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Noise Reduction in CMOS Image Sensor for High Quality Imaging Using ACF

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Abstract: **The new method for image noise detection and reduction in complementary metal oxide semiconductor (CMOS) image sensors inspired from audio noise cancelling techniques. Our algorithm is based on computing efficiently the time-dependent pixel autocorrelation function (ACF) from constant time interval acquired sequences of images. This demonstrate the effectiveness of approach for successfully detecting and reducing white noise. Further, consider an adaptive filter that exhibits significant computational improvements making it highly practical. Finally, the report on experiments displaying the high-quality imaging systems obtained in practice.**

Keywords**—Signal to Noise Ratio , White noise, Colour noise, Charge-coupled device ,the auto-correlation**

I. INTRODUCTION

Digital imaging devices such as digital cameras or camera-phones are becoming very popular and ubiquitous. More and more people are capturing many digital photographs and the number of digital photographs taken is increasing rapidly. Capturing an image from a camera is a physical process. The sunlight is used as a source of energy. A sensor array is used for the acquisition of the image. So when the sunlight falls upon the object, then the amount of light reflected by that object is sensed by the sensors, and a continuous voltage signal is generated by the amount of sensed data. In order to create a digital image, we need to convert this data into a digital form. This involves sampling and quantization. The result of sampling and quantization results in a two dimensional array or matrix of numbers which are nothing but a digital image. Many digital cameras or camera phones today provide poor quality shots in low illuminations such as indoors or night situations. It is very difficult to capture good quality photographs in these situations since elongating exposure time increases motion blur and shortening exposure time reduces the signal-to-noise-ratio (SNR). This results in image noise. The common definition of Signal to Noise Ratio (SNR) is the ratio of Power of wanted signal to the noise power. It can be calculated as follows. SNR=(power of required signal)/(power of noise signal) Image noise is an unavoidable side-effect occurring as a result of image capture, more simply understood as inaudible, yet inevitable fluctuations. In a digital camera there are several ways noise is added to the image, for example If the light which enters the lens misaligns with the sensors, it will create image noise. When the images are transmitted over channels, they are corrupted with impulse noise due to noisy channels. It is therefore of the utmost importance to consider image processing noise reduction techniques to circumvent these sensor limitations in order to deliver crispy and vivid artefact-free images to consumers.

A. Types of Noises

The various sources of noise in a CMOS image sensor can be classified into two disjoint groups: White noise (W) Colour noise(C) White noise is a random signal with a constant power spectral density i.e. will have almost constant integrated power at different frequency bands of same duration (bandwidth).The fig 1 depicts various types of noises along with their physical locations and white/colouredtype classifications White noise

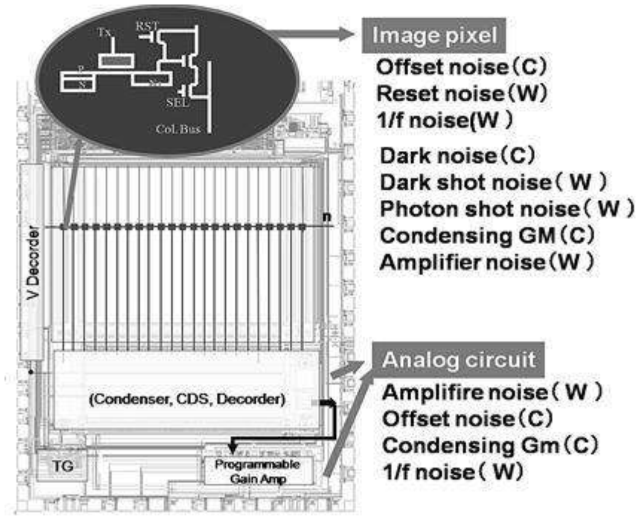


Fig. 1. Figure 1: Depicts these various types of noise along with their physical origin locations and White/Coloured type classifications.

