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A Circular Adaptive Median Filter for Salt and Pepper Noise Suppression from MRI Images

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An adaptive median filter with a circular kernel, named as circular adaptive median filter (CAMF) is proposed in this article, for denoising of magnetic resonance imaging (MRI) images corrupted by salt and pepper noise of varying noise densities. An adaptive operation is incorporated in the proposed filter by varying the size of the circular kernel according to the requirement. The effectiveness of the CAMF is compared with six other competitive networks, i.e., conic adaptive median filter (CoAMF), decision based filter (DBF), modified switching median filter (MSWM), recursive adaptive modified filter (RAMF), plus adaptive median filter (PAMF), and cross adaptive median filter (CrAMF). The performance of all the models is analyzed using peak signal to noise ratio (PSNR) and computational time. Moreover, a non-parametric statistical test is conducted to illustrate the pair wise comparison of other filter with the proposed one. It is observed that the proposed approach has demonstrated superior performance with respect to the two performance measures.

Keywords: Adaptive filter, Median filter, MRI, PSNR, Statistical analysis

Introduction

Denoising of medical images has attracted many researchers as a pre-processing operation in a number of medical diagnostic operations. The process of creating visual representations of the internal structures of a body is called Medical imaging. Diagnostic imaging is an umbrella term for a vast variety of examinations, scans and images, such as X-ray, computed tomography (CT), magnetic resonance imaging (MRI), ultrasound (US) etc. These medical images may get corrupted by various spurious noises at the time of acquisition, or any processing operation, such as segmentation, compression, enhancement etc. Deepa *et al*.[1] have reviewed and carried out a comparative analysis of different noise removal approaches from MRI image. It is found that the fixed and non-adaptive median filtering approaches produce blurred effect on the filtered images. Therefore, different adaptive digital image filters having adaptive parameters and structures have been proposed by different researchers.[2,3] Zhang and Xiaobo[4] have proposed dual tree complex wavelet transform and wiener filter with modified thresholding for denoising of image. In some research papers, the window size is increased as per the requirement[5] and parameters are changed according to the environment.[6] With the presence of high density noise, in DBF, the noisy pixel intensity is replaced by the median value of the adjoining pixels, which is obtained from the previous processing step.[7] Hence, the performance of this technique needs proper selection of the adjoining pixels. The modified switching median filter, i.e., MSWM[8] uses rank order to enhance the effectiveness of the median filter.

In the last few years, different computational intelligence based techniques have been applied for the denoising of different medical images. Kumar and Mishra[9,10] have used parameter less heuristic techniques like teaching learning based optimization (TLBO) and Jaya for the training of the neural network filters, and effectively suppressed the dominant noise of magnetic resonance image (MRI) and US images. However, all these techniques need a lot of expertise on machine learning algorithms and on artificial neural networks. Many other adaptive median filters, such as conic adaptive median filter (CoAMF), plus adaptive median filter (PAMF) and cross adaptive median filter (CrAMF) have also been investigated by Roy *et al*.[5] In this paper, circular adaptive median filter (CAMF) technique is proposed that evaluates only the noisy pixels, and substitute the

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noisy pixel value with a median value of the pixels present in the working window. This method overcomes the artifacts caused by a square kernel and provides better filtered image. The contribution of the paper is summarized as: (i) The CAMF, which uses a circular shaped dynamic kernel block as the working window has been proposed for suppression of salt and pepper noise present in MRI images collected from Medanta Hospital, Ranchi (ii) The performance of proposed CAMF is compared with six approaches, such as DBF, MSWM, RAMF, CoAMF, PAMF and CrAMF in terms of PSNR, a Non-parametric statistical test and computational time.

