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Original Article

Design and Analysis of a novel 2D Edge Preservation Adaptive Wavelet Anisotropic Bilateral Filter for Image Restoration of Palm Leaf Manuscripts

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***Abstract** - In the ancient olden period, vital information related to medicines, science, grammar, astrology, mathematics was written on the palm leaves because of its easy availability and reliability. These leaves that are a few hundred years of age are preserved in libraries all over the world. Presently, due to age factors and other factors like weather conditions, pests, improper storage and handling factors, etc., these Palm Leaf Manuscripts (PLM) suffer from degradation. Image restoration plays a vital role in the retrieval of characters text written on older manuscripts made from palm leaves which are affected due to physical wear and tear. Image restoration can be performed through various statistical linear and non-linear filters that are available widely. In this research, a novel 2D Edge Preservation Adaptive Wavelet Anisotropic Bilateral Filter (EPAWABF) is proposed for the restoration of palm leaf manuscript images. To prove the eminence of the proposed restoration technique, the proposed 2D EPAWABF filter is compared with different filters such as 2D Adaptive Median Filter, 2D Adaptive Log Filter, 2D Spatial Domain Filter, 2D Adaptive Wiener Filter and 2D Adaptive Bilateral Filter. Performance evaluation using metrics like peak signal to noise ratio (PSNR) and mean square error (MSE) prove the credibility of the proposed filter for the restoration of PLM.*

Keywords - *Palm-leaf manuscript, restoration, 2D Adaptive Median Filter, 2D Adaptive Wiener Filter, 2D Adaptive Log Filter, 2D Spatial Domain Filter, 2D Adaptive Bilateral Filter.*

I. INTRODUCTION

In the olden days, it was a usual practice of storing many ancient vital as well as traditional information on the various manuscripts like paper, parchments, palm leaves etc. The palm leaf manuscript was considered as the more reliable one and an easy source of writing beyond the fifth century BC period[1]. Such-year-old palm leaf manuscripts are suffering from degradation due to the ageing factor, climatic changes and improper handling of them. There is a need for preserving these old ancestorial documents[2]. Digitization is the only viable solution for safeguarding the manuscripts. But during the digitization process, there occurs noise either through the methods of scanning process, artifacts, background colour of the manuscript etc. [3]. The restoration of this manuscript image is one of the most important and challenging tasks. Normally the noise occurring during the digitization stage of any document can be rectified using some standard available digital filters[4]. There are various works being proposed for the creation of digital manuscript data. The important step in this digitization process is the segmentation and removal of noise since these data are too old[5]. Neural network-based algorithms are popularly being employed for the character recognition of these manuscript data. Algorithms like convolution-based neural network memory-based schemes are also being used [6]. Scanning is a commonly used technique for digitization. However, this process cannot be effectively used since these leaves are aged, and the written data have deteriorated. In addition, these manuscripts suffer from damages such as smudges, stains, holes and dirt [7]. Four important tasks in the processing of palm foliages are scanning, enhancement, binarization and character recognition. Scanning is done to digitize the raw input palm leaf data. Filtration is employed for the removal of noise added to these images due to the ageing factor[8]. This helps to enhance the image. Binarization technique converts the image to a binary data that can be processed easily.Character recognition is used for interpreting the data written on these manuscripts[9]. There are many works related to the filtering of noise related to this manuscript and their performance is notable up to a certain extent[10]. Rahul Vanam and Yan Ye[22] applied the bilateral filter having the adaptive features for the post processing application stage in order to gain the resolution of the video and images respectively. Khare and Kumar[24] performed the restoration of images using non-linear filtering techniques and particularly applied to the general images.

Hence a new two-dimensional Edge Preservation Adaptive Wavelet Anisotropic Bilateral Filter is proposed for the removal of noise directly from raw RGB colour image that is obtained from the scanning of the manuscript.

