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An Efficient Weighted Median Filter for the Restoration of Images Corrupted by Random Valued Impulse Noise

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***Abstract*: The paper proposes a new adaptive weighted median filter for the restoration of impule corrupted digital images by incorporating the limitations posed by Directional Weighted Median Filter (DWMF [4] and the algorithm proposed by Justin et. al [20]-[21]. The algorithm incorporates sixteen directions to identify the presence of edges and to preserve these detected edges while restoring images. The proposed filter uses an adaptive iterative median filter to replace the impulses. The experimental results shows that the proposed filter works better than other competitive filters and is capable of preserving edges.**

***Keywords*:** Median Filter, Adaptive Filter, Impulse Noise, Image Restoration.

I. Introduction

Digital Images are corrupted with impulse noise when they are transmitted through faulty radio channels [1]. In Digital Image Processing, Image Restoration involves the reconstruction or recovery of the original image from the degraded image with a priori knowledge of the degradation phenomenon [2]. So to reconstruct impulse corrupted digital images, the knowledge of impulse noise model, its statistics is essential to frame the restoration algorithms suitably. Impulsive noise affects only a portion of image pixels while leaving other pixels unchanged. The impulses affecting digital images are broadly classified in to Salt & Pepper and random valued impulsive noises [3] – [9]. The first and the most widely used order statistic non-linear filter is the simple Median Filter proposed by Tukey in 1971 [10]-[12] which produce the median of the samples within the window as the restoration value. The Median filter [1] though provides good noise suppression but produces high proficiency output; it uniformly replaces the gray values of all pixels in the image by the median of respective pixels from a prefixed static neighborhood. The Weighted order statistics Filter introduced by Brownrigg [13]-[14] incorporates both spatial and rank-ordered information by weighing the input samples based on a signal restoration criteria and then employing a selection operation based on their rank order. To preserve the signal content in the restored image, the Center Weighted Median Filter [15] weighs only the signal under consideration. But at higher impulse noise ratios when the pixel under consideration is corrupted, the output will be an impulse rather than a true signal due to the additional weight given to the pixel under consideration. A number of other filters like SD-ROM Filter [16], ACWM Filter [17], PWMAD [18] etc. evolved in the literature by involving different switching schemes while performing filtering operations.

The tri-state median filter [19] and the multi-state median filter (MSMF) [9] though can provide ample restoration at lower quantum of impulse noise but failed in cases where image go highly corrupted. The similarity information among pixels are exploited by the conditional signal-adaptive median (CSAM) filter [3], but it lose it’s validity while dealing highly corrupted images. Stefan Schulte et. al. [7] used fuzzy inference rules while detecting impulses, but provided distortions in the edges of restored outputs. The mean and variance are used by Adaptive Switching Median Filter (ASMF) [6] to identify the similarity among pixels. Pinar Civicioglu [8] used Triangle-based Linear Interpolation to identify impulses but the approach is computationally complex due to numerous iterations. Though these detection and switching based filtering approaches address some aspects of image filtering but failed in other vital aspect of image filtering.

Yiqiu Dong et. al. [4] proposed Directional Weighted Median Filter (DWMF) by incorporating directional weights to detect impulses. But the algorithm did not provide much better restoration due to the absence of considering more directions. Also it used all pixels in the restoration window irrespective of the corruption status to restore impulses. The filter proposed by Justin et. al [20] - [21] makes use of difference of the current pixel with its neighboring pixels aligned in 12 directions in the impulse detection phase. After detection of impulsive noise, it takes only the uncorrupted pixels of the 12 directions and is weighted suitably while determining the median in order to preserve image details while removing impulse noise.

In this paper, we propose a new adaptive weighed median filter which incorporates 16 directions. The paper is organized in IV sections. Section II describes the algorithm of the proposed impulse restoration filter. Experimental results and simulation analysis are presented in Section III. Conclusions are made finally in Section IV.

image at position *(i, j)* at iteration *it* whereas $y^{it}_{i,j}$ denotes the pixel value of the output image at position *(i, j)* at iteration *it*.

A binary flag image f^0 of size M x N same as that of the input image x^0 to be filtered is created in order to maintain the corruption status of the pixels identified in the impulse detection stage of the algorithm. $f^0_{i,j}$ denotes the flag value at position *(i, j)* for the first iteration.

