Analysis of Particle Swarm Optimization Based 2D FIR Filter for Reduction of Additive and Multiplicative Noise in Images

V. Muneeswaran[1(✉)] and M. Pallikonda Rajasekaran[2]

[1] Department of Instrumentation and Control Engineering, Kalasalingam University, Krishnankoil 626126, Tamil Nadu, India
munees.klu@gmail.com

[2] Department of Electronics and Communication Engineering, Kalasalingam University, Krishnankoil 626126, Tamil Nadu, India
m.p.raja@klu.ac.in

Abstract. Noise in digital images is the major cause of severe artifacts. Filter design for denoising applications can also be addressed with optimization techniques as conventional filters incur in this. Exploration and Exploitation capability features of the Meta Heuristic Optimization Techniques make them applicable to noise reduction in digital images. An increasing number of Meta Heuristic Optimization algorithms make it suitable for designing FIR filters. In the proposed method, Particle Swarm Optimization, a global optimizer algorithm was used in calculating the appropriate coefficients for 2D FIR Filter. The proposed filter was applied to standard test images for testing its noise suppression capability. Indicators of performance, such as Peak signal to noise ratio (PSNR) values and Structural Content (SC) were used in accessing the efficiency of the proposed method and to the adaptability of the method for removing different noise types. Thus a brief comparison for noise suppression in digital images with both multiplicative and additive noise types using PSO optimized 2D FIR filter is addressed in this paper.

Keywords: 2D FIR filter · Particle Swarm Optimization · Peak signal to noise ratio · Meta Heuristic Optimization · Structural Content

1 Introduction

Noise in digital images is unavoidable in all imaging modalities as the instrumentation facilities and the environmental factors in which the images captured interfere with the internal attributes of the image [4]. All noise types either multiplicative or additive in nature conduce for the degradation of the image almost in all cases. Due to the prevalence of modern imaging facilities it becomes essential to limit or remove the noise signals present in it. In this study the efficiency of the noise elimination scheme using a two dimensional Finite Impulse Response filter based on Particle Swarm Optimization algorithm together with a median

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filter for removing additive and multiplicative noise present in the image is studied and the ability to recover its noiseless form is discussed. The preliminary step to identify the noise present in the image is to analyze the histogram. The basic difference between the additive and multiplicative noise is that, assume a variable $x(t)$ following a stochastic differential equation. If the corresponding random term in the stochastic differential equation of a variable $x(t)$ does not reckon on the state of the system $x(t)$, we call it additive noise. If the random term in the stochastic differential equation depends on the state of the system $x(t)$, then the noise is assumed to be multiplicative in nature. The goal for a denoising filter consists of suppressing the noise while preserving all the useful features such as edges and textural features. In conventional filters the removal of additive and multiplicative noise will result in the blurring and distorted features in the filtered image. The use of population based optimization techniques eliminates the need of performing local statistics and diffusion based methods that was computationally high [9,13]. Optimization techniques do not have the need to have prior knowledge about the amount of noise present.

2 Previous Works

Hitherto more number of studies have been performed on image denoising in the literature. Denoising process in wavelet domain and frequency domain requires optimal threshold and cut-off frequency as their basic components. A few important and recent notable works in the denoising field is discussed in this section. Ratha Jeyalakshmi and Ramar used to modify the morphological image filtering algorithm with arbitrary structuring elements for speckle reduction [10]. Andria and his team produced a denoising scheme using simlet 5 mother function, which are filtered with linear phase. It also involves processing of horizontal, vertical, diagonal and approximation denoised images [2]. Behrenbruch reviewed filtering approaches on the post processing scenario that clarifies the misconception in filtering techniques [4]. Vikrant Bhateja and his team modified the diffusion equation of Perona and Malik by replacing the diffusion coefficient with a non-linear function of coefficient of variations. Noise reduction is achieved in his work by summing up the weighted Laplacian images [16]. In another work Vikrant Bhateja and his research group suppressed the noise content by processing the non-homogenous regions with the application of modified average filtering templates on it [17]. Team of members headed by Nagashettappa Biradar combined fuzzy filters with triangular membership function and conventional SRAD filter in homomorphic domain and non-homomorphic domain for noise reduction [5]. Fatma Latifoglu used artificial bee colony optimization algorithm for determining the optimal co-efficients of the 2D FIR filter [11]. Gupta used soft thresholding process and multiscale decomposition for denoising that is computationally hard [7].

