New Nonlinear Filtering Strategies for Eliminating Short and Long Tailed Noise in Images with Edge Preservation Properties

E. Srinivasan, and D. Ebenezer

Abstract—Midpoint filter is quite effective in recovering the images confounded by the short-tailed (uniform) noise. It, however, performs poorly in the presence of additive long-tailed (impulse) noise and it does not preserve the edge structures of the image signals. Median smoother discards outliers (impulses) effectively, but it fails to provide adequate smoothing for images corrupted with non-impulse noise. In this paper, two nonlinear techniques for image filtering, namely, New Filter I and New Filter II are proposed based on a nonlinear high-pass filter algorithm. New Filter I is constructed using a midpoint filter, a highpass filter and a combiner. It suppresses uniform noise quite well. New Filter II is configured using an alpha trimmed midpoint filter, a median smoother of window size 3x3, the high pass filter and the combiner. It is robust against impulse noise and attenuates uniform noise satisfactorily. Both the filters are shown to exhibit good response at the image boundaries (edges). The proposed filters are evaluated for their performance on a test image and the results obtained are included.

Keywords—Image filters, Midpoint filter, Nonlinear filters, Nonlinear highpass filter, Order-statistic filters, Rank-order filters.

I. INTRODUCTION

NOISE filtering is one of the most important tasks in image filtering. Further, it is to be noted that the human perception is heavily based on edge information. Therefore, the filters designed for image processing are required to yield sufficient noise reduction without losing the high frequency content of edges [1].

Midpoint smoother is a nonlinear point estimator based on order-statistics [2]. Indeed, it has been proven to be the optimal L-filter for smoothing the images contaminated with noise having uniform probability density function [3]. Midpoint filter, however, is not robust against impulse noise and fails to retain the image boundaries [4].

Median smoother, suggested by John Tukey in 1971, is an effective alternative to linear smoother for filtering signals having wide spectrum. It is a good candidate for discarding outliers and preserving the rapidly varying edges [5]. It, however, is found to be inadequate in enhancing the images corrupted with non-impulse noise [5]. Gallagher, Wise and Nodes have analysed the properties of median filters in detail [6,7].

Alpha-Trimmed Midpoint (ATMP) filter is recognised as a good compromise between the midpoint and median smoothers [8]. It is effective in suppressing uniform noise when the trimming parameter, α is close to zero, but destroys the image boundaries. When α is increased to 0.5, the ATMP filter operates as median smoother, which does not attenuate uniform noise sufficiently while preserving the edge structures satisfactorily

A variety of nonlinear filtering techniques have been reported in the literature for removal of noise in images [9-14].These filtering techniques are particularly suited for eliminating impulse noise; however, they are not expected to exhibit satisfactory performance in the presence of short-tailed uniform noise and multiple noise environment.

In this paper, two nonlinear image filtering schemes based on a nonlinear highpass filter algorithm [15] are described. The first filtering scheme - New Filter I, consists of a midpoint filter, a highpass filter and a combiner. Midpoint smoother suppresses uniform noise and the highpass filter preserves the image edges. New Filter I output is produced by the combiner using the midpoint, and highpass filter outputs. The second filtering scheme – New Filter II, is configured by an ATMP filter, a median smoother of window size 3x3, the highpass filter and the combiner. ATMP filter smoothes out both uniform and impulse noise. Highpass filter together with the median smoother detect and preserve the image edges. Combiner synthesizes New Filter II output using ATMP and highpass filter outputs. The proposed filters will be shown to be effective in filtering out the noise besides preserving the image edges intact.

