A Combined Spatial and Frequency Domain Approach for Removal of Impulse Noise from Images

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Abstract— ***Visual quality of any natural image is lost when it is corrupted by noise, especially by impulse noise. Further, essential features of the image cannot be retrieved from noisy image. Considering the reality that noise is ubiquitous, image denoising is an unavoidable prerequisite for any type of higher level image processing. A variant of the existing method of impulse noise removal is proposed in this paper. The method has two stages. Detection of noisy pixels and then replacing the noisy pixels by one of its non-noisy neighbour is the first stage. In the second stage, a multiresolution technique of image denoising is employed. The proposed method is found to be very effective in image denoising of grey as well as color images, as is evidenced by the given experimental results. Also the method is shown to be effective in reducing mixed noise from images.***

Index Terms— ***Denoising frequency domain,impulse noise, multiresolution, spatial method, stationary wavelet.***

I. INTRODUCTION

Images are often corrupted by different types of noise. A noisy image has poor visual quality. Moreover the important features of the image which are essential for image analysis, interpretation and information processing cannot be gathered from noisy images. Image processing operations such as compression, segmentation, detection, object recognition, etc require clean images without noise, so as to get good results from the operations. A noisy image, if subjected to any of the image processing operations, would give unsatisfactory and in many cases wrong results. A typical example could be a noisy medical image. When a physician examines such an image, important and relevant details could not be seen as they are submerged under noise. It may even give wrong interpretations and diagnosis and consequent problems. Many types of noise can corrupt images. Corruptions can occur during its generation, processing or transmission. A photographic camera contains many devices such as charge coupled devices (CCD), Charge injection devices (CID), complementary metal oxide semiconductor (CMOS) devices, etc. These devices introduce noise in the pictures taken by the camera. It is due to the non-ideal operation and malfunctioning of the devices in the camera. Similar is the case with medical images such as Magnetic Resonance Images (MRI), Ultrasonic (US) images, X-ray images, Positron Emission Tomograph (PET) images, etc. In these cases, noise s generated due to the imperfect technological operations of the equipments or the defect of the sensors or the recording devices.

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Signal conditioning such as amplification, Analog to Digital Conversion (ADC) etc are done using electronic circuits. Various devices in the electronic circuits are sources of noise. Noise problems would be serious, especially in the case of low signal to noise ratio input signals, such as in the case of microstructure images. Hence image denoising must be done before the image is subjected to its real applications, to get satisfactory results. Noise corrupting images can be modelled as impulse, Gaussian, Poisson, Rayleigh, speckle, periodic, etc. Depending on the process of generation of images, one or more types of such noise can be seen in any image. Impulse noise (also called as salt and pepper) is generated in image due to the malfunctioning of pixels in the camera sensors, faulty memory locations in hardware, noise in channels through which image signal is transmitted, external atmospheric disturbances, error in ADC, bit error in transmission media, etc. A common type of impulse noise has either very high pixel intensity (salt, appearing as white) or very low pixel intensity (pepper, appearing as black). For an 8 bit image, the respective pixel intensities of the two are 255 and 0. A variation of impulse noise is the so called random impulse noise for which also there are only two noise pixel intensities: high and low. Impulse noise has very high contrast to its surroundings. Even a low noise percentage can drastically change the appearance of the image, as the original image pixels are replaced by noisy pixels. Also the noisy pixels conceal the important features of the image. Extensive research works have already been done in the area of removing impulse noise. Most of such works are in spatial domain. Rest of the paper is organised as follows. Section II briefly describes some of the selected works published in the area of denoising of impulse noise. Multiresolution approach of image denoising is discussed in section III. Recent trends of combined spatial domain and frequency domain denoising, utilising advantages of both are explained in section IV. Solution approach and methodology proposed in this paper is given in section V. Simulation and experimental results of the proposed method are discussed in section VI. Section VII concludes this paper.

