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Performance Comparison of Denoising Methods for Historical Documents

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Graphical abstract

Abstract

Image denoising plays an important role in image processing. It is also part of the pre-processing technique in a binarization complete procedure that consists of pre-processing, thresholding, and post-processing. Our previous research has confirmed that the Discrete Cosine Transform (DCT)-based filtering as the new pre-processing process improved the performance of binarization output in terms of recall and precision. This research compares three classical denoising methods; Gaussian, mean, and median filtering with the DCT-based filtering. The noisy ancient document images are filtered using those classical filtering methods. The outputs of this process are used as the input for Otsu, Niblack, Sauvola and NICK binarization methods. Then the resulted binary images of the three classical methods are compared with those of DCT-based filtering. The performance of all denoising algorithms is evaluated by calculating recall and precision of the resulted binary images. The result of this research is that the DCT based filtering resulted in the highest recall and precision as compared to the other methods.

Keywords: DCT-based image denoising; mean filtering; median filtering, Gaussian filtering

1.0 INTRODUCTION

Removing noise from an image document in order to make the image quality better can be considered as an important phase in enhancing the image. Image denoising also plays an important role in Image processing thus making it an essential process in image processing and computer vision [1]. Image denoising is also part of the pre-processing technique in a complete binarization procedure that consists of pre-processing, thresholding, post-processing. Other examples of pre-processing steps are background estimation and contrast image construction [2, 3, 4].

Ancient and historical manuscripts are usually kept in a museum for a long time. This causes the manuscripts to contain some noises, not only substantive but also additive. Additive noise can be removed completely using mean, median and Gaussian filter. However, most images have multiplication noise. Some researchers argued that the latter noise can be removed with the Discrete Cosine Transform (DCT) better than the commonly used three filters.

After the digitalization phase, these document images will be binarized. Our latest research suggests binarization performance itself can be improved using DCT [5]. The research compared noisy image and noiseless image binarization results with and without denoising using DCT-based denoising of noisy and noiseless images respectively. The experiment suggests that the DCT pre-processing with 50% of coefficient and NICK binarization is used in order to reach the best result.

Buades et al. compared 8 denoising methods [6]. They only used original without hybrid methods such as Gaussian, anisotropic and DUDE. The comparison of these methods used three well-defined criteria as follow: the method noise, the mean square error, and the visual quality of the restored images.
Furthermore, Buades et. al. had carried on research on image denoising using non-local Means (NL-Means) algorithm [7]. They argued that the objective

of image denoising is that to retrieve the original image from the noisy environment without altering the original.

This research focuses on the pre-processing level for removing the noise from the original image in order to improve the binarization process that has been done using the DCT [5]. This paper compared three different common denoising methods that are mean, median and Gaussian filtering with the DCT-based filtering. The performance is measured by calculating recall and precision. Section 2 will explain some supported theories and relevant researches that had been conducted [12-13]. Section 3 elaborates the idea of how this experiment is conducted. Section 4 and 5 will discuss the results and conclusions

2.0 LITERATURE REVIEW

Historical document images need to be restored to ensure the contents can be learned in the present about the history. Binarization is a phase before an image can be processed in the next stage such as Optical Character Recognition (OCR). This phase itself consist of pre-processing, thresholding and post-processing.

Quality of historical document image is needed to be improved so that its appearance is better than that of its original image. This can be done without prior knowledge of how the image should be. The difference between image restoration and image enhancement is that in restoration the prior knowledge about the image is needed.

According to Petrou and Bosdogianni, noise types can be classified into two categories. The first is additive which is also known as Gaussian noise. The latter is multiplication noise which most images have [8]. The mean, median and Gaussian filtering are several fundamental algorithms that can denoise the additive noises. While the DCT has been intensively investigated to denoise multiplicative noises. In this section, formulation and characteristics of mean, median, Gaussian and DCT-based filtering are presented and discussed.