Is made of almost all the frequencies and will have constant power at all these frequencies, hence it is also analogous to white light emitting all the frequencies in the same proportion. For example, with a white noise audio signal, the range of frequencies between 40 Hz and 60 Hz contains the same amount of sound power as the range between 400 Hz and 420 Hz, since both intervals are 20 Hz wide. White noise sources include the reset, 1/f, dark shot, photon shot and amplifier noise just to name a few. Coloured noise will have different integrated power at different frequency bands of same duration, depending upon whether it is grey, pink, blue or brown colour it will have different power spectrum. Coloured noise include the offset noise, the dark noise, and the difference of dimension, among others. Coloured noise depend only on the physical structural properties of the camera imaging system. For example, coloured noise may originate from the threshold value or size scatter of a transistor, or from the sensitivity scattering and open area ratio of a photo diode, etc.

II. PRIOR WORK

The basic idea behind doing a literature survey is to gain knowledge regarding the related work. As mentioned above, various methodologies were used in order to improve quality of images efficiently by reducing noise. To reduce the noise introduced in the high quality images we apply auto-correlation function. Finally filtering is done using suitable filter. So many research papers were taken into consideration and studied. Stress has been laid to summarize the concept of different authors who has worked in this field. Richard Alan Peters II presented a paper titled A New Algorithm for Image Noise Reduction using Mathematical Morphology [2] that focus on analysis of a new morphological image cleaning algorithm (MIC) that preserves thin features while removing noise. MIC is useful for grayscale images corrupted by dense, low-amplitude, random or patterned noise. MIC manipulates residual images the differences between the original image and morphologically smoothed versions. It calculates residuals on a number of different scales via a morphological size distribution. It discards regions in the various residuals that it judges to contain noise. MIC creates a cleaned image by recombining the processed residual images with a smoothed version. This paper MIC creates a cleaned image by recom-bining the processed residual images with a smoothed version. The main disadvantages of this project is parameters have to be set by trial and error to get the best results. It is relatively computationally expensive compared to a median filter. If the noise content of an image is high, MIC highlight some of the noise features making the result look (possibly) worse than the original. Eero P. Simoncelli and Edward H. Adelson published a paper Noise Removal via Bayesian Wavelet Coring [3]. In their research they develop a Bayesian estimator that is a natural extension of the Wiener solution, and that exploits these higher-order statistics. The resulting nonlinear estimator performs a coring operation. They provide a simple model for the subband statistics, and use it to develop a semi-blind noise-removal algorithm based on a steerable wavelet pyramid. This Bayesian estimator provides a natural extension for incorporating the higher-order statistical regularity present in the point statistics of sub-band representations. It also generalizes to other types of distortion, including blurring and corruption with non-additive noise.

Leonid I. Rudin, Stanley Osher and Emad Fatemi presented a paper Nonlinear total variation based noise removal algo-rithms [4]. They proposed to denoise images by minimizing the total variation norm of the estimated solution. They derive a constrained minimization algorithm as a time dependent non-linear PDE, where the constraints are determined by the noise statistics. In this paper they focus on a constrained optimization type of numerical algorithm for removing noise. Their recent experiments indicate that the use of more constraints in the method which yield more details of the solution in denois-ing procedure. S. Grace Chang, Bin Yu and Martin Vetterli proposed a paper Adaptive Wavelet Thresholding for Image Denoising and Compression [5]. This paper proposes an adap-tive, Data-driven threshold for image denoising via wavelet soft-thresholding. The threshold is derived in a Bayesian framework, and the prior used on the wavelet coefficients is the generalized Gaussian distribution (GGD) widely used in image processing applications. The proposed method, called BayesShrink, is typically within 5Ce Liu, Richard Szeliski, Sing Bing Kang, C. Lawrence Zitnick and William T. Freeman presented a paper on Automatic Estimation and Removal of Noise from a Single Image[6]. In this paper, they proposed a unified framework for two tasks: automatic estimation and removal of colour noise from a single image using piecewise smooth image models. They introduced the noise level function (NLF), which is a continuous function describing the noise level as a function of image brightness and then estimate an upper bound of the real noise level function by fitting a lower envelope to the standard deviations of per-segment image variances. For denoising, the chrominance of colour noise is significantly removed by projecting pixel values onto a line fit to the RGB values in each segment. Then, a Gaussian conditional random field (GCRF) is constructed to obtain the underlying clean image from the noisy input. The noise is removed by formulating and solving a Gaussian conditional random field. Antoni Buades and Jean-Michel Morel presented a paper A non-local algorithm for image denoising [7]. They use a new measure, the method noise, to evaluate and compare the performance of digital image denoising methods.