II. ORGANIZATION OF THE RESEARCH WORK

The proposed research work is arranged as stated below. Section 3 comprises a detailed literature survey of the previous works in the literature. Section 4 describes the proposed filter applied for image restoration by constructing a novel filter meant for it. Section 5 details and discusses the results obtained by the proposed methodology. The concludes of this paper is handed over in Section 6.

III. RELATED WORKS

The Palm leaf manuscripts are used even today for various references, educational purposes etc., and are preserved by various organizations and institutes throughout the world. In countries like India, Thailand there are various such kinds of organizations preserving these manuscripts. In South India, some of the few organizations like the Institute of Asian Studies, Tamil Virtual University, Taraprakashna and various district libraries are preserving the manuscripts and helping the researchers for aiding their research works by providing access to these digitized images.

Alexander et al. [11] proposed a system for the image restoration of palm manuscripts obtained from palm leaves, where the manuscript imagery are digitized and stored. Various binarization techniques are used for converting these images into binary values. They include techniques like Otsu thresholding, global thresholding, adaptive and local thresholding. Kesiman et al. (2018)[12] employed a patch extraction technique for the extraction of the text area in the palm leaf manuscripts. This paper used Gabor filters for the patch extraction. The sliding window approach was used since it produces better results compared to fixed windows. The combination of the sliding window with the Gabor filter produced excellent results.

Krishna et al. [13] proposed a technique for the binarization of palm leaf manuscripts based on the clustering technique. Here the foreground data was accurately extracted using clustering with three-dimensional features. This type of binarization produced improved results compared to thresholding techniques for the palm leaf manuscripts. Ratheash et al. [14] presented an analysis of various segmentation techniques that can be used for the segmentation of palm leaf documents. There are various algorithms proposed from the 19th and 20th centuries. In this paper, the review was conducted for the algorithms proposed from the year 2008 to 2018 for the segmentation of palm leaf manuscript documentation.

Kesiman et al. [15] presented a technique in which the benchmarking of palm leaf manuscript images was conducted. Various analysis tests were conducted for the benchmarking datasets. These tests included segmentation, character recognition and binarization. The dataset for this evaluation was taken from south-east Asian countries. Panyam et al. [16] designed a system in which palm leaf character recognition was done based on transform techniques. Here, depth of indentation, a new feature, was used for the recognition of characters in these manuscripts. This feature was capable of capturing effective information in spite of the degradation and noise components of these manuscripts.

Valy et al. [17] presented a scheme for line segmentation based on the binarization process. Here, Khmer palm leaf manuscript images were considered for segmentation. Initially, the stroke width transformation technique for applied to transform the image pixel values. A modified projection profile algorithm was then employed to identify the segmented regions. Kesiman et al. (2015) [18] performed a study on the computation of binary versions of palm leaf manuscript images. Here, the various challenges faced by the traditional binarization techniques were discussed. In addition, a new technique was proposed based on the Prewitt operation and Otsu thresholding algorithm for image binarization.

Chamchong et al. [19] used an optimal selection of binarization algorithms to identify the best algorithm that can be used for binarization of the palm leaf manuscripts. Here, the identification of optimal algorithms was made based on the machine learning techniques. The performance of various algorithms was compared, and the best was identified. Ramya et al. [20] designed a system for the text character recognition from the palm leaf manuscript images. Neural network architectures were employed in this work. In particular, the feed-forward back-propagation structure was used in this work.

Based on the works stated above, it was found that image filtration is an important component in the processing of palm leaf manuscript images. Thus, in this research, a new technique is proposed and realized for the enhancement and removal of noise from these images.