II. RELTED WORKS IN IMPULSE DENOISING

Median filter [1], [2] is a very old but still a popular impulse denoising method. Here each pixel is replaced by the median of pixels of a window (eg. 3 x 3) around the chosen pixel. The elements of the pixels in the window are sorted and its middle value is taken as the median. In this method, irrespective of noisy or not, each pixel is modified, resulting in deformation of the image. To solve this problem, examining each pixel and only after ascertaining that the pixel is noisy, filtering is done [3]. This process is known as noise detection. A popular

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variation of median filter is adaptive median filter [4] in which the window size is adaptively varied depending on the local noise characteristics around the chosen window. When the window size is large, the computation time is high. In [5], diagonal elements of 3 x 3 window around the chosen pixel are sorted and the median value is used for replacement. Computation time is less in this case. Weighted median filters are also seen proposed for impulse denoising [6], [7]. In a recent work [8], modified decision based unsymmetrical trimmed median filter is proposed for impulse denoising. Switching median filters [9] are also employed for denoising. New fast and efficient algorithm for removal of high density impulse noise is proposed in [10]. Combining the advantages of spatial domain and frequency domain filters, removal of mixed noise composed of impulse and Gaussian noises is proposed in [11]. Noise removal from images seems to be a never ending process [12], as improvement in some parameters (visual quality, signal to noise ratio, computational complexity, edge preservation, etc) can be the target of new research.

III. MULTIRESOLUTION APPROACH FOR IMAGE DENOISING

Most of the algorithms discussed in the previous section are of single resolution type in which resolution of the image remains constant during the entire processing. Recently, multiresolution approach of image signal processing is found to have many attractive features. Such algorithms operate at different time frequency resolutions. They are closely linked [13] with human visual systems and processed images have high visual quality. In image denoising, presence of essential signal at some resolutions and noise at many resolutions is usefully utilised. Simultaneous appearance of signal at different frequency bands (different scales/resolutions) exists in multiresolution. Multiresolution analysis enables feature enhancement and extraction from different channels at different resolutions. Useful data signals at different frequencies are processed independently and without exploiting overall information across the bands. Essentially multiresolution analysis has the advantage that a feature in an image can appear at different levels as well as at different scales. Noise and signal information can be distinguished better at some resolution level than at other. In multiresolution analysis, the features that are undetected at certain resolution may be easy to find at some other resolutions. Also optimal features of an image may be available at some scales and at some resolutions. The multiresolution concept was originally proposed by Mallat [14] using wavelet transforms. Use of wavelet transform is a superior approach to other time frequency analysis tools because its time scale width of window can be stretched to match with the original signal. This concept is especially true in image processing studies. This method is particularly useful for non-stationary signal analysis such as noises and transients. In wavelet analysis, a given signal is decomposed to get sub bands of different frequencies using sub band filters. Down sampling is used to analyse the signal at different resolutions. For denoising applications, the noisy signal is decomposed to one low frequency sub band (approximation sub band) and three high frequency sub bands (detailed sub bands). The approximation sub band contains important features of signal. Wavelet coefficients are very large in this band. The detailed sub bands have wavelet coefficients representing high frequencies; edges, lines, curve, etc. It also contains noise, as noise is of high frequency, generally. However the coefficients representing noise are of smaller amplitudes compared to signal present in the bands. These bands are thresholded [15] to eliminate noise and to get high frequency signals. The approximation sub band and the thresolded sub bands are synthesised using inverse wavelet transforms to get the denoised image. Although DWT has good features of multiresolution, sparse representation, edge preservation, etc, it has some important drawbacks in denoising applications. Some of them are its non redundancy, shift variance, poor directionality and lack of phase information. Second generation wavelets like curvelets, contourlets, etc could solve the problem of directionality while stationary wavelet transforms (SWT) could overcome the problem of shift variance [16]. Further the SWT are redundant and do not use down sampling, which avoids pseudo Gibbs phenomenon. In SWT, different resolutions are obtained by adjusting the coefficients of sub band filters. Zero padding is done in the filters to decrease bandwidth. SWT is also called as un-decimated wavelet and “a trous” algorithm. Whereas DWT is a pyramidal algorithm, SWT is a parallelpiped algorithm. It has good localisation properties in scale-space representation and is a good multiresolution analysis tool. Images analysed by SWT have better visual quality. Compared to DWT, noise recognition is better done in SWT due to its time invariance property [17]. The denoising method using SWT is similar to that of DWT, which will be described in the Section V.