2.1 Mean and Median Filter

Mean filter tries to smooth an image that operates in spatial domain by convoluting a kernel with the image, in which the kernel is commonly odd in size, such as 5 x 5 or 3 x 3. The filtering result is the mean (average) of the pixels in each window under consideration. Median filtering operation is similar to mean filtering, this filter replaces the center value of the kernel with the mean pixel's value of all its surrounding values. This filter can be useful if only some part of an image need to be denoised. This median filter almost completely removes Gaussian noise.

(a) Original noisy document with 'fox'

(b) Original noisy document due to water spilling

Figure 1 Examples of noisy document

2.2 Gaussian Filtering

Gaussian filtering is accomplished by convoluting a Gaussian kernel with the image. The digital Gaussian filter is commonly approximated by 3x3 or 5x5 pixel kernel.

2.3 Discrete Cosine Transform and Its Coefficient

Discrete Cosine Transform (DCT) is used in many areas, not just for image processing. Images related applications that use this method such as JPEG compression and image denoising [9, 10]. The DCT consists of four types. However, the two types are defined as the following equation 1:

$$F_c(k_1,k_2) = \frac{2}{N} C(k_1) C(k_2) \sum_{n_1} \sum_{n_2} f(n_1,n_2) \cdot \cos\left(\frac{(2n_1+1)k_1\pi}{2N_1}\right) \cdot \cos\left(\frac{(2n_2+1)k_2\pi}{2N_2}\right)$$

Where $f(n_1,n_2)$ with $0 \le n_1 < N_1$, and $0 \le n_2 < N_2$ is spatial image and $f_c(k_1,k_2)$ with $0 \le k_1 < N_1$, and $0 \le k_2 < N_2$ is DCT coefficient. Gain Control $C(k)$ is given Equation 2:

$$C(k) = \begin{cases} 1/\sqrt{2} & (k=0) \\ 1 & (k \neq 0) \end{cases}$$

An image with a limited frequency-band can be obtained by applying the Inverse Discrete Cosine Transform (IDCT) to the $f_c(k_1,k_2)$ from Eq.1, after selecting a limited number of DCT coefficients. The IDCT of a limited number of DCT coefficient is defined in Equation 3:

$$\hat{f}_c(n_1,n_2) = \frac{2}{N} \sum_{k_1} \sum_{k_2} C(k_1) C(k_2) \hat{F}_c(k_1,k_2) \cdot \cos\left(\frac{n_1(2k_1+1)\pi}{2N_1}\right) \cdot \cos\left(\frac{n_2(2k_2+1)\pi}{2N_2}\right)$$

Here $\hat{f}_c(n_1,n_2)$ with $0 \le n_1 < N_1$, and $0 \le n_2 < N_2$ is a spatial image that is reproduced from a limited number of k_1 and k_2, that is $\hat{F}_c(k_1,k_2)$, with $0 \le k_1 < \hat{N}_1$ and $0 \le k_2 < \hat{N}_2$,in which $\hat{N}_1$ is less than $N_1$and $\hat{N}_2$ is less than N_2.

3.0 METHOD AND EXPERIMENT

The purpose of the experiment is illustrated in Figure 2, i.e. is to determine performance of four denoising methods, namely mean, median, Gaussian filtering, and DCT-based denoising. Particularly, we want to measure performance of DCT-based denoising in comparison with those three classical filtering methods. At the first, the noisy images S shown in Fig. 1 are pre-processed with mean, median, Gaussian filtering and DCT-based filtering. The DCT preprocessing is accomplished by using 50%, 40% or 30% of DCT coefficient respectively.The outputs of this

