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1/f Noise Reduction on CMOS Image Sensors by Autocorrelation based on Adaptive Algorithm

Kunsu Hwang, Jegoon Ryu, HyunKyung Park, ByeongCheol Yoo and Toshihiro Nishimura

***Abstract*— In CMOS image sensor, 1/f noise is determined by width and length of gate at the circuit. Reducing the 1/f noise, a correlative multi sampling and an autocorrelation method have been used, mainly. Nevertheless, a correlative multi sampling has a practical problem of limitation which is the band of applied frequency. Because of the problem, an autocorrelation method is used for the reducing of 1/f noise better than correlative multi sampling. General noise reduction filters along with the smoothing effect. In this study, the autocorrelation method based on adaptive algorithm is proposed to reduce the smoothing effect at the edge of image.**

***Index Terms*—CMOS image sensor, 1/f noise, autocorrelation, adaptive algorithm**

I. INTRODUCTION

1/f noise is existed on all of nature as the wave of sea, the flow of river, the sand glass, and so on. The origin of generation is not same. Nevertheless, because all of 1/f noise is relative with inverse proportion of frequency, they called by 1/f. As smaller size of equipment which is installed CMOS image sensor (CIS) as the influence of 1/f noise becomes more pronounced[1]. In CMOS image sensor, 1/f noise is determined by width and length of gate at the circuit. As a result, it is becoming important to reduce the influence of 1/f noise more accurately. Reducing the 1/f noise, a correlative multi sampling and an autocorrelation method have been used, mainly. Nevertheless, a correlative multi sampling has a practical problem of limitation which is the band of applied frequency[3]. Because of the problem, an autocorrelation method is used for the reducing of 1/f noise better than correlative multi sampling. And then, general noise reduction filters along with the smoothing effect. In this study, the autocorrelation method based on adaptive algorithm is proposed to reduce the smoothing effect at the edge of image.

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K.S. Hwang is with Graduate School of Information, Production and Systems, Waseda University, Kitakyushu, 808-0135 Japan (e-mail: badoogy@suou.waseda.jp).
J.G. Ryu is with Graduate School of Information, Production and Systems, Waseda University, Kitakyushu, 808-0135 Japan (e-mail: jkryu@ruri.waseda.jp).
H.K Park is with the Graduate School of Information, Production and Systems of Waseda University, Kitakyushu, 808-0135 Japan (e-mail: lovey@fuji.waseda.jp).
B.C Yoo is with the Graduate School of Information, Production and Systems of Waseda University, Kitakyushu, 808-0135 Japan (e-mail: queen2me@toki.waseda.jp).
T. Nishimura is with Graduate School of Information, Production and Systems, Waseda University, Kitakyushu, 808-0135 Japan (e-mail: tosi-hiro@.waseda.jp).

II. BACKGROUND AND PREVIOUS RESEARCH

Table 1 shows requirements for image sensors. As smaller size of equipment which is installed CIS as the influence of 1/f noise becomes more pronounced.

Table 1. The Requirement for Image Sensors

High	Low
Resolution	Size
Dynamic range	Consumption of power
Frame rate	Illumination imaging

The 1/f noise of CIS is relative with the size of sensor because it has the parameters which are width and length of gate as following[2],[4].

$$\overline{V}_n^2 = \frac{K_f}{C_{ox}WLF} \qquad (1)$$

where

K_f : flicker noise coefficient
C_{ox} : capacitance of gate
W : width of gate
L : length of gate
F : frequency

Fig. 1 shows the relationship between the 1/f noise level and a width and a length of gate. X axis and Y axis is indicates the frequency and the noise level each other.

