OTSUHARA-WATH Filter for Poisson Noise Removal in Low Light Condition Digital Image

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***Abstract*—Nowadays, the digital images are used widely due to the development of sophisticated technologies. The recent device that is very popular among its users related to digital images is smartphone. This is due to nowadays smartphone is embedded with its own camera that can capture digital images. Nevertheless, the digital image is easily exposed to various types of noise, especially the Poisson noise in low light condition. Therefore, this study aims to develop a new denoising technique for Poisson noise removal in low light condition digital images. This study proposes a denoising method named as OTSUHARA-WATH Filter, which utilizes the Otsu Threshold, Kuwahara Filter and Wavelet Threshold. The proposed methods performance is evaluated based on the Peak Signal to Noise Ratio (PSNR), Mean Squared Error (MSE) and visual inspection. The comparison between the proposed methods and the existing denoising methods is also performed. From the results of PSNR, MSE, computational time and visual inspection, it can be proven that the OTSUHARA-WATH Filter is able to reduce and smooth noise, while preserving the edges and fine details of the image at low and medium level of Poisson noise in comparison to the existing methods.**

***Index Terms*—Kuwahara Filter; Low light; Noise Removal; Otsu Threshold; Wavelet Threshold.**

I. INTRODUCTION

Nowadays, the digital images are used widely with high and sophisticated technology, such as smartphone. This is due to smartphone is embedded with its own camera that can capture digital image. In fact, the camera phones are one of the fastest growing segments of the digital camera market. It comes with the improvement in the quality like the higher mega pixels, better lens and high capacity storage and being offered in some phones.

Nevertheless, the digital images captured by camera phones are easily exposed to various types of noise like Poisson noise from surrounding, especially in low light condition. The low light condition is also known as photon limited condition which arising from weak light source. The Poisson noise becomes dominant source of noise in low light condition [1]. However, not all conditions have the necessity or permitted to use flash for capturing better digital image [2], for example at the Night Safari [3].

There are two basic approaches to denoise image is by applying linear [4][5] and non-linear filters [6][7][8][9]. For transform domain denoising technique, Discrete Wavelet Transform (DWT) is recently one of the most common transform domain to perform denoising technique [10].

The problems that the researchers faced in developing an effective denoising techniques is the output images tend to loss some details and edges. Therefore, a post processing denoising method which is capable to preserve details and remove noise in images captured in low light condition using available average smartphone camera specially those without the use of flash is important.

Moreover, only a few researches are developed specifically techniques to reduce Poisson noise in low light condition image [11][12]. The study in [11] proposed an algorithm for denoising image based on the hybridization of Bilateral Filters and Wavelet Threshold. Therefore, this study is important to provide a pre-processing denoising technique in such condition.

II. METHODOLOGY

This study proposes a denoising methods referred to as OTSUHARA-WATH Filter, which utilizes the Otsu Threshold, Kuwahara Filter and Wavelet Threshold. This study proposes the combination of denoising techniques to eliminate Poisson noise in noisy image captured in low light condition. This development which is developed by using MATLAB software.

A. Processing of Test Images

Figure 1 shows the set of test images in low light condition. These test images are the example of clean image, which is almost free from any noises. These test images are captured using DSLR camera which able to capture the high definition images. These images will then inserted with noise to investigate the performance in terms of the PSNR and MSE, where the pair of clean image and denoised image is needed.

(a) johor.jpg

(b) kl.jpg

(c) sarawak.jpg

(d) masjid.jpg

Figure 1: Test images

The set of test images consist of four clean natural images, which are kl.jpg, johor.jpg, sarawak.jpg and masjid.jpg.

After the selection of natural digital image, the Poisson noise is selected to be a source of noise in this study since it is a kind of noise corrupting image captured in low light condition. The Poisson noise is added to the original test images to produce test noisy images with different level of Poisson noise. In this study, there are 2 scales of Poisson noise used, which are 1e7, and 1e9. The scale of Poisson noise at 1e7 represents low noise level, whereas 1e9 represents for medium noise level.