III. OUR SYSTEM

Digital still and video cameras equipped with CMOS image sensors are well-known to be prone to noise phenomena, especially in poor lighting dim environments. It is therefore of the utmost importance to consider image processing noise reduction techniques to circumvent these sensor limitations in order to deliver crispy and vivid artefact-free images to consumers. There are number of different techniques to reduce noise in an image taken in poor illumination condition, wherein we introduce an adaptive filter method for measuring and attenuating white noise at the pixel level. In this method a set of images were acquired at regular time interval and we perform at each pixel a time-series analysis based on the autocorrelation function (ACF) for detecting and quantifying the amount of white noise individually. To reduce white noise in the high quality images under poor illumination condition using any linear filter, time is major constraint, because processing on lakhs of pixel will consume lot of time. To overcome this problem ACF is applied to only dark pixels which contributes more to white noise. Figure 2 plotting the time-dependent ACF value as a function of the frame number for two different normalized intensity pixels: (A) bright pixel with intensity 180/256, and (B) dark pixel with intensity value8/256.

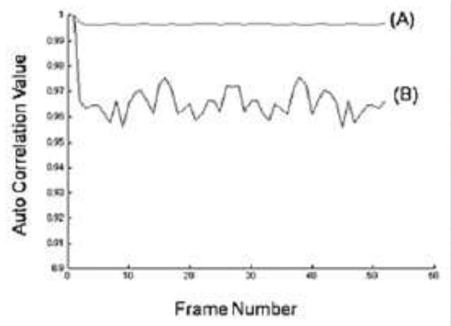


Fig. 2. plotting the time-dependent ACF value as a function of the frame number for two different normalized intensity pixels: (A) bright pixel with intensity 180/256, and (B) dark pixel with intensity value8/256.

Figure 2 plots the ACF value as a function of the frame number in the image sequence for the case of a bright pixel labelled A (intensity 180 on 256 pixel value steps). This bright pixel A shows experimentally almost constant ACF value around the maximum 1.00 (precision up to two digits, i.e. 10-2). We conclude that, in this case, that a large amount of light entered the photo diode and therefore the signal-to-noise ratio (SNR) is large, and as a matter of fact the impact of white noise is not significant in such a bright environment. So here we set a threshold, any pixel values that have their intensity values under this threshold are extracted. Hence large amount of time is reduced. On the contrary, in the case of a dark pixel labelled B in fig 2, the SNR has a smaller value and therefore the contribution of the white noise in the mixed signal cannot anymore be ignored. So for those pixels only we apply the wiener filter to reduce the white noise thus the sharpness of image will not be affected. We observe that the amount of white noise is correlated to the fluctuations of the time-dependent ACF, as depicted in the plots of Figure 3 After performing ACF operation, pixels whose ACF value less than some threshold are considered as affected by noise. So we apply an Adaptive filter to those pixels to remove the noise. An adaptive filter is a system with a linear filter that has a transfer function controlled by variable parameters and a mean to adjust those parameters according to an optimization algorithm. Some of those filters that can be used are mean, median, wiener etc. When compared to any other linear filter wiener filter is most effective in reducing white noise. Wiener filter is a filter used to produce an estimate of a target random process by linear time-invariant filtering of a noisy process. Wiener filter gives the optimal way of tapering off the noisy components, so as to give the best reconstruction of the original signal. But the image loses its sharpness by applying wiener filter to reduce white noise, because all the pixel value of an image will be altered. After performing filtering process, we decide which pixel to be replaced in place of error pixel. In this way a pixel affected by white noise is corrected. The above procedure repeated to every pixel in image and finally an errorless image is obtained.