IV. PROPOSED METHODOLOGY

A. 2D Adaptive Median Filter

The median filter is used for the removal of noise based on median operation over the pixels inside the window. In adaptive median filters, this window size is not constant, and it varies according to the number of noise-less pixels inside the window mask. Let us consider the size of the window as

$$\omega = 2\lambda + 1 \tag{1}$$

where λ refers to a small integer value. In the adaptive median filter technique, the number of noise-free pixels in the window is computed. If this value is less than 8, then the size of the window is increased as

$$\omega = \omega + 2 \tag{2}$$

Now, the 2D adaptive median filtering operation is performed as

$$y(m,n) = \underset{m,n \in \omega}{median}\{x(m,n)\} \quad (3)$$

Here, $x(m,n)$ refers to pixel values of the noisy input image located at (m,n) and $y(m,n)$ is the output filtered at the location (m,n).

The main disadvantage of a 2D adaptive median filter is that the edge information is lost when images are filtered using this technique. In addition, the analytical evaluation of this filtration technique is very difficult.

B. 2D Adaptive Wiener Filter

Wiener filtering technique produces an estimate of noise-less image. This estimate is done such that the mean square error is minimized. During Wiener filtration, the standard deviation of the image and the noise components are computed and used for filtering the images.

$$\hat{y}(m,n) = \bar{y}(m,n) + \frac{\sigma_y^{\,2}(m,n)}{\sigma_y^{\,2}(m,n) + \sigma_n^{\,2}(m,n)}[x(m,n) - \bar{x}(m,n)] \quad (4)$$

where $\hat{y}(m,n)$ is the estimate of noise-less filtered image representation, $\bar{y}(m,n)$ denotes the mean filtered image pixel, $\sigma_y^{\,2}(m,n)$ is the standard deviation of the input image, $\sigma_n^{\,2}(m,n)$ is the standard deviation of noise level, $\bar{x}(m,n)$ is the mean of the image.

The main drawback of the 2D adaptive Wiener filter is that this filter can be used effectively for the removal of noise only when the variance of noise components of the image is low. If the noise variance is large, this filter does not work effectively.

C. 2D Adaptive Log Filter

An adaptive log filter is used for image filtration using logarithmic operations. The denoised image is computed as,

$$y(m,n) = \left[\frac{1}{|\Omega|}\sum_{m,n\in\Omega}\log(x(m,n)) - m(x(m,n))\right] / [sd^2 + \varepsilon] \quad (5)$$

In the above equations, Ω represents a window, $m(x(m,n))$ represents the mean and sd^2 represents the standard deviation of the pixels in the window region Ω.

The main drawback of a 2D adaptive log filter is the degradation in the quality of the image. When the noise components are reduced due to the application of this filter, the quality of the image also decreases linearly.

D. 2D Spatial Domain Filter

Spatial domain processing is a type of filtration in which filtration operation is applied directly over the pixels without any transformation technique. This operation is based on the application of two filter types, namely the linear and non-linear filters. Linear filters directly act on the pixels of the image, whereas the non-linear filters act on the images that are initially filtered using low pass filtration operation. Mean linear filters are the popularly used spatial domain filters. It is given by,

$$y(m,n) = S\{x(m,n)\} \quad (6)$$

$$S(m,n) = mean\{x(m,n)\} \quad (7)$$

where $S\{x(m,n)\}$ is the spatial domain operation over the input image $x(m,n)$?

Spatial domain filters are not popularly employed since the edge information gets blurred when the filtration operation is applied to the spatial domain of the image. This cause loss of useful information.

E. 2D Adaptive Bilateral Filter

The operation of bilateral filtering is defined as

$$y[m,n] = \sum_k \sum_l R^{-1}(k,l) h_d(m,n;k,l) h_r(x[m,n], x[k,l]) x[k,l] \quad (8)$$

Here, $x(m,n)$ refers to the pixel of noisy input image located at (m,n) and $y(m,n)$ is the pixel details of the output filtered image defined at the location (m,n). Also, h_d and h_r represents the area and width of the filters, respectively. They are expressed as

$$h_d(m,n;m_0,n_0) = e^{-\left(\frac{(m-m_0)^2+(n-n_0)^2}{2\sigma_d^2}\right)} \quad (9)$$

$$h_r(x[m,n], x[m_0,n_0]) = e^{-\left(\frac{(x[m,n]-x[m_0,n_0])^2}{2\sigma_r^2}\right)} \quad (10)$$

Here $[m_0, n_0]$ describes the centre pixel. Also, σ_d and σ_r represents the standard deviation of the domain and the range of the filter, respectively.