B. Otsu Threshold

The Otsu Threshold is used as a technique to separate objects from background. After insertion of noisy image, the edge detection using *graythresh* function will be applied on the noisy images, $n(i,j)$. The *graythresh* function is a function that choose the threshold to minimize the intraclass variance of the black and white pixels which has setting values at [0 1]. In simple words, the colorful noisy images should be turned to grayscale images to compute the gray level histogram. Then, that grayscale images will be thresholded into the binary images, $bw(i,j)$. Besides that, this *graythresh* function default setting is [0 1], which is the range of the black and white in color code. Furthermore, there are two processes that involved in thresholding process which are minimizing the weighted variance within class variance and maximizing weighted variance between class variance. Then, *bwareopen* function is used to remove the connected components (objects) that have fewer than the connected component threshold, p. The p value is used as the parameter setting to reduce the connected component in image in avoiding the losses of the image details. The *bwareopen* function produced the image, $o(i,j)$.

C. Kuwahara Filter

Kuwahara Filter is a non-linear smoothing filter used in image processing for noise reduction. This filter is able to apply smoothing on the image while preserve the edges [13]. In Kuwahara Filter, a mask, R in size of $(2r+1)*(2r+1)$ is applied to only the smooth area of the test noisy image, $n(i,j)$, where r is size of sampling window. Then, the neighborhoods are divided into four regions which are *a, b, c,* and *d* as shown in Figure 2. The regions are represented by $R_d = \{R_1, R_2, R_3, R_4\}$. In each region, the mean and variance are calculated respectively.

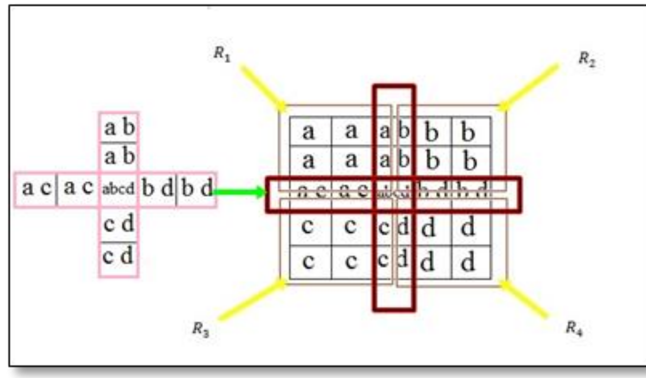


Figure 2: The scheme of Kuwahara Filter

The mean, μ (R_d), and variance, $\sigma^2(R_d)$, of each region are calculated by using Equation (1) and Equation (2) respectively.

The mean, μ (R_d), can be defined by:

$$\text{mean}, \mu(R_d) = \Sigma\,(A\,(R_d) / B\,(R_d)) \tag{1}$$

where,
$A\,(R_d)$: length of window $(2r+1)$ of d^{th} region
$B\,(R_d)$: area of d^{th} region $(2r+1)*(2r+1)$

The variance, $\sigma^2(R_d)$, can be defined by

$$\text{variance}, \sigma^2(R_d) = \Sigma\,(x_d - \mu)/n \tag{2}$$

where,
x_d: pixel value of d^{th} pixel
μ: mean

Then, the centre pixel value (*abcd*) is assigned with the value of mean of the region with least variance which is illustrated by Equation (3). This value replaces the similar position pixel value in Kuwahara filtered image, $k(i,j)$.

$$k(i,j) = \min\{\sigma^2(R_1), \sigma^2(R_2), \sigma^2(R_3), \sigma^2(R_4)\} \tag{3}$$

where;
σ^2: variance
R_1: Region *a*
R_2: Region *b*
R_3: Region *c*
R_4: Region *d*

The process is repeated to all pixels belong to smooth regions in the whole images.

D. Wavelet Threshold

The Wavelet Threshold is that exploits the capabilities of wavelet transform for signal denoising. This Wavelet Threshold is proposed by Donoho and Johnstone [14]. Discrete Wavelet Transform (DWT) is a transformation of the wavelet in discrete sample.