II. FILTERING SCHEMES

A. New Filter I

The filtering scheme that removes uniform noise with edge preservation properties is shown in Fig.1. An image corrupted with uniform noise is the input to both the midpoint and highpass filters. Let the two-dimensional sequences {s} and {x}, respectively, represent the noise-free image and the uniform noise contaminated image of p rows and q columns.

$$x(i, j) = s(i, j) + n_u(i, j) \qquad (1)$$

where i = 1,2,…,p and j = 1,2,….,q and $n_u(i,j)$ is the (i,j)th sample of uniform noise sequence {n_u}.
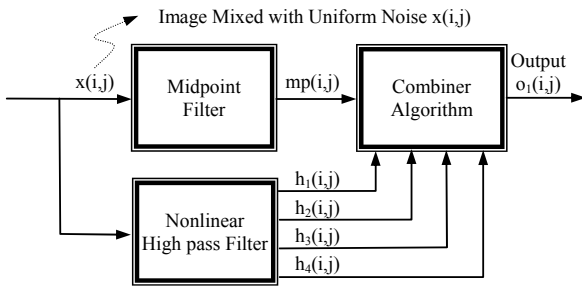

Fig. 1 New Filter I: A filtering scheme for suppressing uniform noise with edge preservation properties

Midpoint filtering is a nonlinear technique based on order-statistics. It slides a window of size (2N+1) x (2N+1) points (where N is an integer) over the noisy input image {x}. At each point, the samples inside the window are sorted out (arranged in ascending order) and the average of the smallest, and largest samples inside the window is used as the filter ouput. The filtering procedure is described as:

$$mp(i, j) = \frac{1}{2}\left(\min(x(i + r, j + s)) + \max(x(i + r, j + s))\right), \\ - N \le (r,s) \le N \qquad (2)$$

where mp(i,j) is the (i,j)th sample of the output sequence of the midpoint filter {mp}.

(i) Nonlinear Highpass Filter Algorithm

Nonlinear highpass filter algorithm described in [15] for 1-D signals is the one, which selects or discards the samples by comparing the absolute value of the difference in amplitude between two samples with a pre-selected threshold value. This algorithm is modified in this paper to detect and preserve horizontal, vertical, left diagonal and right diagonal edges of an image. The highpass filter algorithm separates the image edges by sliding a space-ordered window of size 3 x 3 over

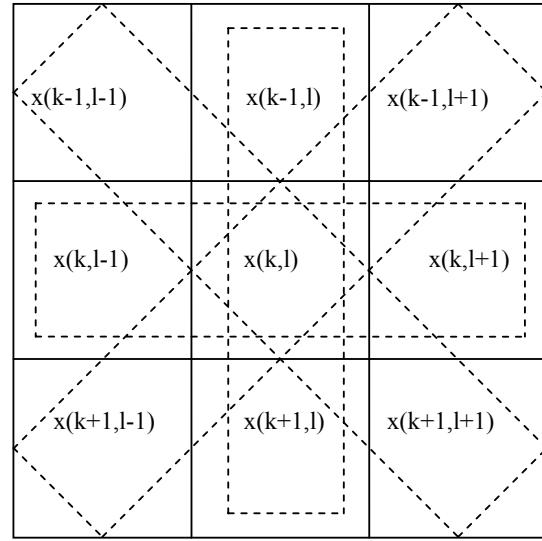the noisy input image {x}. The filter algorithm is explained using Fig. 2.

Fig. 2 Two-dimensional high-pass filtering for image edge separation using 3 x 3 space-ordered window

The centre sample x(k,l) is detected as a horizontal edge if

$$\begin{aligned}|x(k,l-1) - x(k,l)| \ge \Delta t \quad \text{or} \\ |x(k,l) - x(k,l+1)| \ge \Delta t\end{aligned} \qquad (3)$$

(Δt is the user defined threshold value) and is preserved in the (k,l)th location of a two-dimensional array {h_1}. Similarly, x(k,l) is recognized as vertical edge if

$$\begin{aligned}|x(k-1,l) - x(k,l)| \ge \Delta t \quad \text{or} \\ |x(k,l) - x(k+1,l)| \ge \Delta t\end{aligned} \qquad (4)$$

and is preserved in an array {h_2}; it is declared as a left diagonal edge if

$$\begin{aligned}|x(k-1,l-1) - x(k,l)| \ge \Delta t \quad \text{or} \\ |x(k,l) - x(k+1,l+1)| \ge \Delta t\end{aligned} \qquad (5)$$

and is preserved in an array {h_3} and if

$$\begin{aligned}|x(k-1,l+1) - x(k,l)| \ge \Delta t \quad \text{or} \\ |x(k,l) - x(k+1,l-1)| \ge \Delta t\end{aligned} \qquad (6)$$

then x(k,l) is a right diagonal edge and is preserved in {h_4}. If x(k,l) does not satisfy the criteria for an edge horizontally, vertically or diagonally, then it is declared a non-edge component and therefore, the (k,l)th location of {h_a}, a = 1,2,3

and 4 is stored with zero. Thus, the highpass filter detects, separates and preserves the image edges.

