thus, the standard deviation for Gaussian noise become large, the value of estimate error of the proposed method will become small.

Fig. 14, 15 shows the estimation results of small Gaussian noise images ($\sigma = 5, 10$). The estimation results are large estimation error when edge and detail (Car and APCs, Car and APCs2, Mandrill, Tank2, Tank3) is image which exists mostly. That is, the sub-block of only flat area does not exist in these images. The cause is in the parameter m of Eq. (5) being small, those edges and details exist mostly. On the other hand, Fig. 16 and 17 denote there is no dependability of the image about large Gaussian noise ($\sigma = 20, 30$).

In the result of our experiment, the proposed method has confirmed that the standard deviation of Gaussian noise of images could be estimated.

V. CONCLUSION

In this paper, we proposed new algorithm to estimate the standard deviation for Gaussian noise from the images corrupted by Gaussian noise. The proposed method corrected the estimation value to estimate the noise level based on the image quality. Reduction of estimation result was able to do reduce 10 % .

However, the future direction of this study will be improvement in accuracy of the estimate error of the small Gaussian noise images ($\sigma = 5$).

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