The above two equations were modified by [21] with the inclusion of an offset component. Thus, the modified 2D Adaptive Bilateral filters are defined as

$$h_d(m,n;m_0,n_0) = e^{-\left(\frac{(m-n_0)^2+(m-n_0)^2+\varsigma}{2\sigma_d^2}\right)} \quad (11)$$

$$h_r(x[m,n], x[m_0,n_0]) = e^{-\left(\frac{(x[m,n]-x[m_0,n_0]-\varsigma[m_0,n_0])^2}{2\sigma_r^2}\right)} \quad (12)$$

The sharpness of the image is controlled by the sharpness threshold ς. The image gets blurred when the value ς is moved closer to the mean. However, by moving it away from the mean, the filtered image gets sharper.

The main limitation of this technique is the difficulty in the identification of the optimal value of the sharpness threshold. The image quality greatly depends on this threshold value and hence must be identified correctly.

F. Proposed 2D EPAWABF (Edge Preservation Adaptive Wavelet Anisotropic Bilateral Filter)Algorithm

The proposed Edge Preservation Adaptive Wavelet Anisotropic Bilateral Filtration algorithm is performed based on the bilateral filtration technique. Initially, each individual pixel of the image is considered. A window of size $s \times s$ is selected around the considered pixel. Then, the number of noise-free pixels in the window ψ is computed as γ. If $\psi < \lambda$, then s is incremented. Apply DWT to ψ and find 4 bands, namely $LL_\psi, LH_\psi, HL_\psi, HH_\psi$. It HH_ψ has edge regions. The major aim of the proposed algorithm is the preservation of edges. Hence, bilateral filtration is not applied to the edge region. The next step is to apply the bilateral filtering as in Equation 8 to $LL_\psi, LH_\psi, HL_\psi$ and to find $LL_\psi^{bf}, LH_\psi^{bf}, HL_\psi^{bf}$. Finally, using inverse DWT to $LL_\psi^{bf}, LH_\psi^{bf}, HL_\psi^{bf}, HH_\psi$ find the filtered window ψ^f.

Algorithm: Proposed 2D Edge Preservation Adaptive Wavelet Anisotropic Bilateral Filtration Algorithm(2D EPAWABF)

Input:

Input image $X \in R^{M \times N}$.

Parameters:

Window size $s \times s$

Threshold λ

Steps:

for $m = 1 : M$

for $n = 1 : N$

Consider each pixel $x(m,n)$.

Find the window ψ of size $s \times s$.

Compute the number of noise-free pixels in the window ψ as γ.

if $\psi < \lambda$

$s = s + 1$

end

Apply DWT to ψ and find 4 bands, namely $LL_\psi, LH_\psi, HL_\psi, HH_\psi$.

Apply the bilateral filtering to $LL_\psi, LH_\psi, HL_\psi$ find $LL_\psi^{bf}, LH_\psi^{bf}, HL_\psi^{bf}$.

Using inverse DWT to $LL_\psi^{bf}, LH_\psi^{bf}, HL_\psi^{bf}, HH_\psi$ find the filtered window ψ^f.

end

end

Output:

Output filtered image $Y \in R^{m \times n}$.

V. RESULTS AND DISCUSSION

To validate the effectiveness of the proposed image filtration algorithm, six different palm leaf manuscript images were selected from the Tamil Virtual Academy dataset that can be accessed at http://www.tamilvu.org/.