There are two types of Wavelet Threshold which are hard threshold and soft threshold. This study utilizes Bayes soft threshold. The Wavelet Threshold is applied on the OTSUHARA filtered image, $ok(i,j)$. Before further process, $ok(i,j)$ is transformed to wavelet domain by using the DWT. The Bayes soft threshold [15] is used for recognizing the important characteristics in the image like edges, details and textures of that image. Next, it will be reconstructed by transformation of Inverse Discrete Wavelet Transform (IDWT). Finally, the final filtered image, $okw(i,j)$ is produced.

E. Proposed Method: OTSUHARA-WATH Filter

OTSUHARA-WATH Filter is developed based on the combination of three denoising techniques which are the Otsu Threshold, Kuwahara Filter and Wavelet Threshold. OTSUHARA-WATH filter is developed to help users in reducing the noise, while preserving the edges and details of original image. Besides that, the advantage of this filter is that it can denoise and smooth the noise at the background of the noisy image, while preserving the foreground of the noisy image to avoid the losses of the edges and details of the noisy image.

The Otsu Threshold is applied to the noisy image, $n(i,j)$ for separating the background and foreground of the noisy image. This will produce a Otsu binary image, $o(i,j)$ which has two gray levels values. The two values of gray levels in this binary image are 0 and 1. 0 indicates the background of noisy image, $n(i,j)$ based on the location of 0 value in the Otsu binary image, $o(i,j)$. On the other hand, 1 represents the foreground of the noisy image, $n(i,j)$ based on the location of 1 in the Otsu binary image, $o(i,j)$.

Then, the Kuwahara Filter is applied on the background of the noisy image, $n(i,j)$.that represented by 0 value in Otsu binary image, $o(i,j)$, while the foreground of noisy image represented by 1 value in Otsu binary image, $o(i,j)$ remains unchanged. Therefore, the OTSUHARA-WATH filtered image, $ok(i,j)$ is produced by combining the noisy image, $n(i,j)$ smooth region that have been filtered by Kuwahara Filter and the noisy image, $n(i,j)$ texture regions which use directly the noisy image pixel values in corresponding locations.

Lastly, the Wavelet Threshold is applied to the OTSUHARA-WATH filtered image, $ok(i,j)$ to further reduce the noise while preserving the edges and details of the image. It shows the johor.jpg test image for the Poisson noise level of 1e11. Besides that, the process flow for this filter is illustrated in Figure 3.