w^1

-1	0	0	0	0
0	-2	0	0	0
0	0	6	0	0
0	0	0	-2	0
0	0	0	0	-1

w^2

0	0	-1	0	0
0	0	-2	0	0
0	0	6	0	0
0	0	-2	0	0
0	0	-1	0	0

w^3

0	0	0	0	-1
0	0	0	-2	0
0	0	6	0	0
0	-2	0	0	0
-1	0	0	0	0

w^4

0	0	0	0	0
0	0	0	0	0
-1	-2	6	-2	-1
0	0	0	0	0
0	0	0	0	0

w^5

0	-1	0	0	0
0	-2	0	0	0
0	0	6	0	0
0	0	0	-2	0
0	0	0	-1	0

w^6

0	0	0	0	0
-1	-2	0	0	0
0	0	6	0	0
0	0	0	-2	-1
0	0	0	0	0

w^7

0	-1	0	0	0
0	0	-2	0	0
0	0	6	0	0
0	0	-2	0	0
0	0	0	-1	0

w^8

0	0	0	-1	0
0	0	-2	0	0
0	0	6	0	0
0	0	-2	0	0
0	-1	0	0	0

w^9

0	0	0	0	0
0	0	0	-2	-1
0	0	6	0	0
-1	-2	0	0	0
0	0	0	0	0

w^{10}

0	0	0	-1	0
0	0	0	-2	0
0	0	6	0	0
0	-2	0	0	0
0	-1	0	0	0

w^{11}

0	0	0	0	0
-1	0	0	0	0
0	-2	6	-2	0
0	0	0	0	-1
0	0	0	0	0

w^{12}

0	0	0	0	0
0	0	0	0	-1
0	-2	6	-2	0
-1	0	0	0	0
0	0	0	0	0

w^{13}

-1	0	0	0	-1
0	-2	0	-2	0
0	0	6	0	0
0	0	0	0	0
0	0	0	0	0

w^{14}

0	0	0	0	0
0	0	0	0	0
0	0	6	0	0
0	-2	0	-2	0
-1	0	0	0	-1

w^{15}

-1	0	0	0	0
0	-2	0	0	0
0	0	6	0	0
0	-2	0	0	0
-1	0	0	0	0

w^{16}

0	0	0	0	-1
0	0	0	-2	0
0	0	6	0	0
0	0	0	-2	0
0	0	0	0	-1

Figure 1. Directional Masks for Convolution

II. Proposed Algorithm

The Algorithm proposed in this paper filter addresses the limitations of DWMF and the algorithms proposed by us as our previous publications [20] – [21]. Unlike our previous algorithms, the proposed algorithm considers 16 directions to identify and preserve edges and these 16 directions are with it's mask value is shown in Figure. 1. We use $x^0_{i,j}$, $x^1_{i,j} \ldots x^{it}_{i,j}$ .. $x^n_{i,j}$ and $y^0_{i,j}$, $y^1_{i,j} \ldots y^{it}_{i,j}$ .. $y^n_{i,j}$ to represent the input and output images of the proposed algorithm in different iterations starting from '0'. The $x^{it}_{i,j}$ denotes the pixel value of the input

We set $f_{i,j} = 0$ when the pixel value at spatial position *(i, j)* is identified as an impulse and $f_{i,j} = 1$ when the pixel value at *i* is non-impulsive. Initially the flag image, *f* is set to '*0'* at all its spatial locations assuming that all the pixels of the image, *x* are corrupted. The algorithm of the proposed filter can be tracked through the following steps.

Step1: The larger values in the convoluted input image with all the directional masks indicate the presence of impulsive nature where as lesser value in any of the directions indicates the presence of edges in that direction.

We find the convoluted image from the give input image in all 16 directions as

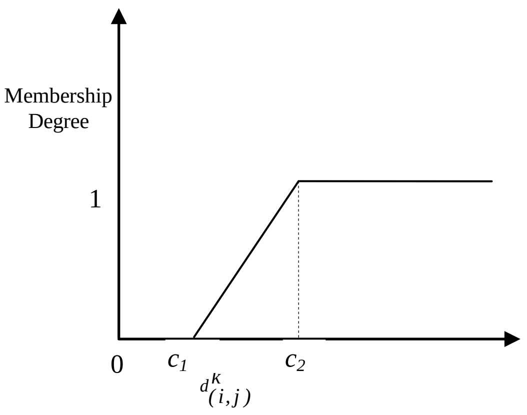

Figure 2. Membership functions for LARGE

$$d^k = \left| x \otimes w^k \right| \quad for\ all\ k=1\ to\ 16 \qquad (1)$$

where w^k is the directional mask in k^{th} direction as shown in Figure. 1. Once the convolution of the input image with that of the directional masks are done, the following observations can be done as in [4] as

Case 1) for any pixel at position *(i, j),* if all the convoluted values are larger, then it is declared as impulse since it's correlation between all the other pixels in the neighborhood defined by the directional masks are very less.

Case 2) For any pixel at position *(i, j),* if all convoluted values are lesser, then it is declared as uncorrupted pixel from a smooth area since it's correlation between all the other pixels in the neighborhood defined by the directional masks are very less.

Case 3) For any pixel at position *(i, j),* if at least one convoluted value is lesser, then it is declared as uncorrupted pixel belongs to an edge area since it's correlation between all the other pixels in the edge defined by the directional masks are very less.

Step2: We fuzzify the amount of corruption of each $d_{i,j}^k$ at position (i, j) and the flag value, $f_{i,j}^{it+1}$ at iteration $it+1$ is found accordingly as

$$f_{i,j}^{it+1} = SMALL\left(\left\{d_{i,j}^k \ / \ k=1\ to\ 16\right\}\right) \qquad (2)$$

The SMALL function is defined in Figure. 2.