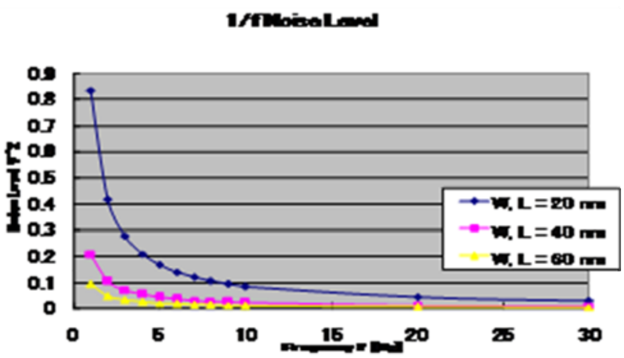

Fig. 1. The Relationship between 1/f Noise Level and A Width and A Length of Gate.
(W : a width of gate, L : a length of gate)

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A Correlative multi sampling is one of methods to reduce the 1/f noise. This is performed by taking the difference of a reset signal and the pixel signal. When the method is used, the frequency band which difficult with reducing of 1/f noise is caused by physical characteristic at the circuit of sensor. Fig. 2 shows the theory of a correlative multi sampling.

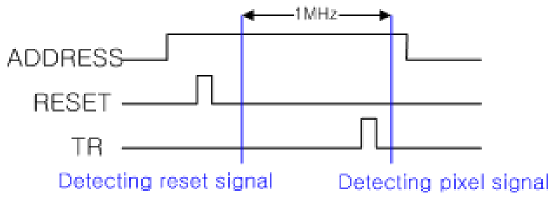

Fig. 2. The Theory of A Correlative Multi Sampling

Fig. 3 shows the limitation of correlative multi sampling. X axis and Y axis is indicates the log scale of frequency and the noise level each other.

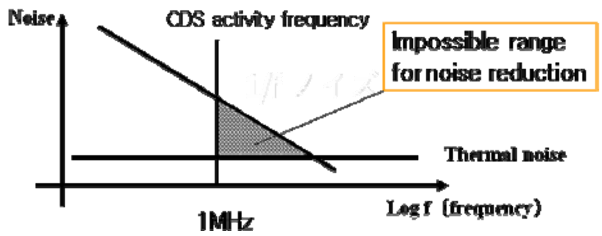

Fig. 3. The Limitation of A Correlative Multi Sampling

III. Experiment

Fig. 4 shows the process of experiment. In 1/f noise generation process, the coefficients and constants are considered as a flicker noise coefficient K_f is 10^{-25}, a capacitance of a gate C_{ox} is $300 \times 10^{-12}(F)$, a width of gate W is $20 \times 10^{-9}(m)$ and a length of gate L is $20 \times 10^{-9}(m)$.

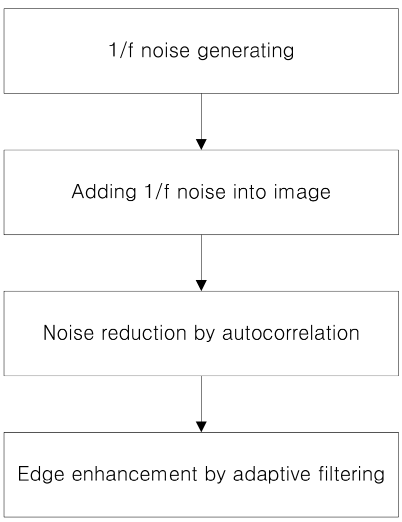

Fig. 4. The Process of Experiment

A. Autocorrelation Method

Autocorrelation is focused on the relationship between self-similarity and periodicity[5]. Because this method has simple process, speed-up of calculation is able.

In signal processing, the above definition is often used without the normalization, that is, without subtracting the mean and dividing by the variance. When the autocorrelation function is normalized by mean and variance, it is sometimes referred to as the autocorrelation coefficient[6].

$$R_x(i) = \frac{1}{N-\tau}\sum_{i=1}^{N} x(t)\cdot x(t+\tau) \quad (2)$$

B. Adaptive Autocorrelation Method

General noise reduction filters along with the smoothing effect because the pixel value is calculated by surrounding pixel value.