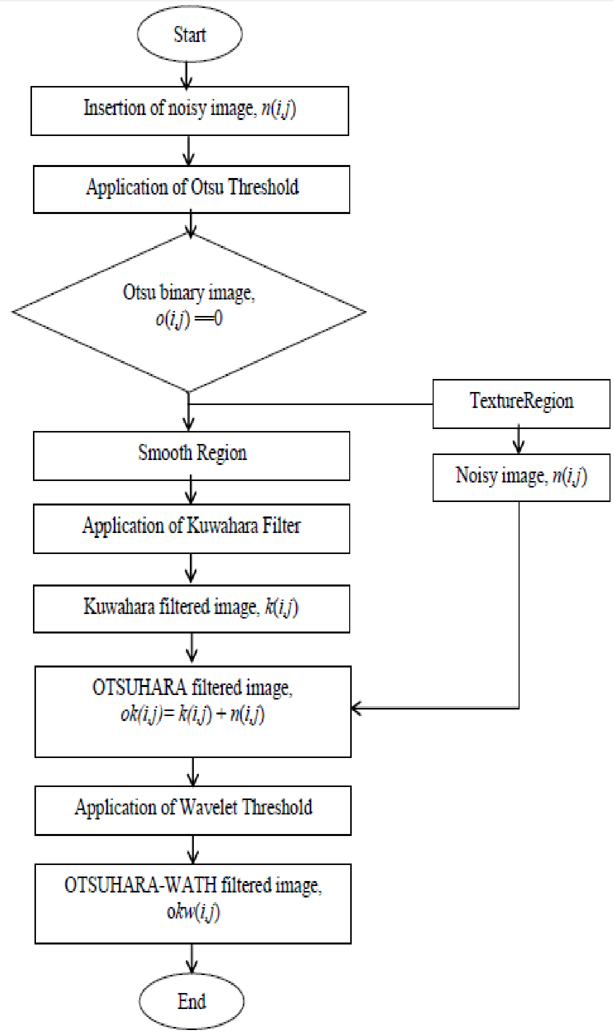


Figure 3: Flowchart for OTSUHARA-WATH Filter

F. Performance Evaluation

There are three evaluation methods that are utilized in this study. The evaluation methods are Peak Signal to Noise Ratio (PSNR), Mean Squared Error (MSE) and visual effects inspection. The PSNR is commonly used to measure the quality of reconstructed image that have been corrupted by noise compared to clean image. It is usually expressed in Decibels (dB)[16]. A higher PSNR would normally indicate that the reconstructed image is of higher quality. The PSNR is most easily defined via the MSE, where the lower the value of MSE means the lower error occurred in the restored images.

The evaluation methods are given by Equation (4) and Equation (5).

The MSE can be defined by:

$$MSE = (1/mn)\ \Sigma\ [x(i,j) - okw(i,j)]^2 \qquad (4)$$

where,
$x(i,j)$: original image
$okw(i,j)$: denoised image
m : row in input image
n : column in input image

whereas, the PSNR can be defined by:

$$PSNR = 10 \times \log 10 \left[(256)^2 / MSE\right] \quad (5)$$

From the analysis performed, the higher the value of PSNR, the better quality of the images produced. On the other hand, the lower the value of MSE, means the lower error occurred in the restored images.

III. Results and Discussion

The experiment conducted on the selected test images which are kl.jpg (367x374), johor.jpg (375x500), sarawak.jpg (599x422) and masjid.jpg (800x600). These test images are captured in low light condition. The kl.jpg and sarawak.jpg are chosen because both images have more textures like edges and details. On the other hand, johor.jpg and masjid.jpg are chosen due to both images have the lower amount of edges and details in images. The experiment is conducted to measure the effectiveness of the proposed methods in removing noise in the images with different levels of Poisson noise. There are two scales of Poisson noise selected, which are 1e7 and 1e9. Further, the proposed method is compared with conventional denoising techniques such as Kuwahara Filter, and the combination of Bilateral Filter and Wavelet Threshold [11]. The performances of these methods were evaluated based on Peak Signal to Noise Ratio (PSNR), Mean Squared Error (MSE), and visual inspection.

A. Parameter setting

This section discussed the suitable parameters utilized in the proposed Method, OTSUHARA-WATH Filter. The parameters setting for all methods are shown in Table 1.

Table 1: The parameter setting for denoising methods

Methods	Types of Parameter	Setting
OTSUHARA-WATH Filter	Threshold setting	[0 1]
	p	30
	Kuwahara filter size	3x3
	DWT Decomposition Level	1
Kuwahara Filter	Filter size	3x3
BL + WT [11]	*w*,window size	5
	DWT Decomposition Level	1

Meanwhile, the results for the PSNR and MSE comparison are shown in Figure 4 to Figure 7, respectively.

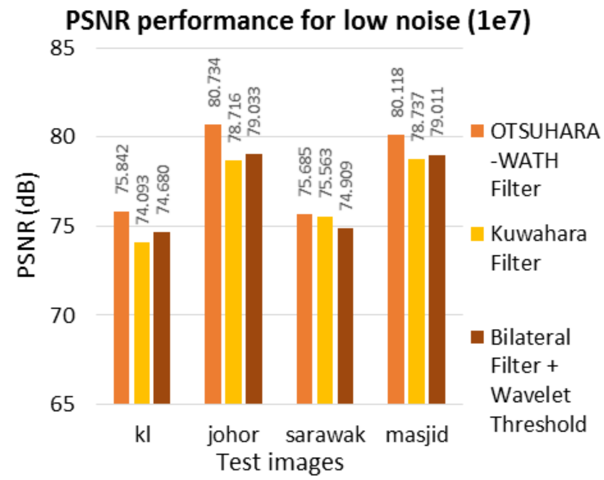


Figure 4: PSNR performance for low noise (1e7)