Step3: We find the direction r which provides the minimum $d_{i,j}^k$ for the better restoration of corrupted pixels as

$$r = arg \min_k \left\{d_{i,j}^k \ / \ k=1\ to\ 16\right\} \qquad (3)$$

Step4: The restoration output at position *(i, j)* is found with the knowledge of the direction of edge and the corruption status of pixels in flag image f^{it} as

$$y_{i,j}^{it} = x_{i,j}^{it} \times f_{i,j}^{it+1} + O_{i,j}^{it} \times (1 - f_{i,j}^{it+1}) \qquad (4)$$

where

$$O_{i,j}^{it} = Median\left(\left\{wt_{s,t} \lozenge x_{i+s,j+t}^{it} \ / \ -1 \le s \le 1\ and\ -1 \le t \le 1\right\}\right) \qquad (5)$$

here ◊ is the repetition operator.

$$wt_{s,t} = \begin{cases} 0 & if\ f_{i,j}^{it+1}=1 \\ \left|w_{3+s,3+t}^r\right| & if\ w_{3+s,3+t}^r \ne 0\ and\ f_{i,j}^{it+1}=0 \\ 1 & Otherwise \end{cases} \qquad (6)$$

Step 5: Move to next pixel for processing and repeat from Step:1 through Step:4.

Step 6: After processing all pixels of the image, the iteration is continued from step 1for a prefixed maximum number of iterations T after setting $x^{it} = y^{it}$.

The algorithm incorporates 16 directions while detecting and restoring impulses. The chances of wrongly detecting impulses as uncorrupted pixels and vice versa are much reduced due to the consideration of 16 directions. And it provides better restoration than other filters mentioned in the literature survey as it takes only non impulsive pixels while restoring corrupted pixels. We use c_1, c_2 as 20 and 35 respectively for experimental purposes.

III. Experimental Results

The algorithm proposed in this paper is tested with different standard greyscale images of 512x512 size including Lena, Boats, Bridge and Peppers. The comparative filters used in the experiments are Simple median Filter (SMF), Adaptive impulse detection filter (AIDMF), Directional Weighted Median Filter (DWMF), conditional signal-adaptive median (CSAM) filter, Fei Duan et. al filter [5] Justin et. al filter1 [20] and Justin et. al filter2 [21]. Computer simulations in Matlab 10 were carried out to assess the subjective and objective performance of the proposed filter. The Objective analysis of the restored outputs of different filters is made with Peak Signal to Noise Ratio (PSNR) and Mean Absolute Error (MAE) metrics. The PSNR of the restored image with that of the original uncorrupted image is

$$PSNR = 10 \log_{10}\left(\frac{(255)^2}{MSE}\right) (dB) \qquad (8)$$

Here the Mean Square Error (MSE) is determined by the formula

$$MSE = \frac{1}{M \times N} \sum_{i_1=1}^{M} \sum_{i_2=1}^{N} \left| y(i_1, i_2) - a(i_1, i_2) \right|^2 \qquad (9)$$

The Mean Absolute Error (MAE) is determined by the formula

$$MAE = \frac{1}{M \times N} \sum_{i_1=1}^{M} \sum_{i_2=1}^{N} \left| y(i_1, i_2) - a(i_1, i_2) \right| \qquad (10)$$

The PSNR values of restored outputs of different algorithms of Lena and Boat images are respectively shown in Table 1 and Table 3. The better PSNR values of the restored outputs of the proposed algorithm demarcate the extended detail preservation capability of the proposed algorithm over the other algorithms. Table 2 and Table 4 provide the MAE values obtained from Lena and Boat images. The subjective analysis on Lena, Boats and peppers are respectively made in Figure.3, Figure.4 and Figure.5 clearly demonstrates the improved performance of the proposed filter. The subjective comparisons of the proposed algorithm over our previously published algorithms are made in Figure 6.

We used percentage of not detected edges, ξ_1 and percentage of wrongly detected, ξ_2 to analyze the edge preservation capability of the proposed filter over other filters. The percentage of not detected edges ξ_1 is the percentage of edges present in the edge image of the impulse-free image but not present in the edge image of the impulse filter's output.

filters. The name of the impulse corrupted image, impulse noise ratio and the type of salt & pepper impulse corruption (Salt & pepper or extreme range) are mentioned in the corresponding figure name. The green label denotes original edge pixel positions, red label undetected edge pixel positions and blue label denotes wrongly detected edge pixel positions. It is very clear that the images produced by the proposed filter maintain the image features when compared to other filters.