(ii)   Combiner Algorithm

Midpoint filter, while averaging the minimum and maximum valued samples to reduce the uniform noise, blurs the image edges and their neighbourhoods. The number of samples blurred about, and including an edge sample along any direction (horizontal, vertical or diagonal) are 2N+1, where (2N+1) x (2N+1) is the window size of the midpoint smoother. The combiner algorithm, appropriately, modifies the midpoint filter output by restoring the edges and their neighbourhoods that are smeared during the filtering (averaging) operation. First, the algorithm scans the array $\{h_1\}$. Whenever it comes across a non-zero element, it indicates that a horizontal edge is present at the corresponding sample of the input signal. Consequently, the combiner algorithm will remove 2N+1 horizontal samples about and including that edge sample from the noisy input sequence $\{x\}$ and replace the corresponding samples of the midpoint smoother output with the removed samples. This procedure is repeated for all non-zero values of $\{h_1\}$. Similarly, the combiner scans the arrays $\{h_2\}$, $\{h_3\}$ and $\{h_4\}$ in sequence. For every non-zero element of these arrays, the combiner performs the removal and replacement of 2N+1 samples in the same way as described above except that it is done along vertical, left diagonal and right diagonal directions respectively. Let $\{o_1\}$ denote the output sample sequence of New Filter I

$$o_1(k,l) =$$

$$\begin{cases} mp(i,j), k=i, l=j & if\ h_a(i,j)=0, a=1,2,3,4 \\ x(i,l), k=i, l=j-N+d, d=0,1,2,...,2N & if\ h_1(i,j) \neq 0 \\ x(k,j), k=i-N+d, l=j, d=0,1,2,.,2N & if\ h_2(i,j) \neq 0 \\ x(k,l), k=i-N+d, l=j-N+d, d=0,1,2,.,2N & if\ h_3(i,j) \neq 0 \\ x(k,l), k=i-N+d, l=j+N-d, d=0,1,2,.,2N & if\ h_4(i,j) \neq 0 \end{cases}$$

$$(7)$$

where i=1,2,…,p and j=1,2,…,q. The New filter I is as effective as the midpoint filter in attenuating uniform noise, while its edge preserving properties are found to be superior to that of latter. The edges and their neighbourhoods at the output of New Filter I are likely to be noisy, because they are the samples extracted from the noisy input image. However, it is to be noted that the human eye is more tolerant to noise in the neighbourhood of an edge than in the homogeneous regions.

B. New Filter II

The scheme of the filter capable of removing both uniform and impulse noise without blurring image boundaries is shown in Fig. 3. To corrupt the uniform noise contaminated image $\{x\}$ further with impulse noise, it is assumed that the positive impulses appear as white dots (s_{max}) with a probability of
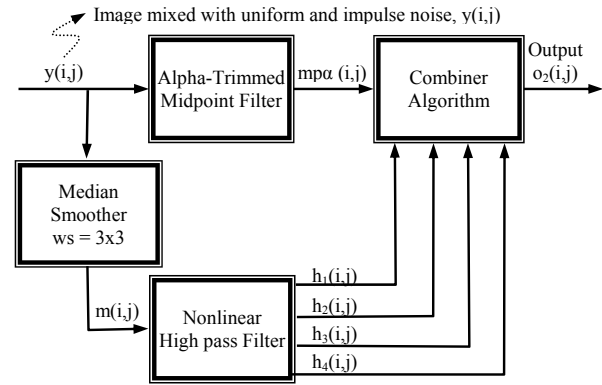

Fig. 3 New Filter II: A filtering scheme for eliminating uniform and impulse noise with edge preservation properties

occurrence p_p and the negative impulses appear as block dots

(s_{min}) with a probability p_n. This yields:

$$y(i,j) = \begin{cases} s_{min}\ with\ probability\ p_n \\ s_{max}\ with\ probability\ p_p \\ x(i,j)\ with\ probability\ 1-\{p_p+p_n\} \end{cases} \quad (8)$$

where i = 1, 2,..., p and j = 1, 2,..., q.