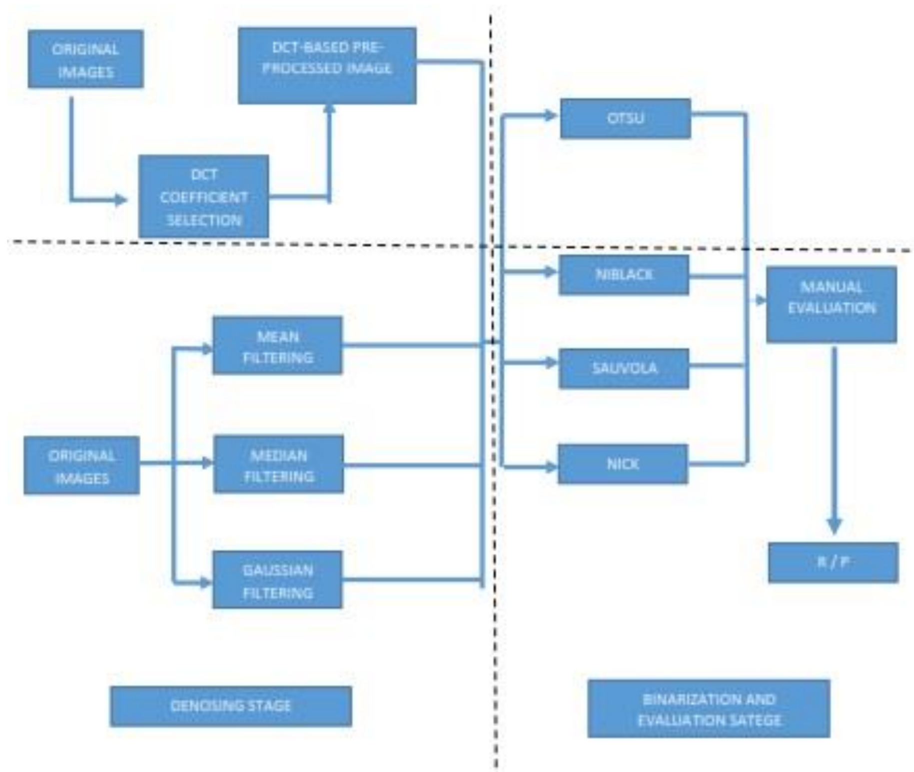
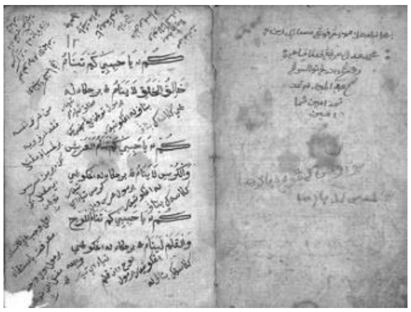
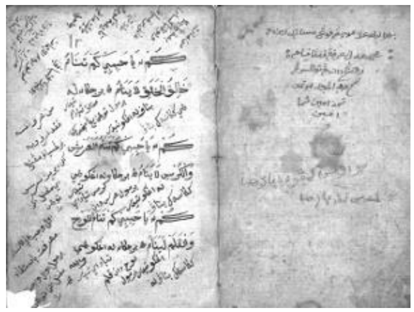


Figure 2 Experimental Setting of Denoising and Binarization Procedure

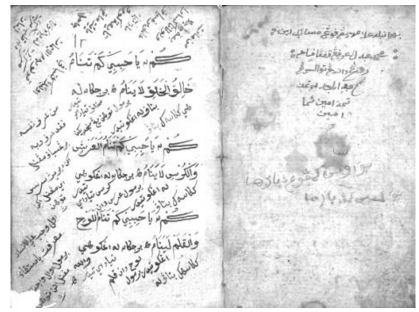
a. Original noisy document with 'fox'