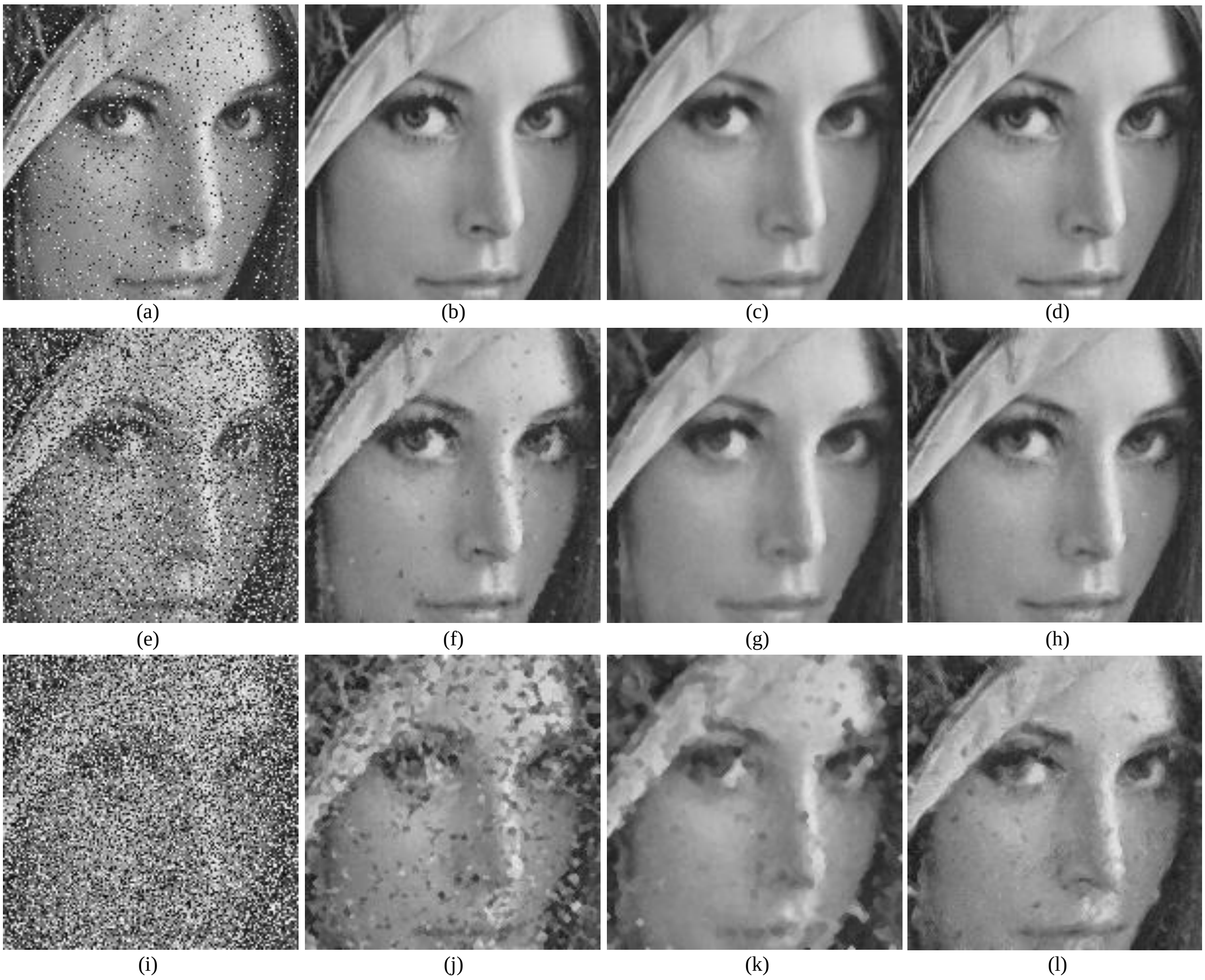

Figure 3. Outputs of AIDF, DWMF and the Proposed Filter of Lena image respectively from the 2nd column against varied random valued impulse levels ((a) 10%, (e) 40%, (i) 70%)

The percentage of wrongly detected edges, ξ_2 is the percentage of edges that are present in the edge image of the restored output but are not present in the edge image of the impulse-free image. We used Canny edge detection method to find the edges of original noise free image and restored image. The Table 5 and Table 6 respectively shows ξ_1 and ξ_2 produced by filters for Lena and Boats at different noise levels.

The impulse detection / correction characteristics of filtering algorithms used in the comparative study are prone to wrongly identify impulsive pixels as edges and vice-versa. So the concern of the proposed detail preserving filter to retain only true edge pixels is demonstrated through Figure. 7 and Figure. 8 which contains Canny's Edge images with the labels of original, undetected and wrongly detected edge positions obtained from the restored outputs produced by different

Here Figure. 7 and Figure. 8 respectively show the edge images produced by Lena and Boats. It is noted that the red pixels represents the edges present in the uncorrupted image but are not present in reconstructed image and the blue pixels represents the edges not present in the uncorrupted image but are present in reconstructed image while green color represents the edges present in both uncorrupted and reconstructed image.