IV. COMBINED SPATIAL AND FREQUENCY DOMAIN APPROACH FOR DENOISING

Some of the recent research work in the area of image denoising utilises combined spatial domain and frequency domain techniques so as to get the advantages of both. The bilateral filter [18] which is a spatial domain filter takes in to account of the local neighbourhood pixels and their spatial and intensity distances. In this way, edge preservation and noise reduction are simultaneously achieved. However its computational complexity is enormous. The bilateral filter performs spatial averaging without smoothing edges. Wavelet filtering is employed for frequency domain operation. The proposed work in this paper uses a spatial domain process of noisy pixel detection and replacing the noisy pixel with one of the non noisy neighbouring pixels. Thereafter a multiresolution environment is implemented using SWT to remove the remaining noise and to give good picture quality for the denoised image. Thresholding of the detailed sub bands of the SWT is done to reduce the residual noise left after the proposed first stage of denoising. An additional advantage of the proposed method is that it can reduce mixed noise composed of impulse and Gaussian noises. Impulse noise reduction is mainly from the first stage of the proposed method whereas Gaussian noise is removed mainly due to the action of the second stage of denoising.

V. SOLUTION APPROACH AND METHODOLOGY

Impulse noise in image is characterised by either high pixel intensity or very low pixel intensity. Typically, it is assumed

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that these intensities are either 255 or 0, for an 8 bit grey image. In this paper, it is proposed that each of such pixels is replaced by one of the non noisy nearest neighbours. Before doing the replacement, both the pixel to be replaced and the pixel with which replacement is done are ascertained to be non noisy. No sorting operation is done. If all immediate neighbours are noisy, the next neighbours can be used for replacement. The proposed scheme works well even for high noise density. Since noise detection is done before replacement, non noisy pixels in the picture are not tampered and hence visual quality of the denoised image is good. Also since the noisy pixels are replaced by the neighbouring pixels only, the local characteristics of the image are retained. In the second stage of denoising, SWT is employed, which as discussed earlier is a good multiresolution tool and hence provides good noise rejection as well as good visual quality for the images. At one level of decomposition, SWT gives four sub bands. One of them gives all low frequency components of the image. All wavelet coefficients of this band are of higher amplitudes and represents salient features of the original image. Noise in this band is extremely low as it is a low pass output. The three detailed sub bands give all directional coefficients and are of high frequency components. As the noise is also of high frequency, these bands contain most of the noise components. But the amplitudes of these noise coefficients are small compared to the signal amplitudes in these bands. The simplest method of eliminating these noisy coefficients is to use thresholding. Hard thresholding, soft thresholding or adaptive thrsholding can be used. Adaptive thresholding[19] is used in this work. The thresholded detailed sub bands and the approximation sub band are used for reconstruction which is by using inverse SWT. Instead of thresholding, the detailed sub bands can be forced to zero and inverse SWT can be applied to get a lower quality denoised image, which reduces the computation time. However the edge characteristics are lost in this method. The method of denoising is applicable to color images also. In this case, the colour components are decomposed, giving red, blue and green colours. The two stage denoising is applied to each of the colour components and finally they are concatenated to get the denoised image. Results of the proposed denoising on colour images are also encouraging. Further, an interesting result observed is that the denoising sheme works well for removing mixed noise also; specifically images containing impulse noise and Gaussian noise could be denoised. The second stage of the proposed method is more responsible for Gaussian noise removal. The first stage is more involved for impulse noise removal.

VI. EXPERIMENTAL RESULTS

The noise detection of pixels and neighboring non noisy pixel replacement in place of noisy pixels is tested using a 2D matrix, as given in Table1. The matrix contains large number of noisy pixels (with element values 255 and 0). After application of the first stage of the proposed denoising scheme, all the noisy pixels got removed. The 2D input and corresponding 2D output matrices are shown in Table 1 and Table 2 respectively.