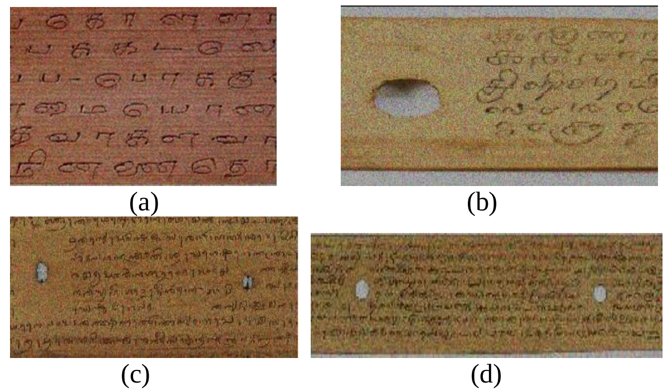

Fig.1. Input sample noisy palm leaf manuscript images

Fig.1 shows four sample noisy palm leaf manuscript images. These images contain noisy components. Thereby the legibility level of these manuscripts is very low. To remove the noise components, various filtration techniques like 2D Adaptive Median Filter, Two-dimensional Adaptive Log Filter, 2D Adaptive Wiener Filter, 2D Spatial Domain Filter and 2D Adaptive Bilateral Filter were used and compared.

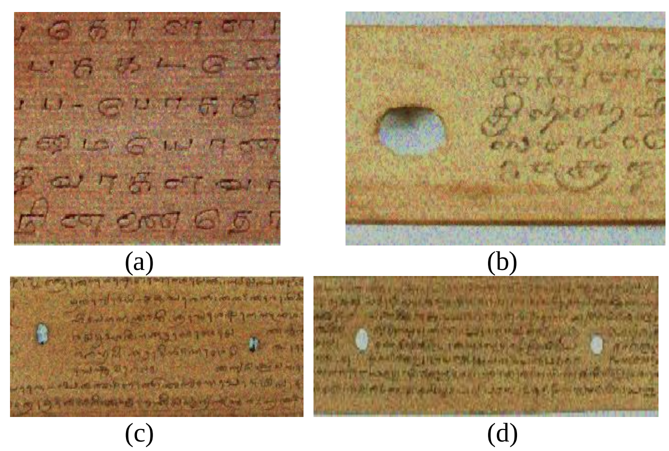

Fig. 2. 2D adaptive median filtered palm leaf manuscript images

Fig.2 shows the 2D adaptive median filtered palm leaf manuscript images. From Fig.2, it is evident that noisy components are still present in the filtered images.

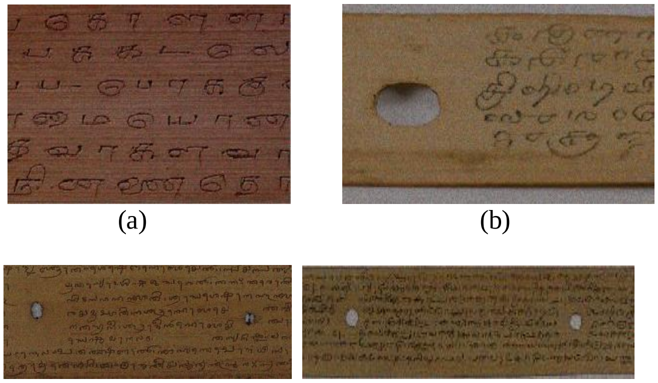

Fig. 3. 2D adaptive Wiener filtered palm leaf manuscript images

Fig.3 shows the 2D adaptive Wiener filtered palm leaf manuscript images. From Fig.3, it is clear that the legibility level of the filtered images is still low.