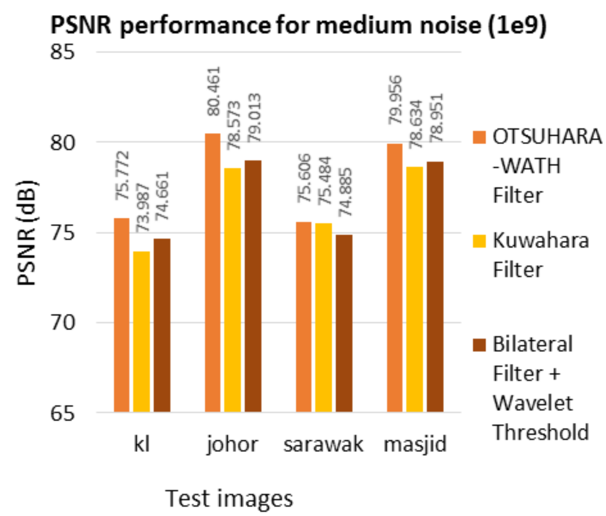


Figure 5: PSNR performance for medium noise (1e9)

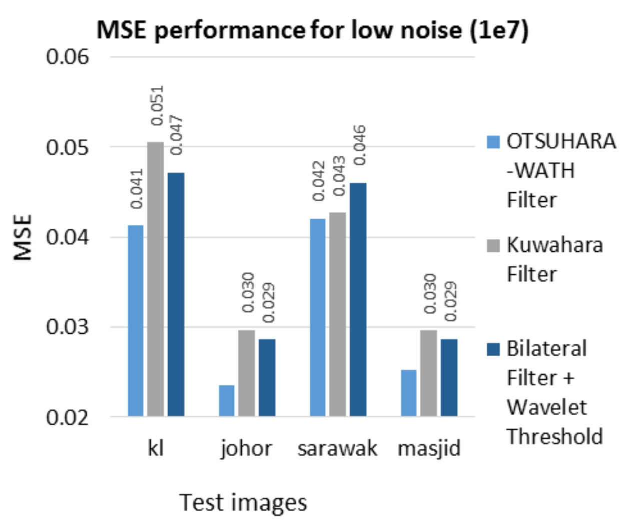


Figure 6: MSE performance for low noise (1e7)

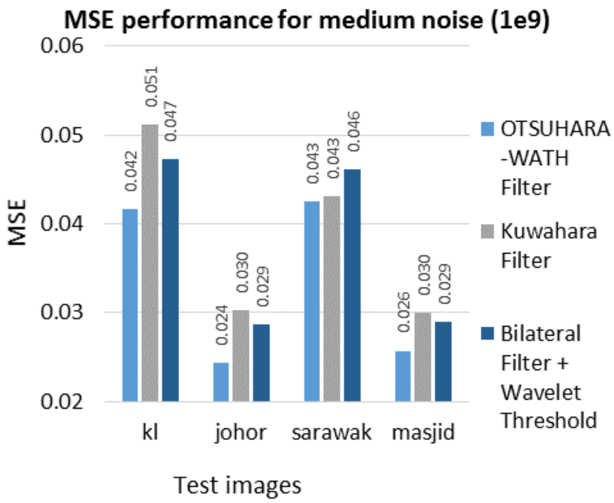


Figure 7: MSE performance for medium noise (1e9)