IV. IMPLIMENTATION

Image acquisition is the first key step to master in the image analysis process. An image sensor is used for image acquisition which can be analog or digital. Charge-coupled device (CCD) is one of the main Analog sensor and CMOS sensor is one of the main digital sensor used. In our project we use CMOS camera system for image acquisition. The sensor image size is about 2.0 million pixels and 10 images were acquired at regular time interval. The sensitivity index standardized by the International Standard Organization 3 was set to 1600 ISO. We captured the image both under low and normal illumination conditions, for analysis and comparisons. The low illuminance scene was primarily acquired for studying the effect of the ACF in the case where the white noise becomes significant compared to the source signal. All images were saved in 12-bit native raw format and were also later post-processed and converted into standard 8-bit RGB JPEG format. These images are next processed using MATLAB.

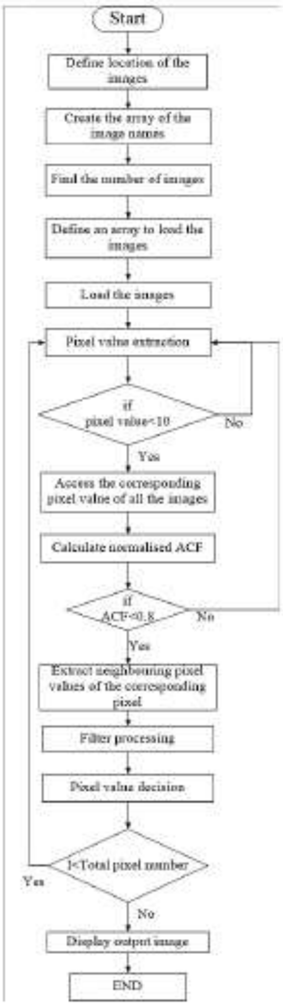
In MATLAB imread command is used to read an image. We are considering sequences of images, so we first create an array of images prior to process them. In order to create the array, first a file array need to be created. To create a file array we define the location of the image where the images are stored. In the defined location the required file names of the images are accessed and formed as array. In this way file array is created. Then number of files in array is counted which defines number of images taken for processing. The images are accessed sequentially using imread command and formed as array with the help of image name specified in the file array. Normal noise reduction techniques perform operation on image by extracting each pixel value, detecting the presence of noise in each pixel and correcting the pixel which are affected by noise. Overall they process the image by considering every pixel. High quality images consist of millions of pixels in an image. If we try to reduce the white noise in high quality images taken at different time interval using normal noise reduction techniques, it consumes hours of time which is impractical. This introduces computational complexity.

V. RESULT

Several tests were carried out in-between stages during the development of the proposed noise reduction algorithm to ensure proper workability of each part of the algorithm. After a complete algorithm is developed, several runs were carried out under different conditions to determine better performance, efficiency and reliability of the algorithm. Figure shows the result of this algorithm on the former low illumination. We subjectively confirm that the level of noise was significantly decreased by this ACF adaptive filter algorithm. Note that since the filter is not called for bright pixels (above intensity 10), the resolution of the image is preserved in those areas while the amount of noise is minimized in dim areas.

A. Filter response under various brightness conditions

In order to evaluate furthermore the performance of the ACF filter algorithm, we carried out a series of experiments by taking different images that exhibit both dark and bright areas, as shown in Figure 4 Figure 4 shows the acquired picture: Namely, the first picture of a burst sequence of ten shots. In order to tune the threshold values required by our ACF noise reduction filter, we further investigated the computational complexity of applying the filter as a function of the ACF threshold value for a given