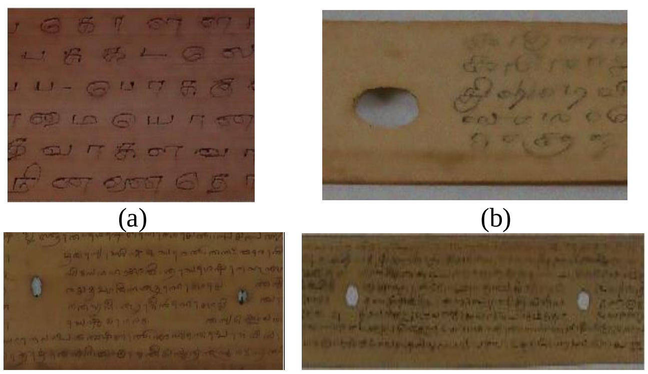

Fig. 4. 2D adaptive log filtered palm leaf manuscript images

Fig.4 shows the 2D adaptive log filtered palm leaf manuscript images. From Fig. 4, it is seen that the noise level is low. However, the data written on the manuscript appear in a blurred format.

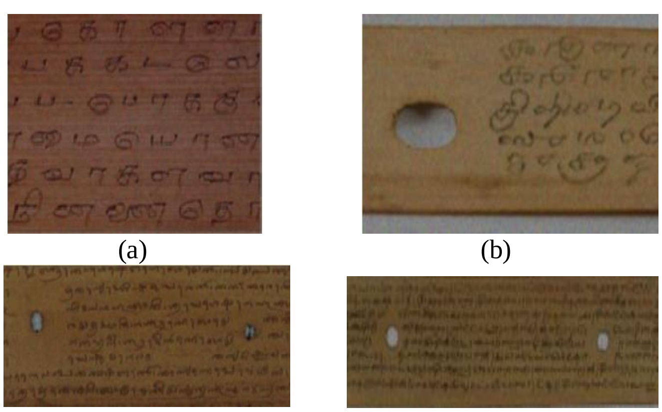

Fig. 5. 2D spatial domain filtered palm leaf manuscript images

Fig. 5 shows the 2D adaptive log filtered palm leaf manuscript images. From Fig. 5, it is seen that the clarity of the filtered images is low.

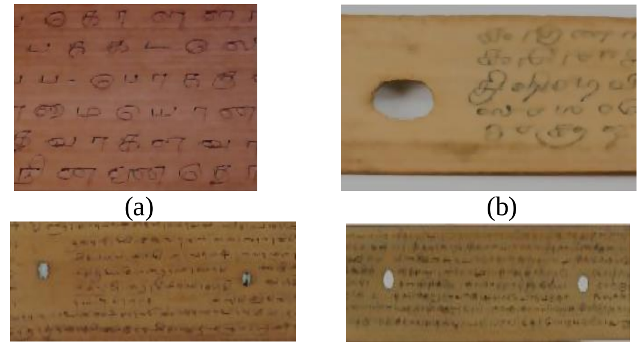

Fig. 6. 2D adaptive bilateral filtered palm leaf manuscript images

Fig. 6 depicts the 2D adaptive bilateral filtered palm leaf manuscript images. From Fig. 6, it is seen that the adaptive bilateral filtration operation does not completely remove the noise components.

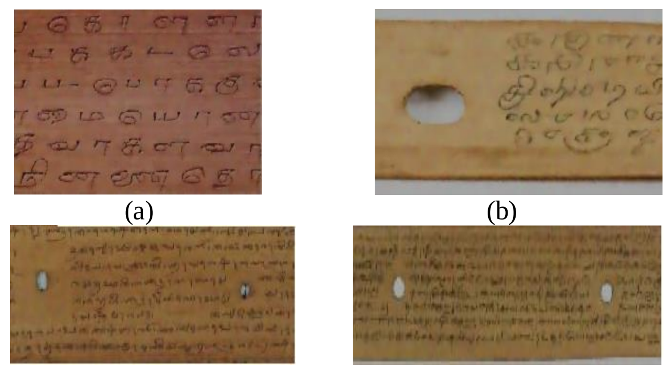

Fig. 7. Proposed 2D EPAWABF filtered palm leaf manuscript images

Fig.7 shows the proposed EPAWABF filtered palm leaf manuscript images. It can be inferred from these images that the noise components are completely removed. In addition, the clarity of these images is also greatly enhanced. Thus, it is evident that the proposed EPAWABF system achieves the best performance visually compared to other filtration algorithms.