The Alpha-Trimmed Midpoint (ATMP) filtering is an effective order-statistic filtering strategy for discarding impulses and attenuating uniform noise [8]. In ATMP filtering, as the window (of size (2N+1) x (2N+1)) slides over $\{y\}$, the samples inside the window are sorted out at each point. Let $\{Z_{(b)}\}$, b=1,2,…, (2N+1) x (2N+1) denote the sequence of the ordered samples, i.e., arranged in the ascending order, inside the window at any point. Depending upon the value of the trimming parameter α, a few and equal number of data points are trimmed (removed) from both the ends (symmetric trimming) of the ordered sequence $\{Z_{(b)}\}$. The smallest and the largest of the remaining samples are averaged and the result is used as the filter output. The ATMP can be expressed as:

$$Z_\alpha = \frac{1}{2}\left(Z_{([\alpha(2N+1)(2N+1)]+1)} + Z_{((2N+1)(2N+1)-[\alpha(2N+1)(2N+1)])} \right) \quad (9)$$

where Z_α is ATMP of $\{Z_{(b)}\}$ and **[.]** is the greatest integer

function. In ATMP filtering, the trimming ensures the rejection of outliers while the midpoint of the remaining samples reduces the uniform noise. It is to be noted that when $\alpha = 0$, Z_α is the sample midpoint and it becomes the sample median when $\alpha = 0.5$ and therefore, it is recognized as a good compromise between the midpoint and median filters. Let $\{mp\alpha\}$ denote the sequence of ATMPs obtained on sliding the window over the entire noisy image sequence $\{y\}$.

The edge preserving part of New Filter II consists of a 3x3 square shaped median filter and a nonlinear highpass filter. Uniform plus impulse noise contaminated image $\{y\}$ is the input to the median smoother, which eliminates impulses while preserving the image boundaries. Two-dimensional median filtering with a 3x3 square window is defined as:

$$m(i, j) = median(y(i+r, j+s)), \ -1 \le (r, s) \le 1 \qquad (10)$$

where m(i,j) is the (i,j)th sample of the median filter output sequence $\{m\}$. The highpass filter, operating upon the median filtered image $\{m\}$, detects and separates the edges that are preserved at the output of the median filter. The combiner algorithm restores the edges and their neighbourhoods (damaged by averaging operation) of the alpha-trimmed midpoint filter output, using the outputs of the highpass and median filters in the same way as described in II.A.(ii). Thus, the combiner produces a new sequence of samples at the output of New Filter II, denoted as $\{o_2\}$.

$$o_2(k,l) =$$
$$\begin{cases} mp\alpha(i,j), k = i, l = j & \text{if } h_a(i,j) = 0, a = 1,2,3,4 \\ m(i,l), k = i, l = j - N + d, d = 0,1,2,...,2N & \text{if } h_1(i, j) \ne 0 \\ m(k,j), k = i - N + d, l = j, d = 0,1,2,..,2N & \text{if } h_2(i, j) \ne 0 \\ m(k,l), k = i - N + d, l = j - N + d, d = 0,1,2,..,2N & \text{if } h_3(i, j) \ne 0 \\ m(k,l), k = i - N + d, l = j + N - d, d = 0,1,2,..,2N & \text{if } h_4(i, j) \ne 0 \end{cases}$$
$$(11)$$

where i=1, 2,…,p and j=1, 2..., q. New Filter II is found to be robust against impulse noise and is able to suppress uniform noise sufficiently. In addition, the filter preserves edge structures quite satisfactorily.