3 Two Dimensional FIR Filter

Two dimensional FIR filter is used for image processing in various applications. Two dimensional Finite Impulse Response filter was always characterized by their filter coefficients $h(m, n)$ [6,8]. The frequency response of the 2D Filter is therefore given by Eq. (1).

$$H(\omega_u, \omega_v) = \sum_{m=-M}^{M} \sum_{n=-N}^{N} h(m, n) e^{-j(m\omega_u + n\omega_v)} \tag{1}$$

where $\omega_u = \frac{2\Pi u}{M}$ and $\omega_v = \frac{2\Pi v}{N}$.

In this equation $h(m, n)$ were the filter coefficients which will be found iteratively with the help of optimization algorithm. The stability condition of a two dimensional filter is given in the following Eq. (2).

$$\sum_{m=-x}^{X} \sum_{n=-x}^{X} |h(m, n)| < X \tag{2}$$

where X is the number of elements from the origin in the mask size of the filter coefficients. In this study the effect of filter coefficients with appropriate zero locations in the complex plane produced using particle swarm optimization algorithm is analyzed for suppression of Gaussian and speckle noise present in images.

4 Median Filter

Median filter is one of the conventional filters that is extensively used in the spatial filtering process due to its non-linear property. It is widely used in image processing algorithm with the intention of noise reduction and in pre-processing [12]. The process of median filtering is accomplished by placing median of a window as a value instead of its original value. While calculating the median value the following procedure is adopted. All the values in the mask will be sorted in numerical order and the middle value in the sorted order will be considered as the value to be replaced. Thus the property of median filter is achieved.

5 Additive and Multiplicative Noise in Images

5.1 Additive Noise

Gaussian Noise. A probability density function (PDF) of the Gaussian noise will resemble the normal distribution. Thus the noise value are Gaussian distributive in nature. The prime cause of Gaussian noise in images occurs during capture e.g. noise due to improper illumination and/or due to abrupt changes in temperature, and/or during transmission e.g. noise of electronic circuit. Most commonly Gaussian noise can be suppressed using a spatial filtering approach, despite the smoothing of image, an unwanted outcome may end up in the blurring of edges and details as they will be processed in the task of blocking high frequencies. Traditional spatial filtering approach for noise reduction comprises:

mean filtering technique, median filtering technique and Gaussian smoothing technique for a random variable z its probability density function P is given by Eq. (3).

$$P_G(Z) = \frac{1}{\sigma\sqrt{2\pi}}e^{-\frac{(z-\mu)^2}{2\sigma^2}} \tag{3}$$

where Z is the gray level present in the image, μ and σ are the mean and standard deviation respectively.

Salt and Pepper Noise. An image is considered to be getting exposed to salt and pepper noise only if it has random occurrences of white and black pixels. It is observed that over heated imaging components may cause salt and pepper noise.

5.2 Multiplicative Noise

Speckle Noise. Images that are formed with coherent energy sources and imaging systems impose a serious threat of speckle noise. It is often termed as dominant multiplicative noise. Removing speckle noise becomes harder as its intensity varies with the image intensity [14]. Speckle noise in rare cases may contain useful texture information. As speckle noise is multiplicative in nature it is modeled only with the random value multiplications as given in Eq. (4).

$$J = I + n * I \tag{4}$$

where J is the speckle affected image, I is noiseless input image and n is the noisy image of variance v.

6 Particle Swarm Optimization

Optimization is the process of finding the best available values from the input values [13]. Particle Swarm Optimization is a mathematical modelling of social behavior of certain animals within their team. Particle Swarm Optimization is often preferred for its robustness in finding the global best location of particles [1]. For a iteration l the velocity of the particle i is calculated by sum of global best solution g_{best}, its current best value p_{best} and its current velocity v^l. Considering $v_i^{l=0} = 0$ the new velocity vector is calculated by the Eq. (5).

$$v_i^l + 1 = W * v_i^l + \alpha * C_1 * [g_{best}^i - x_i^l] + \beta * C_2 * [p_{best}^i - x_i^l] \tag{5}$$

The tradeoff between p_{best} and g_{best} is controlled by W the inertial weight parameter. The relative attraction between p_{best} and g_{best} is indicated by C_1 and C_2. α and β are random values between 0 and 1. The new position is calculated as

$$x_i^{l+1} = x_i^l + v_i^{l+1} \tag{6}$$

The range of v_i lies between $[v_{min}, v_{max}]$. When the new position is calculated the particle will shift to it and at the last iteration the g_{best} becomes the optimal solution found.