TABLE I- INPUT MATRIX

255	2	0	255	5	255	7
0	4	255	0	10	12	0
11	0	255	0	0	255	15
25	255	0	0	255	20	255
0	0	255	255	22	23	24
255	10	255	26	27	0	255
28	0	255	30	31	255	33

TABLE 2- OUTPUT MATRIX

4	2	2	10	5	5	7
4	4	2	2	10	12	5
11	4	4	2	2	10	15
25	11	4	4	2	20	10
25	25	11	4	22	23	24
25	10	25	26	27	22	23
28	25	10	30	31	27	33

A grey 2D image is added with impulse noise of 10%. The original image and noisy image are shown in Figure 1(a) and 1(b) respectively. Due to the impulse noise, the noisy image can be seen to have lost most of its visual quality. Results of application of the first stage of the proposed method are shown in Figure 1(c). It can be seen that the noise is completely removed. There is an increase of about 7 dB of PSNR of this image with that of the noisy image. Now the second stage of denoising (using SWT) is employed to the output of the first stage of denoising. SWT with "db4" is used. Results of the final combined two stage denoising are shown in Figure 1(d). The visual quality of the image is improved to a large extent. With increased noise density to 20 %, experiment was repeated and results of the proposed denoising are shown in Figure 2(a), 2(b), 2(c) and 2(d).

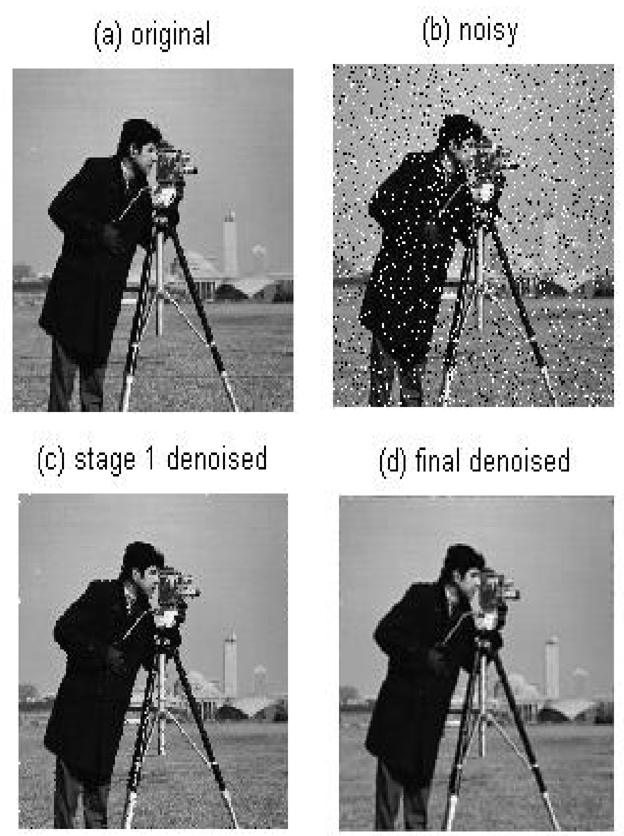

FIG. 1 DENOISING OF IMAGE WITH 10% NOISE

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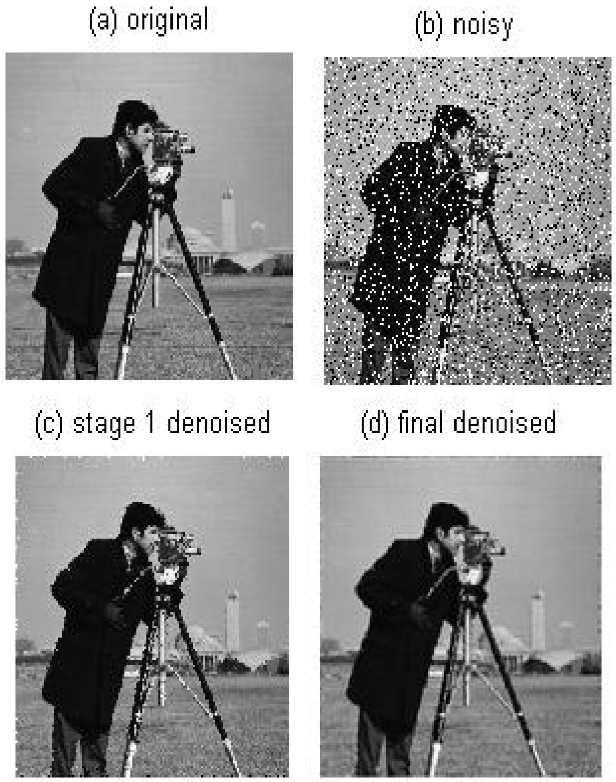