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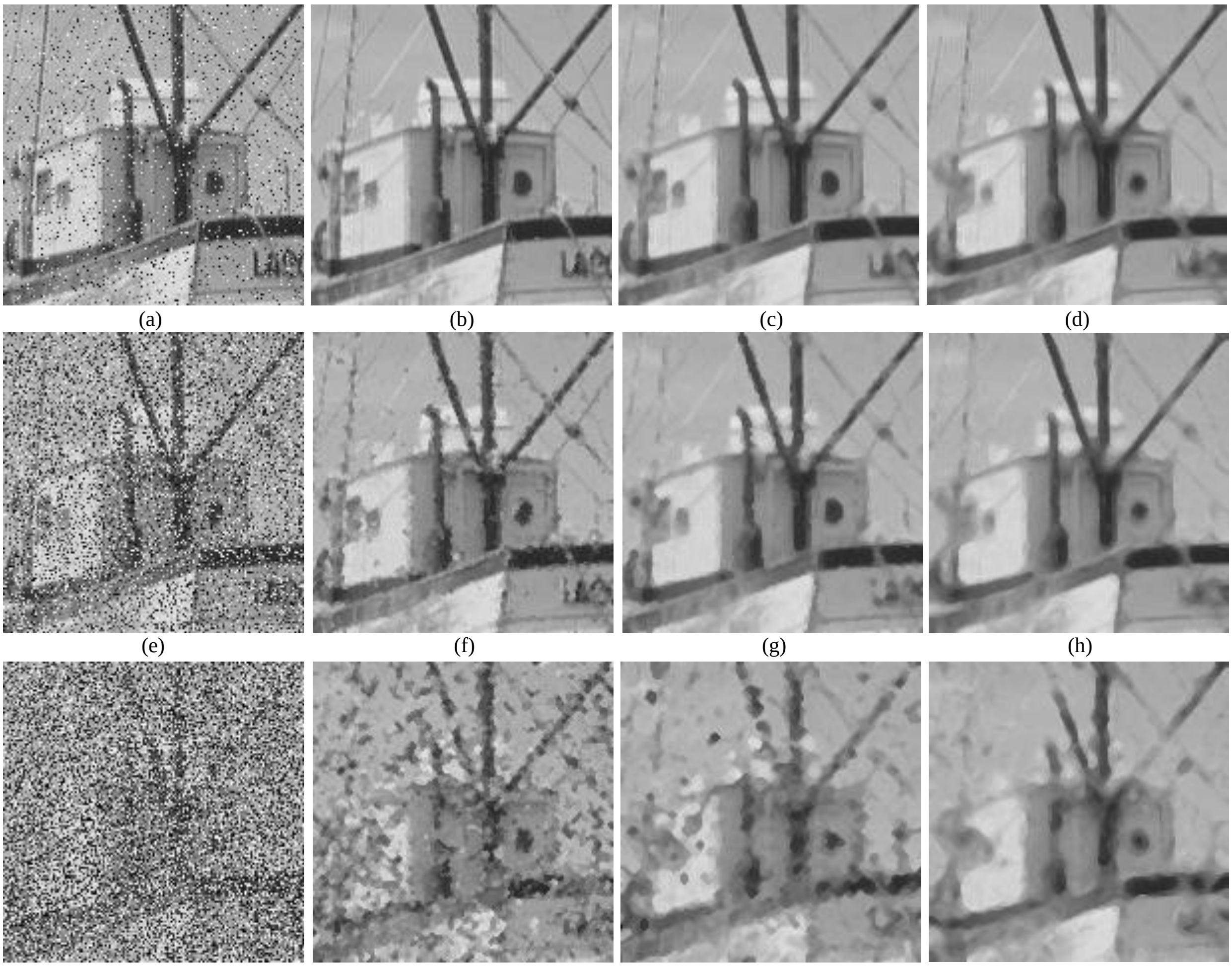

Figure 4. Outputs of AIDF, DWMF and the Proposed Filter of Boat image respectively from the 2nd column against varied random valued impulse levels ((a) 10%, (f) 40%, (k) 70%)

Table 1. PSNR of Lena image produced by filters at different noise levels

Filters	Noise Ratio			
	10%	40%	50%	70%
SMF	33.96	31.50	29.26	27.89
CSAMF	32.43	30.52	29.13	27.78
Fei Duan	33.82	30.37	26.57	23.09
DWMF	36.90	34.60	32.55	30.95
AIDMF	37.47	34.15	31.86	29.12
Justin et.al 1	38.54	35.04	33.49	31.87
Justin et.al 2	38.84	35.24	33.62	31.93
Proposed Algorithm	39.45	36.51	34.47	32.13

Table 2. MAE of Lena image produced by filters at different noise levels

Filters	Noise Ratio			
	10%	40%	50%	70%
SMF	2.78	3.43	4.90	5.72
CSAMF	1.20	2.08	3.05	4.23
Fei Duan	2.57	3.45	4.96	7.68
DWMF	0.71	1.32	2.02	2.81
AIDMF	0.64	1.32	2.12	3.34
Justin et.al 1	0.63	1.17	1.80	2.38
Justin et.al 2	0.61	1.14	1.77	2.31
Proposed Algorithm	0.54	1.02	1.61	2.12