7 Design Formulation

In the given scheme two image signals were used on the input side such as the noiseless image $I_{org}(n)$ and $I_{noisy}(n)$ is the noisy image contaminated by either additive and multiplicative noise. The 2D FIR filter system with optimization using Particle Swarm Optimization together with median filter will produce the denoised image. The objective of the optimization process is to reduce the Mean Square Error value that results as a difference between noisy image and 2D FIR filter output [11] as shown in Fig. 1.

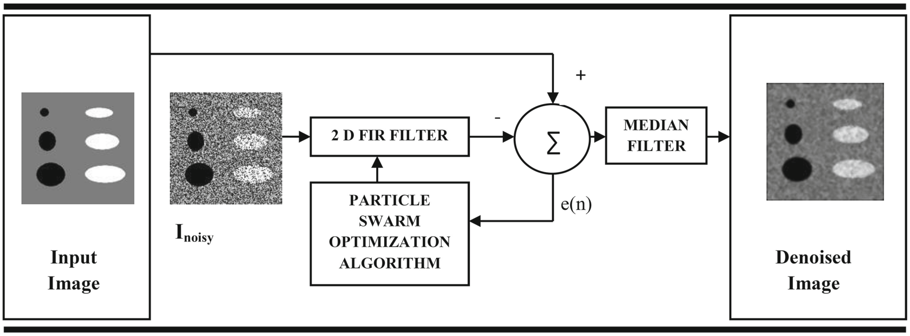

Fig. 1. Proposed denoising scheme.

Coefficients of filter were adjusted by minimization of the Mean Square Error value between filter output and $I_{org}(n)$ and is given as

$$MSE = \frac{1}{KL} \sum_{k=0}^{K-1} \sum_{l=0}^{L-1} [I_{org}(k, l) - I_{Noisy}(k, l)]^2 \tag{7}$$

In this proposed methodology, Particle Swarm Optimization is used in finding optimal coefficients. The steps of PSO based 2D-FIR are given below

1. Set the number of population(window size of filter), learning parameter (C1, C2).
2. Generate the swarm with the condition given in Eq. (2).
3. Update the variables p_{best} and g_{best} at the current iteration based upon the fitness function The fitness function for this problem is given is given in Eq. (7).
4. Generate new p_{best} and g_{best} (values) with fitness values and compute the velocity and position using Eq. (5).
5. Look up for the termination condition and repeat steps 3–5 till the optimum value of g_{best} is reached or upto the termination condition (Number of iterations is set as 100 in this case).

8 Results and Discussion

The simulated test image, as shown in Fig. 2 in its JPG format with 128 × 28 pixels was used in the experiments. For its noisy version the standard image is corrupted with additive and multiplicative noise at different noise level and it is shown in Fig. 3. Consciously degrading an image with noise will allow us to validate the effectiveness of an image denoising operator to noise and assess its performance as shown in Tables 1, 3 and 4.

It can be seen that from Fig. 4 the amount of the additive and multiplicative noise is reduced on the application of the proposed denoising scheme and the visualization of the filtered images is also improved to a great extent when compared with the noisy form in Fig. 3. The quality of the denoised images

Fig. 2. Simulated image

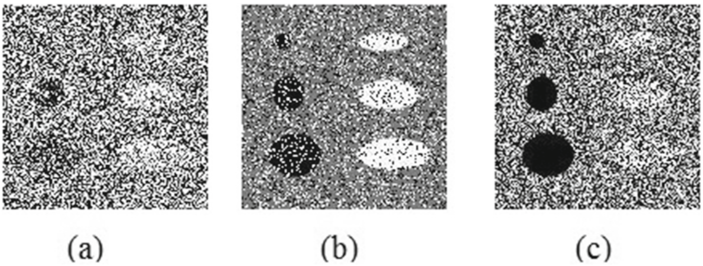

Fig. 3. Noised form of simulated image

Table 1. 3×3 Mask

a_{00}	a_{01}	a_{02}
0.0621	0.1024	0.0616
a_{10}	a_{11}	a_{12}
0.1021	0.2736	0.1026
a_{20}	a_{21}	a_{22}
0.0614	0.1022	0.0621