FIG. 2 DENOISING OF IMAGE WITH 20% NOISE

Table 3 shows the PSNR values of noisy image, median filtered (included for comparison of PSNR values with the proposed method), results of first stage and combined first first and second stages. Superior performance of the proposed method can be visualised. More than the improvement in PSNR, it is the improvement of the visual quality which is the attractive feature, for which the second stage is more responsible.

TABLE 3 PSNR VALUES

% Noise	Noisy Image	Median Filtered	Stage 1	Stage 1 & Stage 2
10	34.84	35.49	41.46	42.34
20	34.36	35.15	38.71	39.01
30	32.59	34.52	37.21	37.76
40	31.34	33.81	35.89	36.12
50	30.40	32.79	35.02	35.28

A noisy (10%) colour image is tested for validity of the proposed method. The RGB image is decomposed to Red, Green and Blue components. The first stage of denoising is applied to each of the three colour components and then the denoised components are concatenated to get the denoised output. The original, noisy and the denoised images are shown in Figure 3 (a), (b) and(c). It can be seen that whereas the noisy image has extremely low visual quality due to the noise, denoised image has no noise and has good visual quality. The PSNR improvement of the denoised image is about 2 dB. The second stage of denoising is applied to each of the three colour components obtained as the output of the first stage of denoising. The detailed sub bands of each color components are thresholded. ISWT is applied to get three denoised colour components. The three color components are concatenated to get the final denoised color image. It is shown in Figure 3(d). The overall PSNR improvement is about 6 dB. Experiment is repeated for colour image with higher noise of 20 % and results are shown in Figure 4.