III. RESULTS AND DISCUSSION

The proposed filters are applied to enhance the images corrupted by short and long tailed noise and are evaluated for their noise suppression and edge preservation properties. The test image used is the picture of Lena (256x256 pixels, 8 bits/pixel). Two sets of noisy images are generated for evaluating the described filtering schemes. New Filter I is

examined using images contaminated by uniform noise. These images are corrupted further with positive and negative impulses for analyzing the efficacy of New Filter II. The trimming parameter α for ATMP filter is chosen to be 0.25
For New Filter I

$$F_e = \frac{\sum_{i=1}^{256}\sum_{j=1}^{256}(s(i,j) - x(i,j))^2}{\sum_{i=1}^{256}\sum_{j=1}^{256}(s(i,j) - o_1(i,j))^2} \qquad (12)$$

and for New Filter II

$$F_e = \frac{\sum_{i=1}^{256}\sum_{j=1}^{256}(s(i,j) - y(i,j))^2}{\sum_{i=1}^{256}\sum_{j=1}^{256}(s(i,j) - o_2(i,j))^2} \qquad (13)$$

where $\{s\}$ denotes noise-free image, $\{x\}$ and $\{y\}$ are noisy images and $\{o_1\}$ and $\{o_2\}$ represent filtered images. Removal of noise, achieved as a result of filtering, reduces the mean square error after filtering (denominators of equations (12) and (13)). Therefore, a filter is said to perform well when it yields a higher image enhancement factor. In addition, noise-free, noisy and filtered images are presented for qualitative evaluation of the filters on the basis of subjective visual criterion.

The results of filtering of images corrupted by low and high level uniform noise, when passed through the midpoint filter and New Filter I with 5x5 square window, are summarized in Figs. 4 and 5.
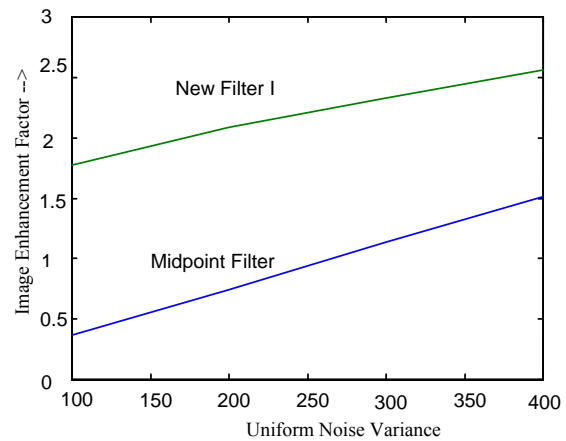

Fig. 5 Comparison of image enhancement factor between Midpoint filter and New Filter I with 5x5 square shaped windows at higher, and different levels of zero mean uniform noise

It can be seen that the image enhancement achieved using New Filter I is superior to that obtained using the midpoint filter, irrespective of the noise level. The efficacy of New

Filter I is further illustrated through a qualitative process. Fig. 6 presents the results of filtering the test image corrupted with uniform noise (mean=0 and variance=100) using New Filter I and conventional midpoint filter. Midpoint filtered image is shown in Fig. 6(c). Midpoint filter, as can be seen, suppresses uniform noise satisfactorily; but it fails to preserve the edge information and therefore, the image is not pleasant to view. The output of New Filter I is shown in Fig. 6(d). It can be observed that New Filter I attenuates uniform noise as effectively as the midpoint filter while preserving the image boundaries and fine details faithfully. The other filtered images are not presented because, they lead to a discussion similar to the one stated above.