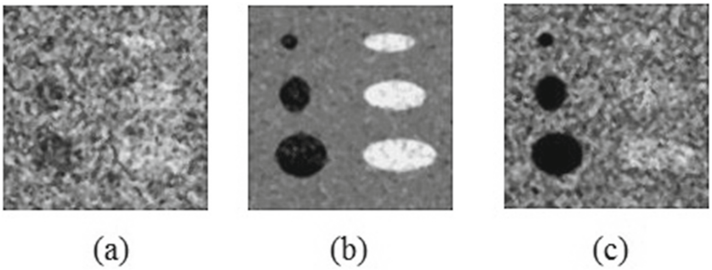

Fig. 4. Denoised form of simulated image

Table 2. Quality metrics

Metrics	Gaussian noise			S & P noise			Speckle noise		
	Mask size			Mask size			Mask size		
	3×3	5×5	7×7	3×3	5×5	7×7	3×3	5×5	7×7
PSNR	13.48	12.23	10.34	17.46	17.23	15.03	15.63	15.11	13.54
MSE	0.022	0.026	0.030	0.010	0.010	0.012	0.014	0.016	0.024
SC	1.703	1.792	1.890	0.932	0.972	1.239	1.375	1.484	1.643
ENL	6.994	6.843	6.544	9.223	9.094	8.564	7.512	7.012	6.843

Table 3. 5×5 Mask

a_{00}	a_{01}	a_{02}	a_{03}	a_{04}
0.0238	0.0281	0.0137	0.0092	0.0784
a_{10}	a_{11}	a_{12}	a_{13}	a_{14}
0	0.0390	0.0268	0.0153	0.0602
a_{20}	a_{21}	a_{22}	a_{23}	a_{24}
0.0569	0.0609	0.1260	0.0885	0.0429
a_{30}	a_{31}	a_{32}	a_{33}	a_{34}
0.0635	0.0497	0.0782	0.0582	0.0403
a_{40}	a_{41}	a_{42}	a_{43}	a_{44}
0.0079	0.0373	0.0510	0	0.0119

were evaluated by standard metrics such as Peak Signal to Noise ratio (PSNR) [8], Mean square error (MSE) [3], Structural Content (SC) [15] and Equivalent Number of Looks (ENL) [18]. It is evident that there is very less blurring in the filtered image with 3×3 window mask and the value of quality metrics for different window size supports the aforementioned fact. The limit on window size reduces the computational complexity as well as effect of blurring in the resultant images. The obtained results are above compromising level even at high noise densities without much iterative application of the filtering algorithm. It is seen

Table 4. 7 × 7 Mask

a_{00}	a_{01}	a_{02}	a_{03}	a_{04}	a_{05}	a_{06}
0.0525	0.0122	0.0497	0.0516	0.0136	0.0391	0
a_{10}	a_{11}	a_{12}	a_{13}	a_{14}	a_{15}	a_{16}
0.0399	0.0685	0.0524	0.1058	0.0748	0.0767	0
a_{20}	a_{21}	a_{22}	a_{23}	a_{24}	a_{25}	a_{26}
0	0.0224	0	0.0082	0	0.0801	0.0076
a_{30}	a_{31}	a_{32}	a_{33}	a_{34}	a_{35}	a_{36}
0	0.1031	0.0916	0.0076	0.0431	0.0325	0.0007
a_{40}	a_{41}	a_{42}	a_{43}	a_{44}	a_{45}	a_{46}
0.0713	0.0282	0	0.0545	0.0430	0.0061	0.0120
a_{50}	a_{51}	a_{52}	a_{53}	a_{54}	a_{55}	a_{56}
0	0.0397	0.0048	0	0.0884	0.0456	0

from Table 2, that the coefficients for 3 × 3 mask performs well in the following hierarchy of removing noise, it efficiently removes salt and pepper noise in the images, whereas the ability to remove the speckle content and salt and pepper noise content in the images was relatively low. The effect of increasing window size is also clearly illustrated in Table 2. It is clearly seen with the augumentation in window size the quality of the image decreases which is clearly illustrated in Table 2. Thus the 3 × 3 mask can be preferred for denoising applications such as Ultrasound Images, SAR Images etc.

9 Conclusion

We have proposed a optimization based filtering technique for image denoising process. In this proposed denoising technique, the qualitative and quantitative aspect of filtering are discussed. It is clearly realized that the filter coefficients produced by the mask size 3 is more suited in purging salt and pepper noise, whereas the same values when applied for removing speckle noise and Gaussian noise performs relatively low. The performance of the optimization based filtering technique was illustrated with efficient quality indicators. Hence the proposed optimization technique based FIR filter can be used for noise elimination process. Future work includes the development of noise elimination schemes using different meta-heuristic optimization algorithms. Filter coefficients that can suppress both the additive and multiplicative noise can also be a future work.

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