In this paper, the adaptive algorithm is applied to use the robust characteristic on the edge of image. The algorithm is effective in the changeable edge at the image. The adaptive algorithm is described as following equations,

$$e(n+1) = d(n+1) - [\overline{H}(n)\cdot \overline{X}(n+1)] \quad (3)$$

and

$$\overline{H}(n+1) = \overline{H}(n) + [\mu e(n+1)\cdot \overline{X}(n+1)] \quad (4)$$

where

n : a designated time step

$\overline{X}$: a vector composed of the current and last $nH-1$ scalar inputs

d : a desired signal

$\overline{H}$: a vector composed of the current set of filter taps

e : the error or $d - [\overline{H}(n)\cdot \overline{X}(n+1)]$

μ : the step size

Adaptive filters have a characteristic of self-learning. As the signal into the filter continues, the adaptive filter coefficients adjust themselves to achieve the desired result, such as identifying an unknown filter or canceling noise in the input signal[7].

An adaptive filter designs itself based on the characteristics of the input signal to the filter and a signal that represents the desired behavior of the filter on its input.

Designing the filter does not require any other frequency response information or specification. To define the self-learning process the filter uses, you select the adaptive algorithm used to reduce the error between the output signal y(k) and the desired signal d(k). When the LMS performance criterion for e(k) has achieved its minimum value through the iterations of the adapting algorithm, the adaptive filter is finished and its coefficients have converged to a solution. Now the output from the adaptive filter matches closely the desired signal d(k). When you change the input data characteristics, sometimes called the filter environment, the filter adapts to the new environment by generating a new set of coefficients for the new data. Notice that when e(k) goes to zero and remains there you achieve perfect adaptation, the

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ideal result but not likely in the real world[8].

Fig. 5 shows the block diagram of defining general adaptive filter algorithm input and output.

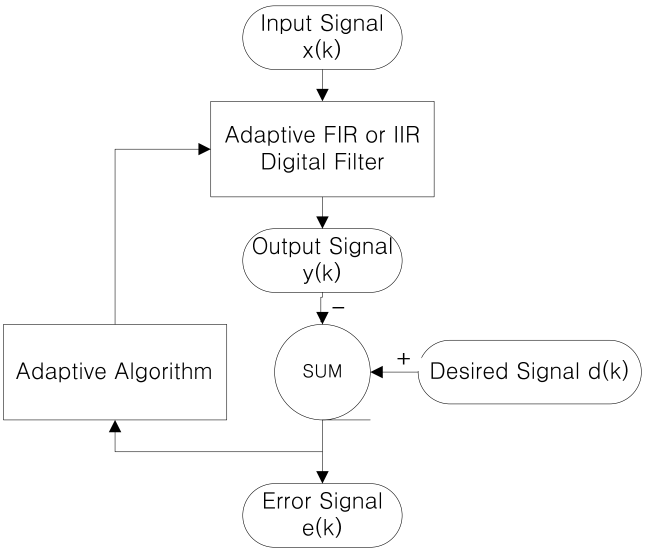

Fig. 5. Block Diagram of Defining General Adaptive Filter Algorithm Input and Output

The system identification of adaptive filtering is shown in Fig. 6.

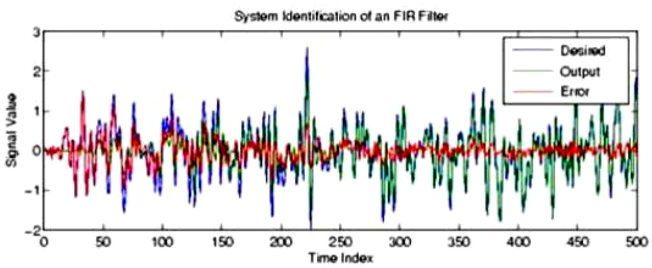

Fig. 6. The System Identification of Adaptive Filtering.