To quantitatively assess the performance of the proposed 2D EPAWABF algorithm, peak signal to noise ratio and mean square error are computed. Table-1 indicates the qualitative evaluation using squared mean error. It is clear that the MSE value is 42.51 for the 2D adaptive median filter. 2D adaptive Wiener filter aids with an average MSE of 7.152. Similarly, the two-dimensional adaptive log filter attains an average MSE of 10.251. The average MSE attained by the 2D spatial domain filter is 21.089. 2D adaptive bilateral filter attains an average MSE of 8.277. However, the proposed 2D EPAWABF algorithm attains an average MSE of 0.0636. Thus, the performance of the proposed 2D EPAWABF is the best in comparison to all other algorithms used in terms of MSE.

Table 1. Performance evaluation using Mean Square Error

Image Number	MSE					
	2D Adaptive Median Filter	2D Adaptive Wiener Filter	2D Adaptive Log Filter	2D Spatial Domain Filter	2D Adaptive Bilateral Filter	Proposed 2D EPAWABF
1	48.941	1.056	11.887	29.162	10.155	0.0668
2	9.844	8.686	5.664	4.482	1.551	0.0659
3	37.618	3.162	9.569	11.905	5.510	0.0667
4	49.721	21.647	11.075	24.127	13.076	0.0399
5	51.463	1.018	11.458	26.541	9.740	0.0710
6	57.518	7.339	11.855	30.314	9.631	0.0713

Table-2 indicates the qualitative evaluation using PSNR. From Table-2, it is obvious that the mean value of PSNR for the 2D adaptive median filter is 22.42dB. 2D adaptive Wiener filter produces an average PSNR of 30.01dB. Similarly, the 2D adaptive log filter attains an average PSNR of 28.15dB. The average PSNR attained by a 2D spatial domain filter is 25.66dB. 2D adaptive bilateral filter attains an average PSNR of 25.52 dB. However, the proposed 2D EPAWABF algorithm attains the highest average PSNR of 50.46dB. Thus, the performance of the proposed 2D EPAWABF is superior when compared to all other algorithms used here in terms of PSNR.

Table 2. Performance analysis

Image Number	PSNR in dB					
	2D Adaptive Median Filter	2D Adaptive Wiener Filter	2D Adaptive Log Filter	2D Spatial Domain Filter	2D Adaptive Bilateral Filter	Proposed 2D EPAWABF
1	21.234	34.2094	27.3801	23.4826	22.1482	49.7686
2	28.1987	27.673	30.5992	31.6156	38.4709	49.8695
3	22.3768	30.8071	28.3222	27.3736	27.4584	49.7397
4	21.1654	24.8406	27.6872	24.3058	19.9528	55.2809
5	21.0158	34.3229	27.5398	23.8916	22.5114	49.1574
6	20.5327	28.1958	27.3919	23.3143	22.6088	48.9635

Fig. 8 shows the Histogram analysis results of Original image 1, Enhanced image 1 using proposed 2D EPAWABF algorithm, Squared error image 1, Histogram of original image 1, Histogram of enhanced image 1 and Error histogram of image 1. From Fig, 8 it is evident that the enhanced image histogram is narrowed using the proposed 2D EPAWABF algorithm. The flat histogram of the noise is eliminated using the proposed algorithm, due to which the enhanced image histogram is narrow downed.