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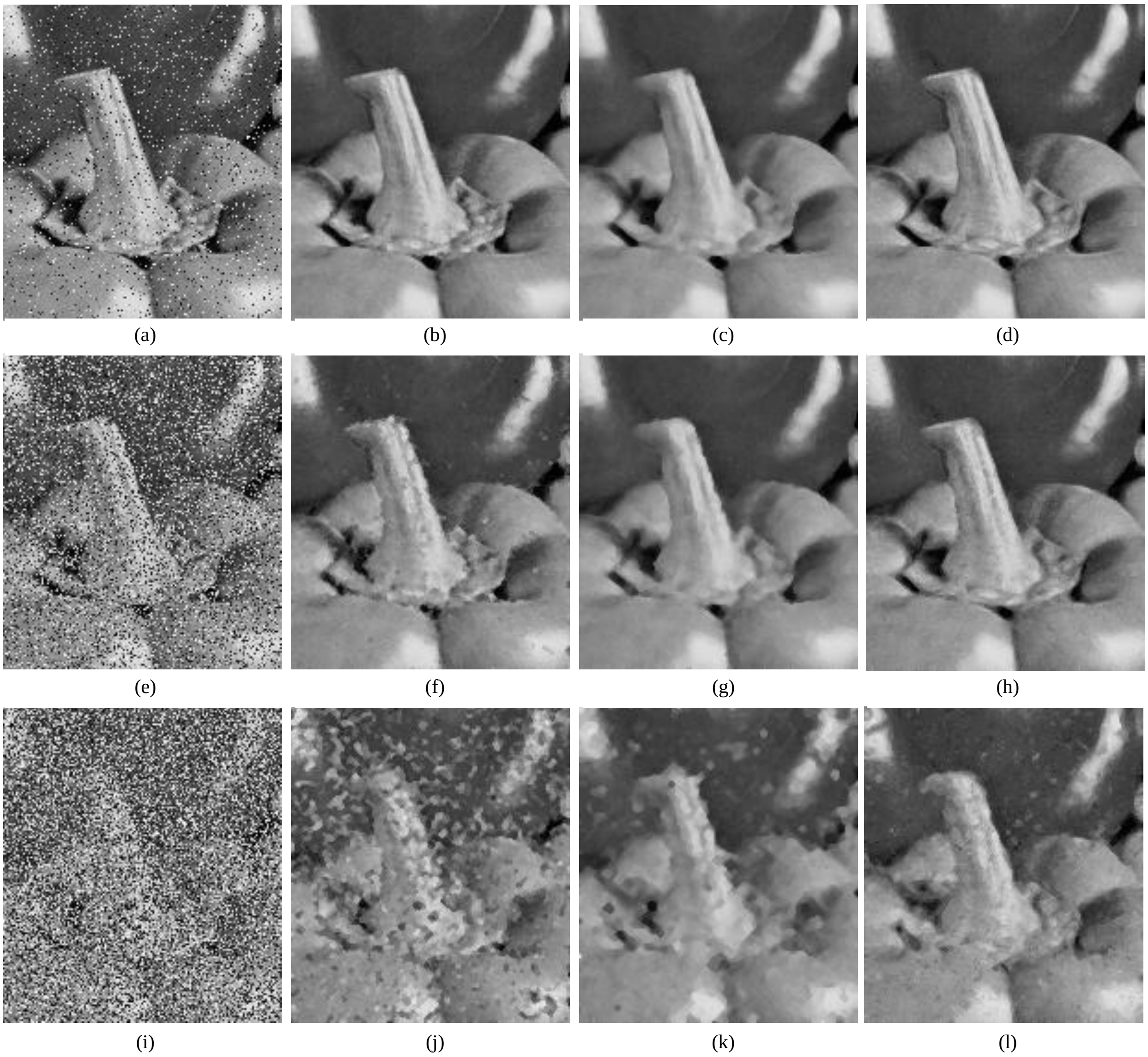

Figure 5. Outputs of AIDF, DWMF and the Proposed Filter of Peppers image respectively from the 2nd column against varied random valued impulse levels ((a) 10%, (f) 40%, (k) 70%)

Table 3. PSNR of Boat image produced by filters at different noise levels

Filters	Noise Ratio			
	10%	40%	50%	70%
SMF	30.97	29.20	26.62	25.66
CSAMF	28.75	27.25	25.99	24.97
Fei Duan	31.13	28.58	25.16	22.19
DWMF	34.07	31.45	29.69	28.25
AIDMF	33.84	31.10	29.09	27.09
Justin et.al 1	35.58	32.03	31.37	29.03
Justin et.al 2	35.61	32.21	31.39	29.25
Proposed Algorithm	36.38	33.71	32.33	30.51