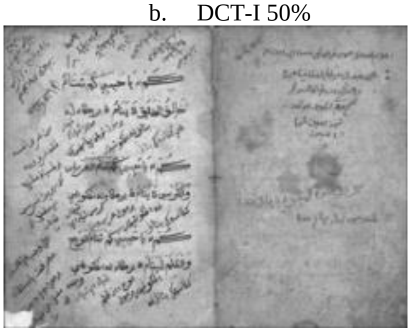
b. DCT-I 50%



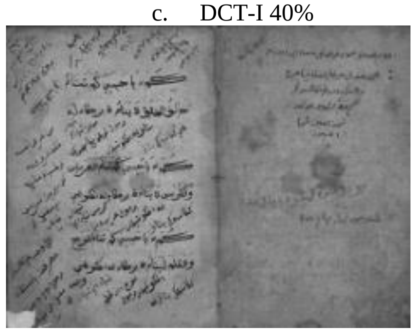
c. DCT-I 40%



d. DCT-I 30%



e. Mean Filtering



f. Median Filtering

g. Gaussian Filtering

Figure 3 Impact of DCT-based denoising, mean, median and Gaussian filtering on noisy document with 'fox'.

process are then passed through four binarization methods, namely Otsu (O), Niblack (Ni), Sauvola (S), and NICK (N). The resulted binary images are finally evaluated by manually (M) calculating recall and precision values.

Figure 3 presents the images as the results of the denoising procedure. Figure 3 (a) is the original noisy document due to 'fox'. Figures 3 (b), (c) and (e) are the representations of noisy document images using 50%, 40% and 30% lower-band frequency of DCT coefficients respectively. It can be seen that the 'fox' slightly fades when 50% of the DCT coefficient are used, while the text remains. When 40 % of DCT coefficients is used, the 'fox' decreases significantly. However, some characters in the text become unclear when roughly 30 % of low frequency of DCT coefficients was used, all 'fox' disappears, but more parts of the text become indistinct.

Figures 3 (e), (f) and (g) are the results of mean, median and Gaussian filtering respectively. The kernel size of the mean and median filter are 11x11, and that of Gaussian filter are 3x3 with variance 0.5.

The performance of denoising algorithm is measured by calculating recall and precision values described in [5]. Equations 3 and 4 are formulation of recall and precision used in this paper. The NCD denotes the number of correctly detected characters in binary document, the GT denotes the total number of characters in the original document images, which is also referred to as ground-truth, and TR refers to the total number of characters detected in binary documents, including correctly detected and broken characters.

$$Recall = NCD/GT \tag{4}$$

$$Precision = NCD/TR \tag{5}$$

The ground-truth images are generated manually by calculating number of readable and broken characters in the original noisy document image.

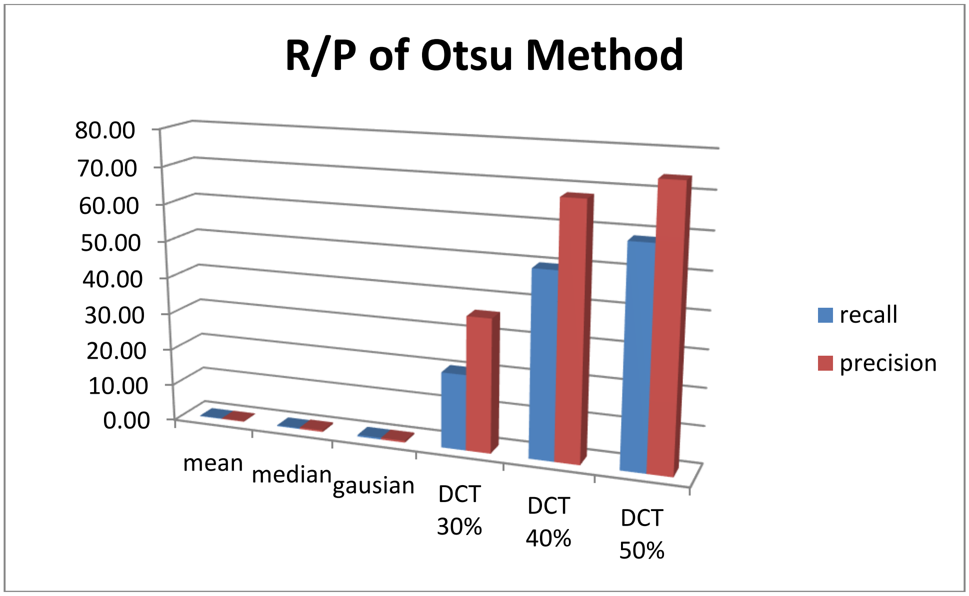
4.0 RESULT AND DISCUSSION

Performances of all filtering/denoising methods are provided in Fig. 4 and Fig. 5 respectively. From the graphs, it is clearly shown that the DCT-based processing outperformed the other three denoising approaches for all binarization methods. The recall and precision (R/P) values of mean, median and Gaussian filtering are below 1%, and those of the DCT-based filtering are roughly between 10% to 90%.