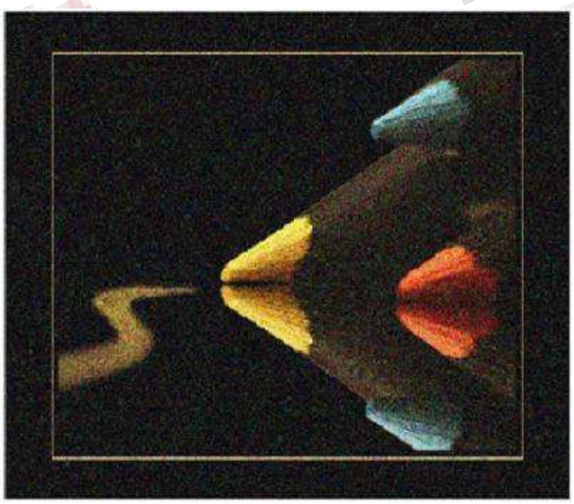


Fig. 4. Noised image

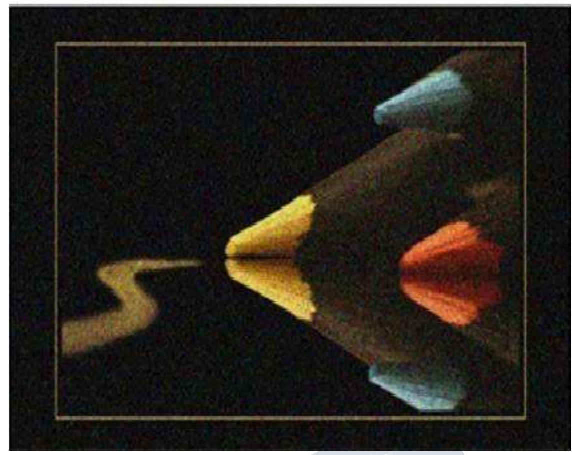


Fig. 5. DeNoised image

natural image. This study allows one to subjectively evaluate the image quality and permits us to choose the appropriate trade-off computation time and ACF value. (overall number of selected pixels)/image quality.

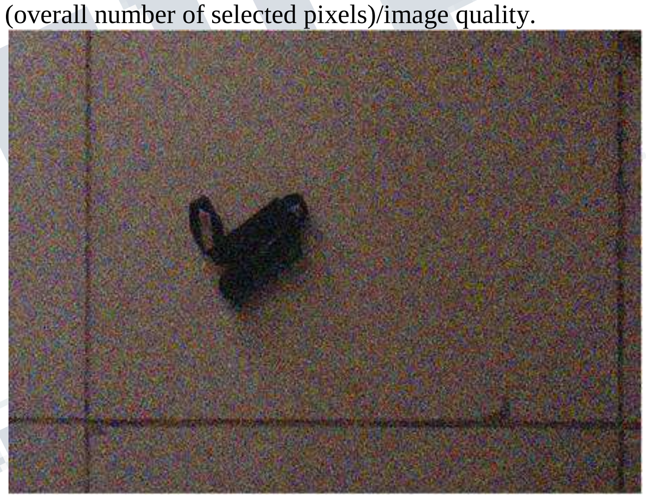


Fig. 6. Acquired picture

For example, a change in image quality is hardly perceived with the ACF threshold value 0.8 of Figure 6 compared with the original source picture. Hence ACF value threshold set to 0.9. Figure 7 displays the noise-reduction technique performed for all pixels with intensity values below the prescribed thresh-old by setting the ACF threshold value to 0.995. We observe from that series of experiments that the image quality is not degraded at the pixel boundaries where the ACF filter response change. That is, after careful inspection of the filtered image,

Fig. 7. image with ACF lessthan 0.8

we could not find any trace of edge halation phenomena. Edge halation is characterized by the spreading of light beyond its proper boundaries, and could have potentially be a side-effect of our ACF filter that processes image pixel islands. However, we confirmed in practice that this phenomenon does not occur, and that the ACF filter enhances drastically image quality, especially in poor lighting environments.

VI. CONCLUSION

In this paper,approach for performing noise-reduction in CMOS camera systems inspired by audio signal processing. The new filter is based on the autocorrelation function (ACF) that finds its root in Fourier analysis. The ACF filter processes in parallel independently all image pixels by computing the time-axis ACF from burst image sequences, and by deciding from the respective ACF values the set of pixels containing a fair amount of white noise that need to be adjusted. Since it is quite computationally intensive to perform that processing operation for all pixels, here designed a two level indirection branching algorithm that allows to significantly reduce the number of selected pixels by thresholding both on the pixel intensity and on the ACF values. By carrying out a series of experiments, we demonstrated that our algorithm is well-suited for high quality imaging systems as it effectively attenuates the amount of white noise in images, especially in low lighting challenging environments. A careful inspection further shows that there were no image quality discontinuities nor edge halation phenomena introduced as a side-effect by this adaptive ACF filter.

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