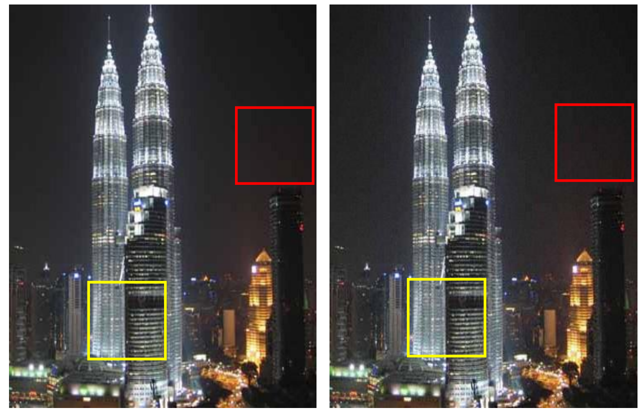
Based on the results in Figures 4 until 7, the OTSUHARA-WATH Filter provides the highest PSNR and lowest MSE for the images with the low and medium level Poisson noise. This is because, the OTSUHARA Filter only denoised the smooth regions of images using the Kuwahara Filter, which contribute to reduction of noise. On the other hand, the texture regions used directly the noisy image pixels values in corresponding locations. This contributes to preservation of the original edges and fine details.

B. *Comparison on Visual Effects Inspection for Denoising Methods*

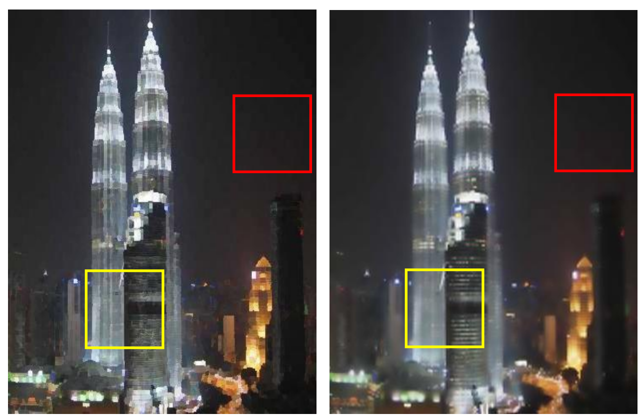
The visual effects inspection is based on the observation using the human vision. The experiments were conducted to observe the physical of the images such as the edges, fine details and quantity of the noises in images. For clearer observation on the denoising result, kl.jpg test image is provided in this paper for medium noise level of 1e9. From the observation in Figure 8, it can observed that in terms of edges and fine details preservation (please refer to yellow boxes in the images), OTSUHARA-WATH Filter provides better preservation in comparison to the Kuwahara Filter and the Bilateral Filter + Wavelet Threshold Filter [11]. On the other hand, in terms of noise reduction (please refer to red boxes in the images), it can be seen that all compared methods have reduced a certain amount of noise. However, OTSUHARA-WATH Filter provides the filtered area which most resembles the original image.

IV. Conclusion

The study aim is to develop a new denoising technique for Poisson noise removal in low light condition digital images without losing the edges and fine details of the images. This study proposed a new denoising technique based on three denoising techniques, which are the Otsu Threshold, Kuwahara Filter and Wavelet Threshold, named as the OTSUHARA-WATH Filter. The performances of proposed methods are analyzed using the PSNR, MSE, and visual inspections. Based on the results, the OTSUHARA-WATH Filter improved the Kuwahara Filter in terms of PSNR by average of 1.30 dB and also has higher PSNR compared to the Bilateral Filter + Wavelet Threshold Filter by 1.13 dB. Meanwhile, the OTSUHARA-WATH Filter has the average of 0.005 lower MSE in comparison to the Kuwahara Filter and the Bilateral Filter + Wavelet Threshold Filter [11]. In terms of visual effects, it is found that the OTSUHARA-WATH Filter provided better edges and fine details while reducing the noise level in the smooth regions.



(a) Original image (b) Noisy image



(c) Kuwahara Filter (d) Bilateral + Wavelet Threshold[11]

(e) OTSUHARA-WATH Filter

Figure 8: Visual effects inspection for denoising methods

ACKNOWLEDGMENT

The authors would like to thank Universiti Tun Hussein Onn Malaysia (UTHM) and Malaysia Government for the support and of this study.

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