The image enhancement factors obtained using conventional filters and New Filter II, in the presence of uniform and impulse noise, are depicted in Figs. 7 and 8. New Filter II is seen to outperform the conventional filters in enhancing the images. Fig. 9 presents the filtered images for subjective evaluation. The test image corrupted with uniform noise (mean=0 and variance=100) and mixed impulses having a probability of occurrence 5% is shown in Fig. 9(b). Median filtered image is shown in Fig. 9(c). Median smoother discards outliers completely, but it does not reduce uniform noise adequately; besides, it produces blurring due to loss of fine details. The loss of fine details is highly undesirable in image processing as it often contains important information. Fig. 9(d) depicts the performance of ATMP filter. The filter, as expected, eliminates impulses and is better than median smoother in removing uniform noise but it does not exhibit good behaviour at the image boundaries. The output of New Filter II is shown in Fig. 9(e). New Filter II is robust against impulse noise and suppresses uniform noise quite well; in addition it has good edge and fine detail preservation properties.
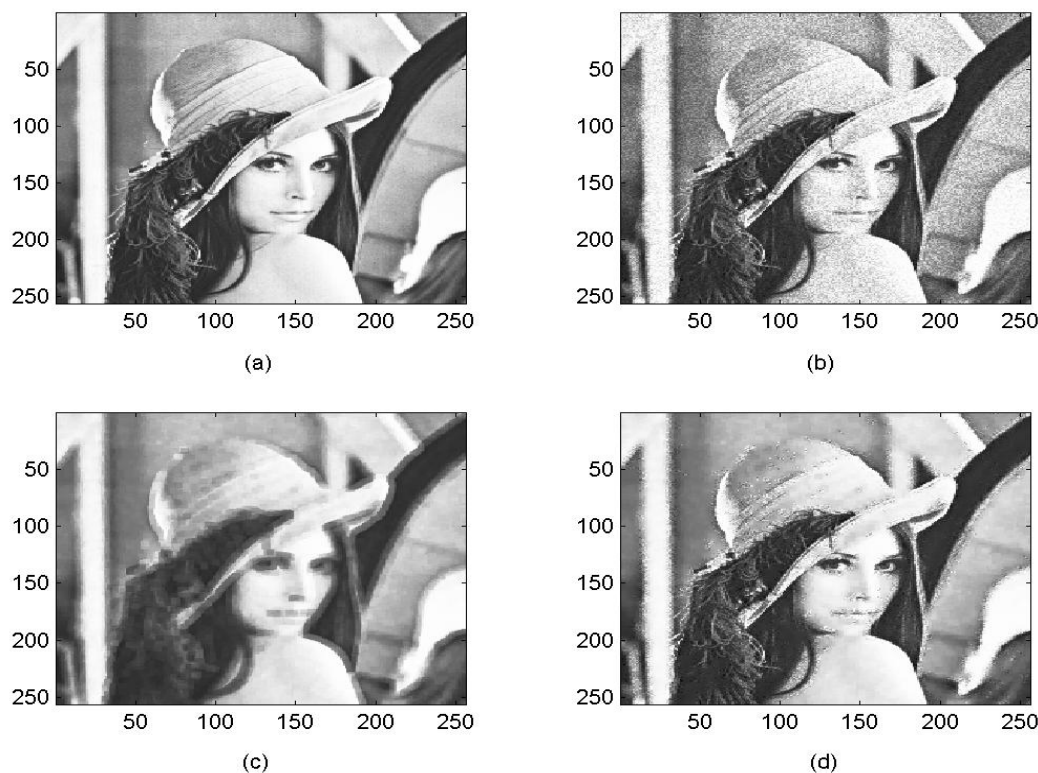