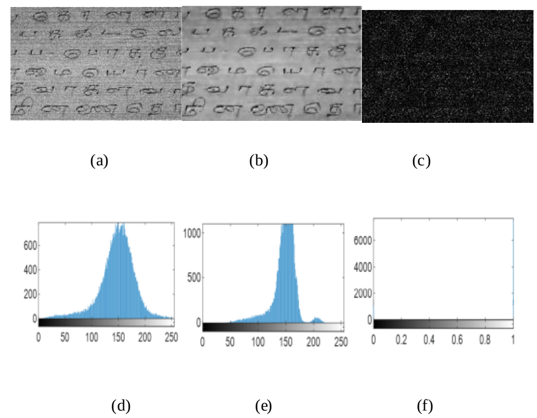

Figure 8. Histogram analysis results (a) Original image 1 (b) Enhanced image 1 using proposed 2D EPAWABF algorithm (c) Squared error image 1 (d) Histogram of original image 1 (e) Histogram of enhanced image 1 (f) Error histogram of image 1

Fig. 9 shows the Histogram analysis results of Original image 2, Enhanced image 2 using proposed 2D EPAWABF algorithm, Squared error image 2, Histogram of original image 2, Histogram of enhanced image 2 and Error histogram of image 2. From Fig. 9, it can be inferred that similar to image 1, the histogram of the enhanced image 2 is also narrowed using the proposed 2D EPAWABF algorithm.

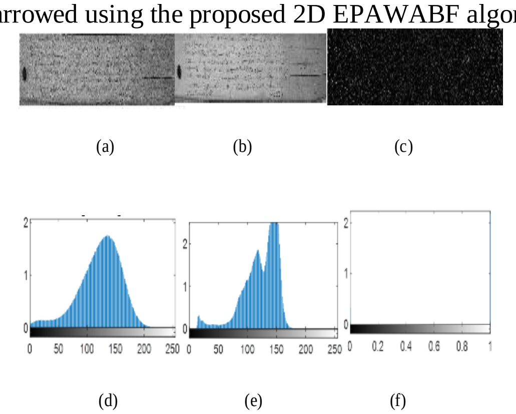

Fig. 9. The histogram investigation results (a) Original image 2 (b) Enhanced image 2 using proposed 2D EPAWABF algorithm (c) Squared error image 2 (d) Histogram of the original image 2 (e) Histogram of the enhanced image 2 (f) Error histogram of image 2

Fig. 10 shows the histogram plot of PSNR for various filtration algorithms. From Fig. 10, it can be inferred that the PSNR of the anticipated algorithm is the highest compared to all other algorithms. Thus, the excellence of the proposed algorithm has been verified both visually and quantitatively and concludes that the proposed algorithm produces the superlative performance compared to all other algorithms.

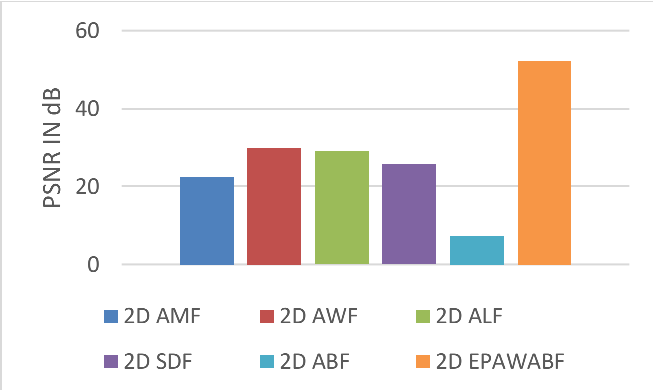

Figure 10. Variation of PSNR for different filtration techniques

VI. CONCLUSION & FUTURE SCOPE

In this research, a new technique called Edge Preservation Adaptive Wavelet Anisotropic Bilateral Filtration was proposed. The major improvement of this algorithm was the preservation of edge information is important for palm leaf manuscripts. Wavelet transform was applied, and the high-frequency band containing the edge information was preserved. To validate the performance of the proposed filtration algorithm with various other algorithms like 2D Adaptive Median Filter, 2D Adaptive Wiener Filter, 2D Adaptive Log Filter, 2D Spatial Domain Filter and 2D Adaptive Bilateral Filter were used for comparison. It was found that the proposed system achieves a very high mean PSNR of 50.46 dB along with a very low average MSE, as stated above. In histogram analysis, filtered image histogram information was narrowed due to the effective removal of noise.

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