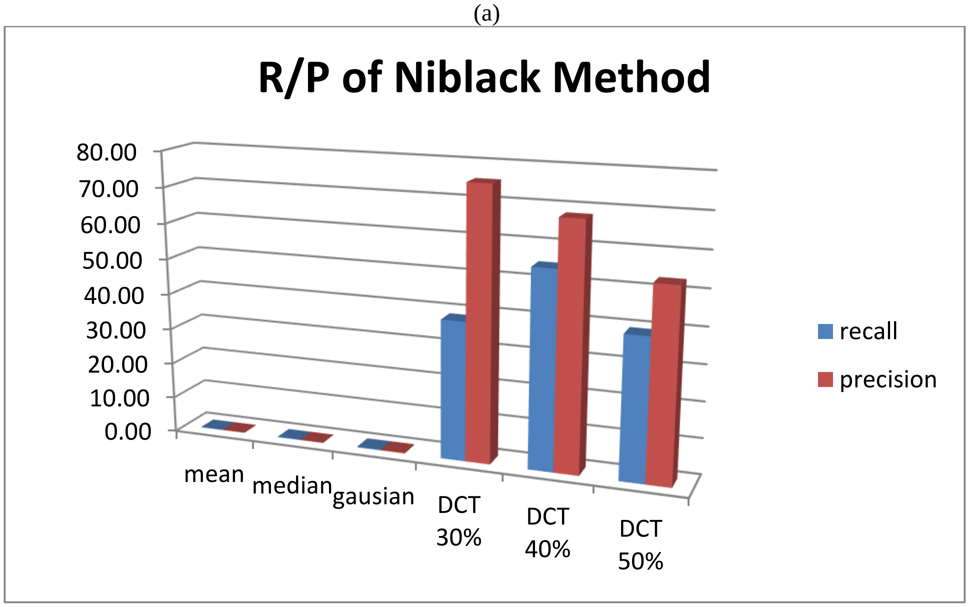
Figure 5 provides average values of recall and precision of all denoising methods. The R/P of mean, median and Gaussian filtering are zoomed to provide a clearer presentation. The averages R/Ps of these three classical methods are below 1%.

4.1 Result of Mean, Median and Gaussian Filtering

The zoomed area in Fig. 6 shows the average R/P of mean, median and Gaussian filtering respectively. The R/P value of mean filtering is the lowest among others. The value is in line with the document image shown in Fig. 3(e), in which the image is the most blurred image as compared to median and Gaussian filtered images. With the kernel of 11x11 pixels, it turned out that the document became too blur, and the



(a)



(b)

Figure 4 Impact of all denosing methods on Recall and precision values (in percentage) of (a) Otsu and (b) Niblack method