Proposed Circular Adaptive Median Filter (CAMF)

In the current investigation, the implementation of DBF, MSWM, RAMF have been dealt. The dynamic kernel blocks used in CoAMF, PAMF and CrAMF along with the proposed circular kernel has been also been considered. The difference lies in the shape of these blocks and the numbers of pixels present inside the blocks are depicted in Fig. 1. The step-by-step of the proposed CAMF algorithm is as follow:

Pseudo code of proposed CAMF algorithm

***Step 1*:** Original image y is taken, and then salt and pepper noise is added to it. The elementary model which takes noise into account is:

$$x=y+n \quad \dots (1)$$

where, x y z is the noisy image, the original image and the added noise respectively. A circular shape (3*3) working window T with centre x[r, c] is considered. The centre pixel x[r, c] of the window is considered as noisy or noise-free. If the pixel is noise free, then it is left unaltered, otherwise, the pixel is further processed as:

$$T= \{x\ [r+ i, c+ j], (i, j) \in w\} \quad \dots (2)$$

Where, w consists of five neighborhood pixels centered around x [r, c] in a circular fashion and w ∈{(−1,0), (0, −1:1), (1,0)}

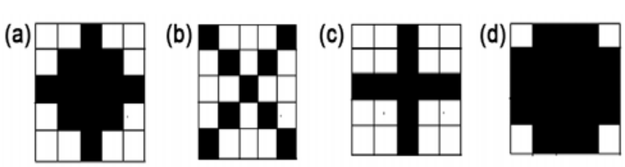

Fig. 1 — (a)(CoAMF)Cone, (b)CrAMF(Cross), (c)PAMF(Plus), (d)CAMF(Circular)

***Step 2*:** If (3*3) circular window contains one or more noise-free pixels then,

x[r, c]= MED(T)

***Step 3*:** The size of window T1 is increased to (5*5), when all the pixels in (3*3) circular window are noisy i.e.

$$T1= \{x\ [r+ i, c+ j],(i, j) \in w1\} \quad \dots (3)$$

Where, w1 consists of twenty-one neighborhood pixels centered around x[r, c] in a circular fashion. w1∈ {(−2, −1:1), (−1:1, −2:2), (2, −1:1)}

***Step 4*:** If (5*5) circular window contains one or more noise-free pixels, then

$$x[r,c] = MED\{T1\} \quad \dots (4)$$

***Step 5*:** If all pixels in (5*5) circular window are noisy, then x[r,c] =MED{T}

***Step 6*:** Steps 1–5 are repeated until all the pixels in the image are processed.

Results and Discussion

Simulation based Experiments

The performance indices PSNR is considered for the objective investigation of all the techniques. Fifteen medical images collected from the Medanta Hospital, Ranchi, are considered in our experiments, where different types of noises are inherently present. The mathematical expression of the *MSE* and *PSNR* are shown in Eqs 5–6, where X represents the value of noise-free pixel value of original image and Y is corresponding noisy pixel.

$$MSE = \frac{\sum_{m=1}^{M}\sum_{n=1}^{N}(X(m,n)-\hat{Y}(m,n)}{MXN} \quad \dots (5)$$

$$PSNR = 10.log_{10}\left(\frac{M\times N}{MSE}\right) \quad \dots (6)$$

The PSNR values obtained by applying various methods for all the tested images with noise density of 20% are shown in Table 1. It is observed that, the RAMF and CAMF provide better results as compared to others. Among all these collected medical images, the MRI2 image is considered and noises having density of (a) 20% (d) 40% (g) 50% (j) 60% are artificially added. The corresponding restored images obtained from RAMF and CAMF are shown in Fig. 2.

Table 1 — Comparative results in PSNR of various filtering techniques for fifteen different images at 20% noise density

PSNR							
IMAGES	FILTERS						
	DBA	SWM	RAMF	CoAMF	PAMF	CrAMF	CAMF
IMG001	25.0045	25.7138	26.5727	25.6099	28.1940	27.6670	28.7718
IMG002	27.9548	27.2219	28.2701	26.5562	28.2364	28.1814	28.3534
IMG003	27.4888	26.1042	28.3290	26.1778	28.1969	27.6952	28.3806
IMG004	28.6800	27.9330	28.2935	25.9911	28.3961	27.9930	28.5770
IMG008	28.1663	27.8653	28.4702	26.8872	28.6217	27.4386	28.9011
IMG015	27.3145	27.6511	28.0872	26.6046	28.2460	27.4765	28.5042
IMG020	27.9886	27.1250	28.0328	26.1395	28.2905	27.3143	28.8386
IMG026	29.3183	28.2953	29.0682	27.3950	28.5599	28.4612	29.7026
HIGHIMAGE	21.5307	21.0825	21.2895	21.0322	22.3622	21.3264	22.6337
MRI1	22.1843	21.8479	22.6590	21.6334	23.2042	22.0127	23.5609
MRI2	29.1001	27.3273	31.0155	30.3178	31.7019	30.7281	31.8505
Brain3	21.5359	21.8519	21.9463	21.6343	23.0094	21.9179	23.1016
IMG012	28.2353	27.6409	28.3518	26.2187	28.6779	27.6381	28.5917
IMG014	28.3673	27.1915	28.4108	26.5445	28.2973	27.8468	28.7328
IMG018	28.2610	27.0547	28.2082	26.2938	28.3613	27.6605	28.7366