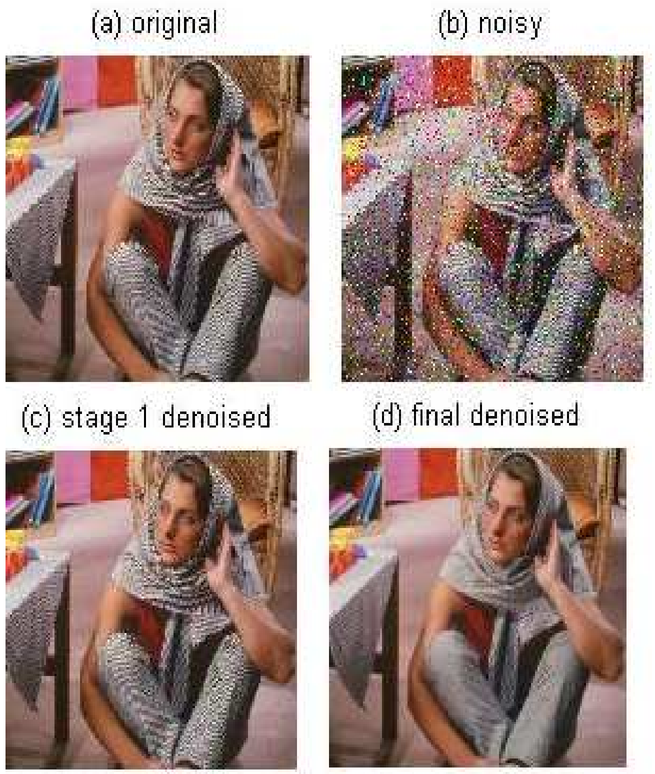

FIG. 3 DENOISING OF COLOUR IMAGE WITH 10% NOISE

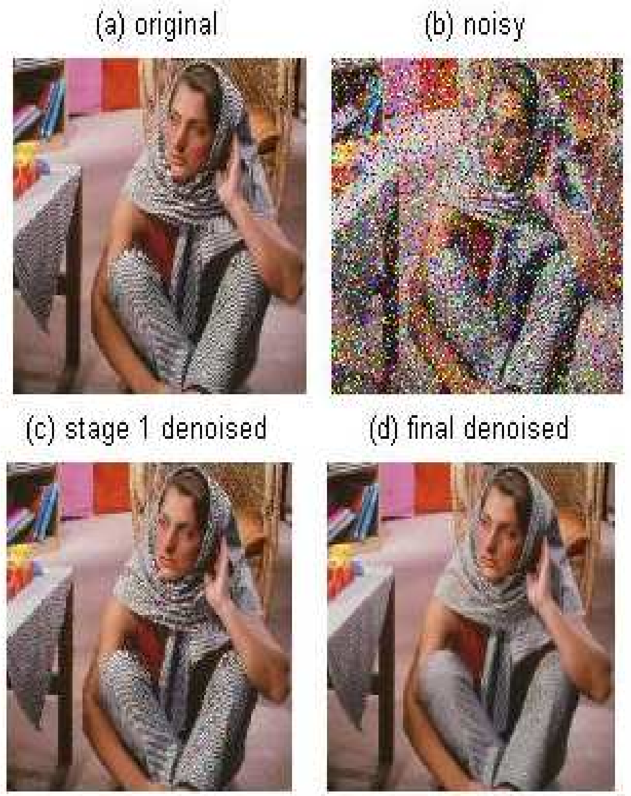

FIG. 4 DENOISING OF COLOUR IMAGE WITH 20% NOISE

For testing the performance of the proposed method in denoising mixed image, impulse noise and Gaussian noise are added to an image and denoising experiment is done on the noisy image. The noisy image and the denoised image are shown in Figure 5. Results show substantial reduction of both types of noises.

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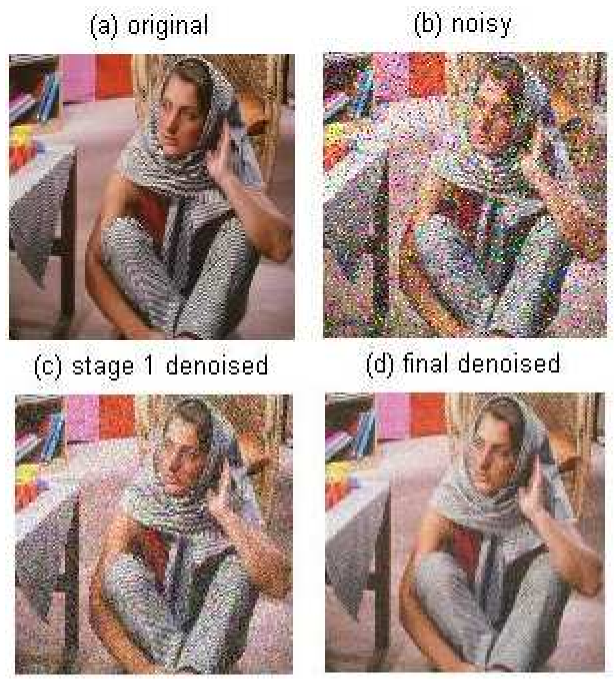

FIG. 5 DENOISING OF COLOUR IMAGE WITH MIXED NOISE

VII. CONCLUSION

A denoising method for the removal of impulse noise from grey as well as colour images is implemented. The method has two stages: a spatial technique as the first stage in which noisy pixels are replaced by non noisy neighbouring pixels and a second stage using a multiresolution technique namely SWT processing. Visual qualities of the denoised images are commendable. The PSNR values obtained are also good, compared to that obtained using the well known median filter. PSNR values suggest that the first stage of denoising provides better results in this respect. However looking at the visual quality of the results, the second stage is also equally effective in denoising. The colour image denoising gives superior results as seen in the Fig. 3 and 4.The method is also found to be useful for denoising mixed noise from images. Computational complexity of the proposed method is substantially lower compared to the existing methods. The technique can thus be effectively employed in denoising images in the field of biomedical science, remote sensing etc.

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