Table 4. MAE of Boat image produced by filters at different noise levels

Filters	Noise Ratio			
	10%	40%	50%	70%
SMF	3.73	4.43	6.53	7.43
CSAMF	2.44	3.71	5.09	6.50
Fei Duan	3.42	4.37	6.22	9.12
DWMF	1.00	1.89	2.85	3.94
AIDMF	1.02	1.98	3.05	4.47
Justin et.al 1	0.95	1.67	2.42	3.14
Justin et.al 2	0.91	1.62	2.22	3.01
Proposed Algorithm	0.83	1.51	2.01	2.89

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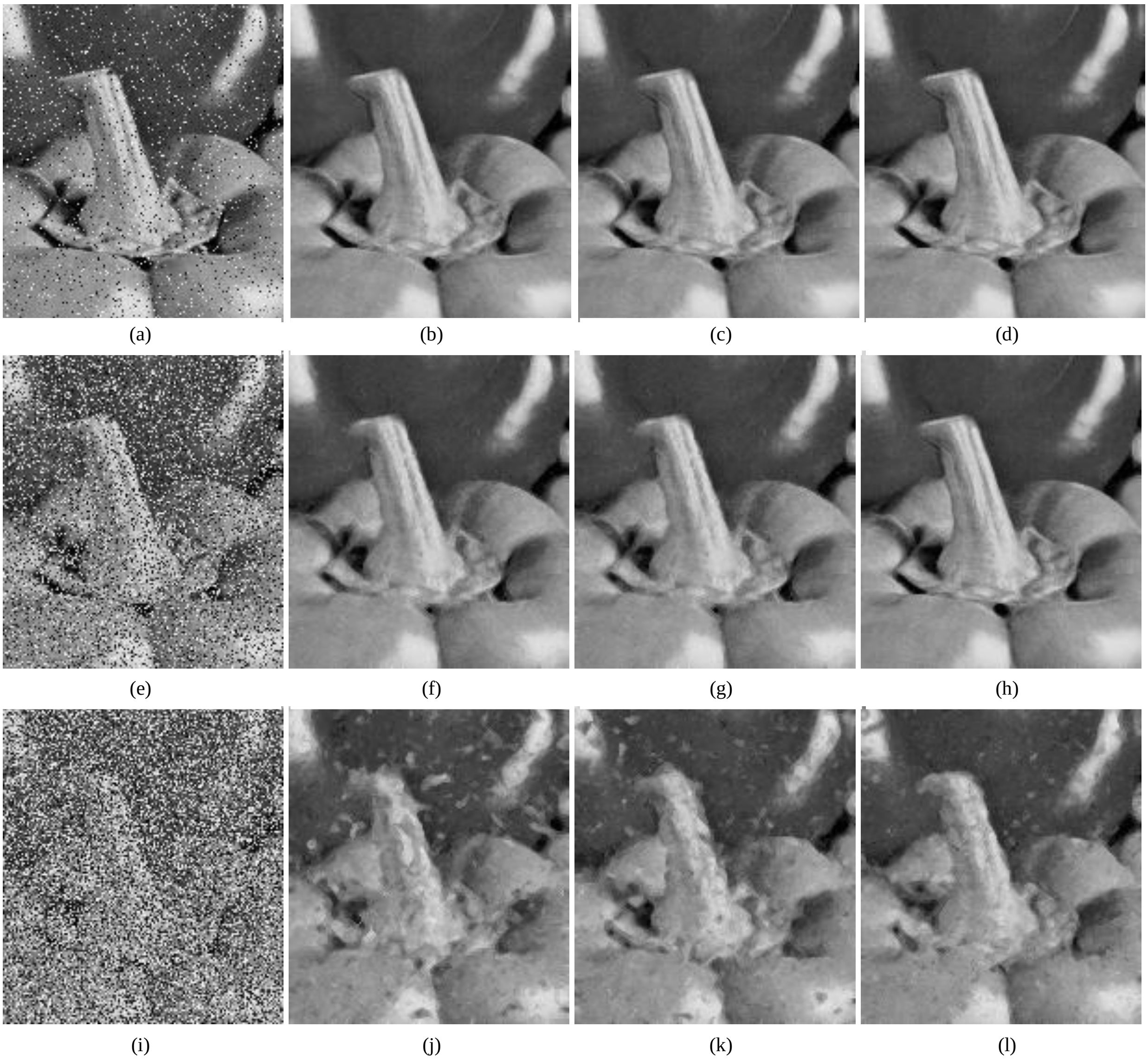

Figure 6. Outputs of Justin et. al. Filter 1, Justin et. al. Filter 2 and the Proposed Filter of Peppers image respectively from the 2nd column against varied random valued impulse levels ((a)10%,(f)40%, (k) 70%)

Table 5. ξ_1 and ξ_2 produced by filters for Lena image at different noise levels

Filters	Noise Ratio					
	10%		40%		70%	
	ξ_1	ξ_2	ξ_1	ξ_2	ξ_1	ξ_2
DWMF	4.1	2.7	5.5	2.8	6.7	4.9
AIDMF	1.9	1.9	4.7	4.6	7.7	12.3
Justin et.al 1	2.2	2.1	4.9	2.8	6.9	5.0
Justin et.al 2	2.1	1.9	4.8	2.7	6.8	4.9
Proposed Algorithm	1.9	1.7	4.6	2.6	6.6	4.8