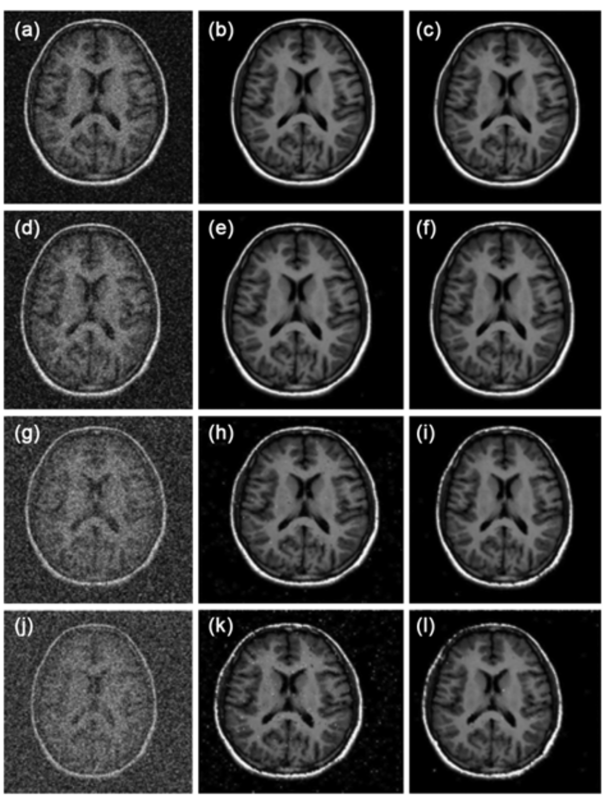

Fig. 2 — MRI 2 image with noise (a) 20% (d) 40% (g) 50% (j) 60%, and their respective restored versions using (e-h) RAMF and (i-l) CAMF (proposed)

The comparison of computational time with other competitive approach listed in Table 2 shows the superiority of the proposed CAMF approach. The

Table 2 — Comparison of computational time

CPU TIME (in sec)	DBF	MSWM	RAMF	CoAMF	PAMF	CrAMF	CAMF
	40.846 s	38.468 s	72.206 s	52.773 s	41.560 s	32.942 s	36.118 s

Table 3 — Wilcoxon signed test using PSNR metric as a winning parameter

Comparison	p value	h value
CAMF WITH DBA	3.09E-05	1
CAMF WITH MSWM	2.70E-05	1
CAMF WITH RAMF	2.70E-05	1
CAMF WITH CoAMF	2.70E-05	1
CAMF WITH PAMF	3.09E-05	1
CAMF WITH CrAMF	2.70E-05	1

Wilcoxon signed test has also been carried out by applying MATLAB function (signrank). In Wilcoxon test, whether the null hypothesis can be rejected or not is decided with the help of h value obtained by sign rank function of MATLAB. The h-value of 1 and 0, signifies that the null hypothesis can be rejected and cannot be rejected respectively as shown in Table 3.

Conclusions

This paper introduced a novel adaptive filter having a circular kernel, namely, the circular adaptive median filter (CAMF) to effectively suppress noise from MRI images. The proposed filter is evaluated with the data set collected from Medanta hospital Ranchi. It is observed that the performance of the CAMF is superior to that of six other competitive filters, such as the DBF, MSWM, RAMF, CoAMF, PAMF, and CrAMF in terms of PSNR. It is concluded that CAMF could denoise the MRI image with better accuracy with reduced computational complexity. The quantitative analysis through Wilcoxon test confirms that it surpassed other competitive filters in preserving significant information in the MRI images. In future, the proposed filter may be investigated for denoising of other medical image modalities having different noise densities.

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