Fig. 6 Performance illustration of New Filter I and Midpoint filter with 5x5 square shaped windows: (a) Test image Lena; (b) Test image   corrupted with zero mean uniform noise of variance 100; (c) Midpoint filtered image; (d) New Filter I output
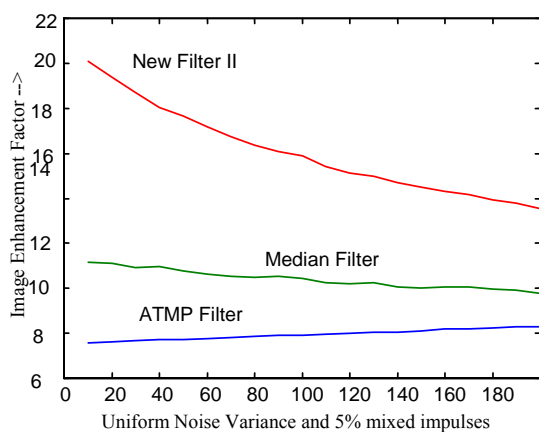
Fig.7 Comparison of image enhancement factor between conventional filters and New Filter II with 5x5 square shaped windows, then applied on test image contaminated with 5% mixed impulses and different levels of zero mean uniform noise
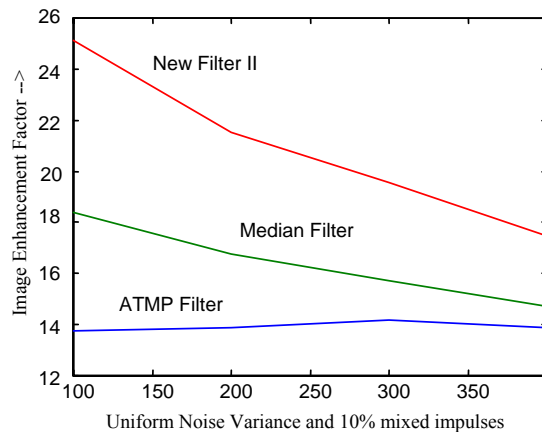
Fig. 8 Comparison of image enhancement factor between conventional filters and New Filter II with 5x5 square shaped windows, when applied on test image contaminated with 10% mixed impulses and higher levels of zero mean uniform noise
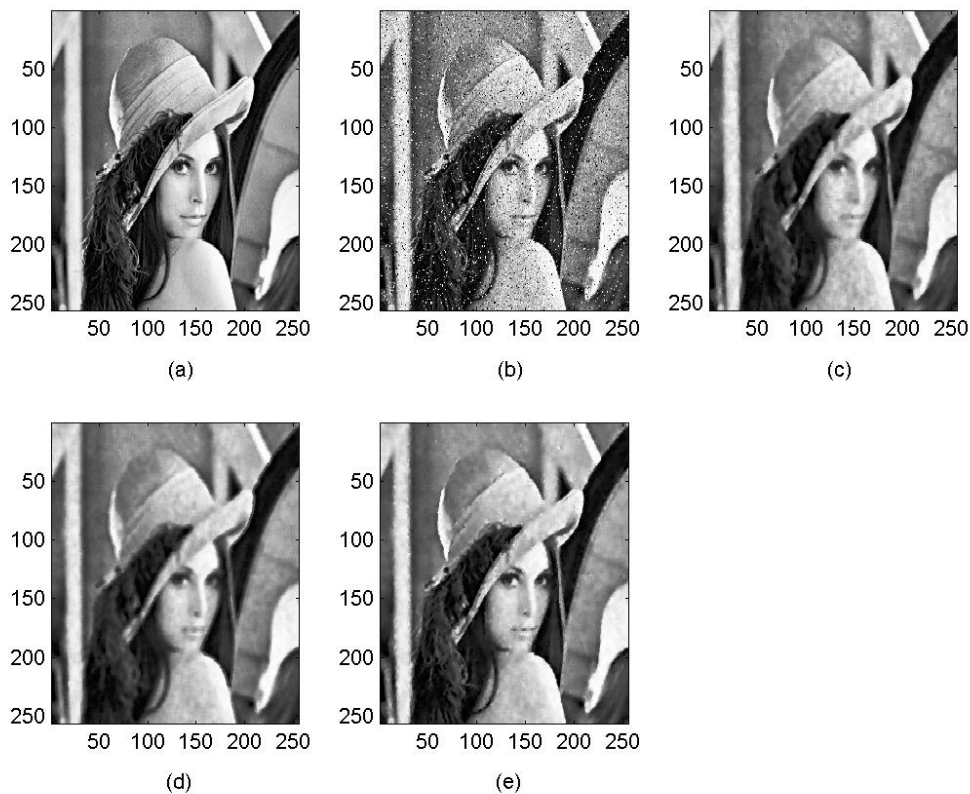

Fig. 9 Performance illustration of New Filter II and conventional filters with 5x5 square shaped windows: (a) Test image Lena; (b) Test image corrupted with 5% mixed impulses and zero mean uniform noise of variance 100; (c) Median filtered image; (d) ATMP filtered image; (e) New Filter II output

IV. Conclusion

Two new nonlinear filtering strategies, useful for image enhancement, are described in this paper. New Filter I is noted to be effective in suppressing noise having uniform probability density function. New filter II is robust against impulse noise besides attenuating uniform noise adequately. The proposed filters have good edge preservation properties and are shown to perform better than conventional filtering techniques, both objectively and subjectively.

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