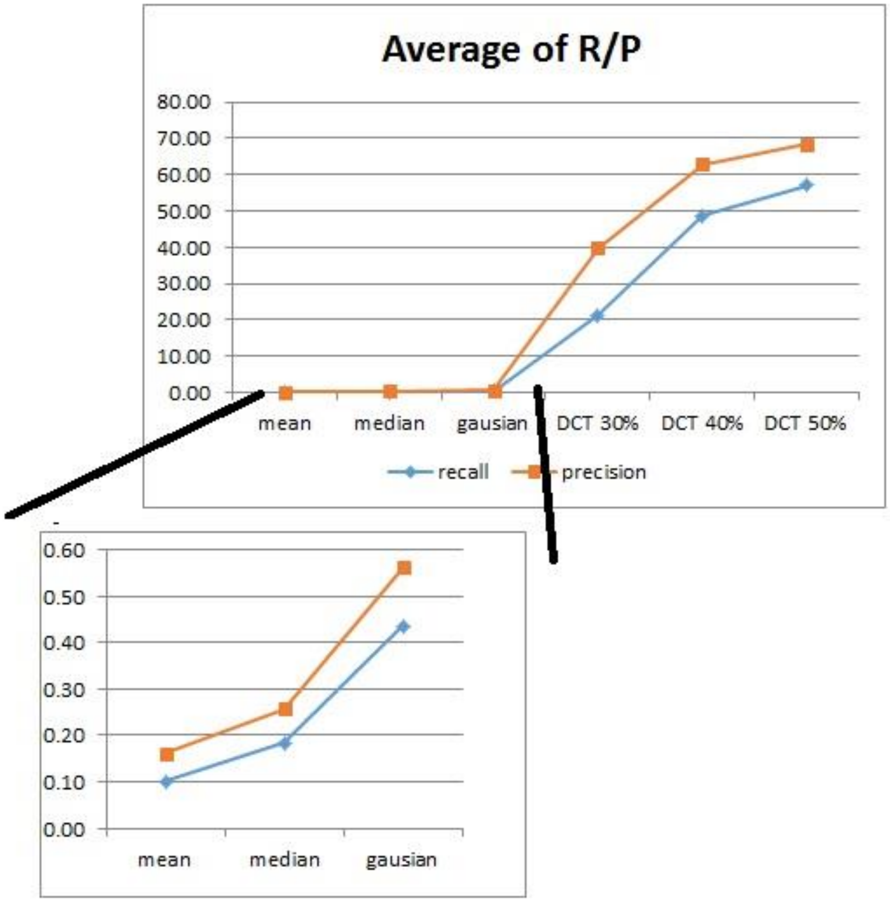


Figure 5 Average values of all denoising methods (in percentage)

denoising step decrease significantly the number of correctly detected characters.

The average R/P of median filtering is slightly higher than that of mean filtering, and the highest is achieved by Gaussian filtering. This pattern agrees with the appearance of the documents. It can be seen at the Fig. 6 (f) and (g) that nevertheless all three methods blur the image, the level of blurring of median filtered image is more significant than that of Gaussian filtered one.

4.2 Result of DCT-Based Denoising/Filtering

The DCT-based image denoising described in [5] subsides the background noise without blurring the text (see Fig. 3 (b), (c) and (d)). Particularly, the lesser the DCT coefficient used in reconstructing the image, the brighter the image background, but the text remains. The graphs in Fig. 4 and 5 shows that the optimum number DCT coefficient used in the pre-processing stage depends on binarization method that will be used subsequently. For example, if Sauvola method is the candidate binarization method, 50% of DCT coefficient predictably achieved the best R/P values.

4.3 Discussion

Performance in terms of recall and precision depends significantly on the number of correctly detected character on binary document image. Thus, the performance is directly related to denoising and binarization characteristics of each method. In this case, binarization performance of a sequence that implements mean, median and Gaussian filtering reduced due to the whole images filtered by those methods became blurred, not only the background that contain noises, but also the text itself. The performance may be increased by lessen the blurring effect, by for example, reducing the size of the convolution kernel.

On the other hands, the text processed by DCT-based filtering remains clear in the document. Thus, this increases the number of correctly detected characters in the resulted binary images

5.0 CONCLUSION

Performance evaluation of denoising methods in denoising historical document image has been presented. The methods are mean, median, Gaussian and DCT-based denoising. The mean, median and Gaussian filters denoise the document and have impact of blurring the text as well as background. Thus, they resulted in low recall and precision values. On the other hands, DCT-based denoising method enhances the document image without blurring the text. Thus, the method resulted in high recall and precision. DCT-based denoising method increased the recall and precision value significantly

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