IV. Experimental Result

To evaluate the efficiency of proposed method, the comparison is performed with autocorrelation method. By using the adaptive method, the effects of smoothing or blurring can be decreased. The size of noise pixel has been decreased relatively. Therefore, brightness has been enhanced. Fig. 7 shows the original image before added noise. Fig. 8 shows result images. Fig. 9 shows enlarged images of Fig. 8 to recognize the difference of edges.

Fig. 7. The Original Image

V. Conclusion

This study is focused on the autocorrelation method. And then an adaptive algorithm is applied to autocorrelation

In general, PSNR or SNR is used for the evaluation of filter. Nevertheless, PSNR or SNR is relative value by using between pixel values of noised image and de-noised image. Because the 1/f noise is related with frequency, the evaluation method which is not independent on pixel value but dependent on frequency is required.

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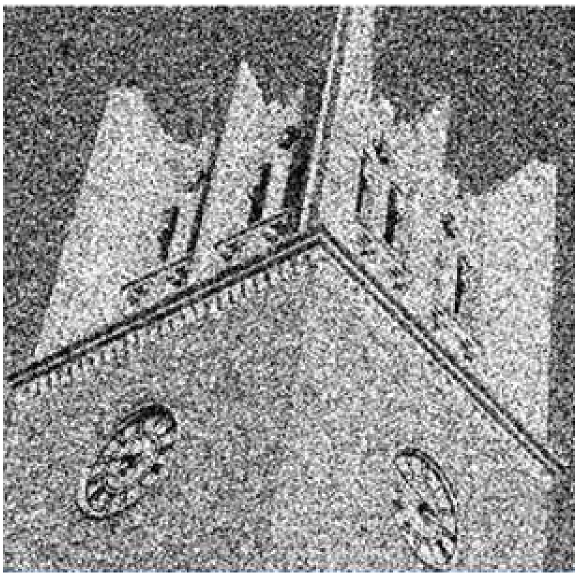
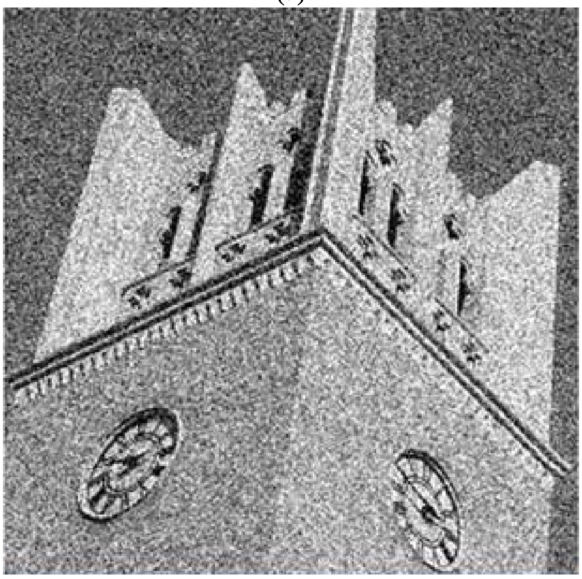
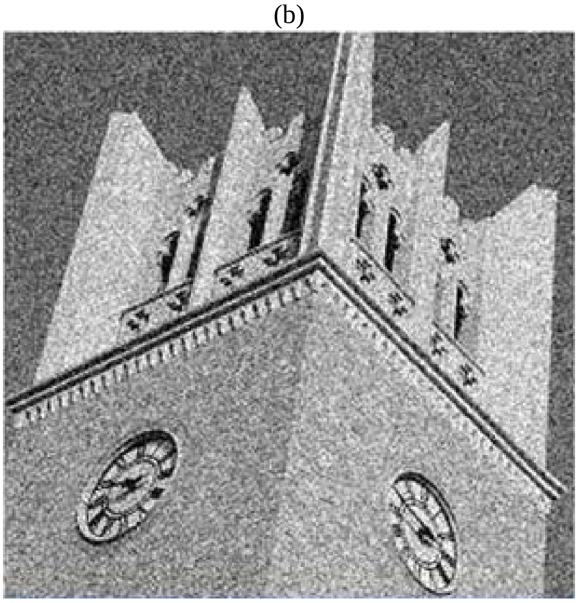


(a)

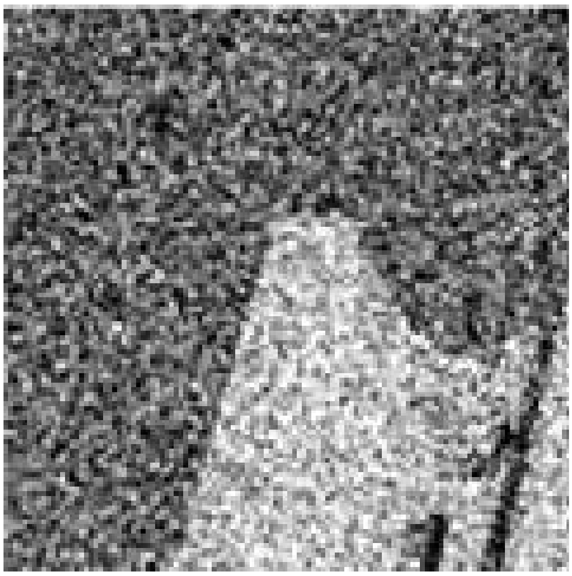


(b)

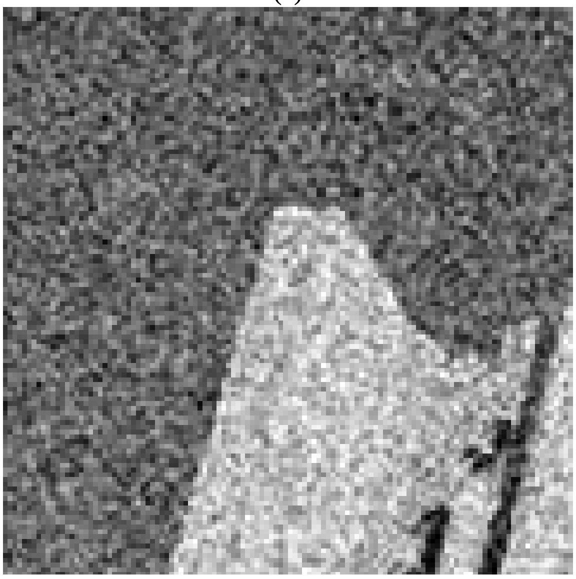


(c)

Fig. 8. Result images.
(a) Noised image (b) Autocorrelation (c) Proposed method



(a)



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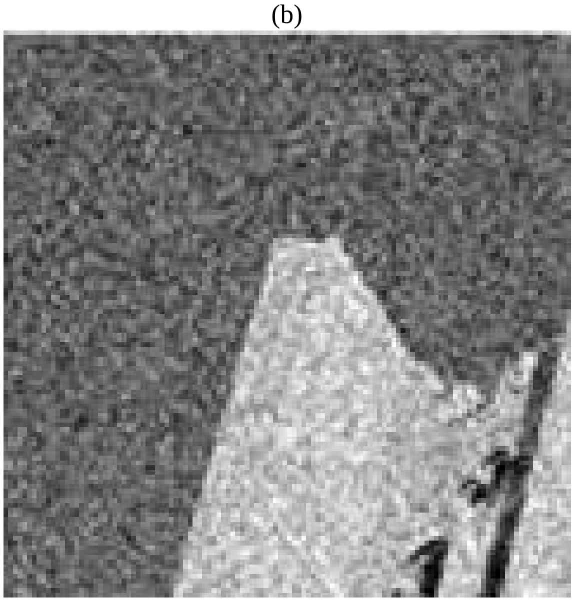

(c)

Fig. 9. Enlarged images of Fig. 3.
(a) Noised image (b) Autocorrelation (c) Proposed method

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