Table 6. ξ_1 and ξ_2 produced by filters for Boats image at different noise levels

Filters	Noise Ratio					
	10%		40%		70%	
	ξ_1	ξ_2	ξ_1	ξ_2	ξ_1	ξ_2
DWMF	2.4	1.5	3.8	2.9	6.3	7.1
AIDMF	1.7	1.2	3.8	4.1	6.6	12.7
Justin et.al 1	1.8	1.3	3.8	2.8	6.5	5.9
Justin et.al 2	1.7	1.1	3.7	2.8	6.4	5.6
Proposed Algorithm	1.7	1.1	3.6	2.7	6.3	5.5

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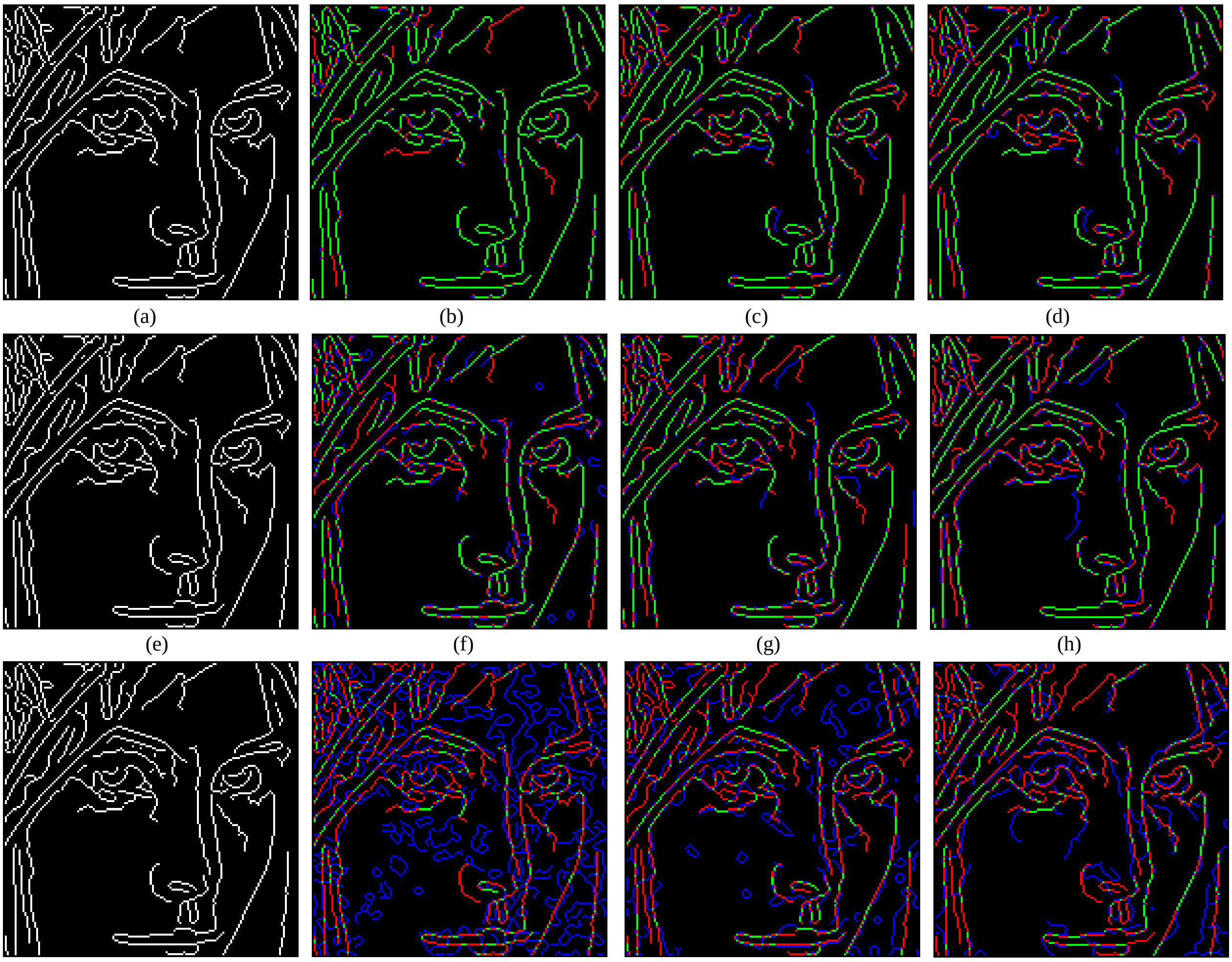

Figure. 7. Canny's Edge images with original, undetected and wrongly detected edge positions from restored outputs of AIDF, DWMF and the Proposed Filter of Lena image respectively from the 2nd column against varied random valued impulse levels ((a) 10%, (f) 40%, (k) 70%)

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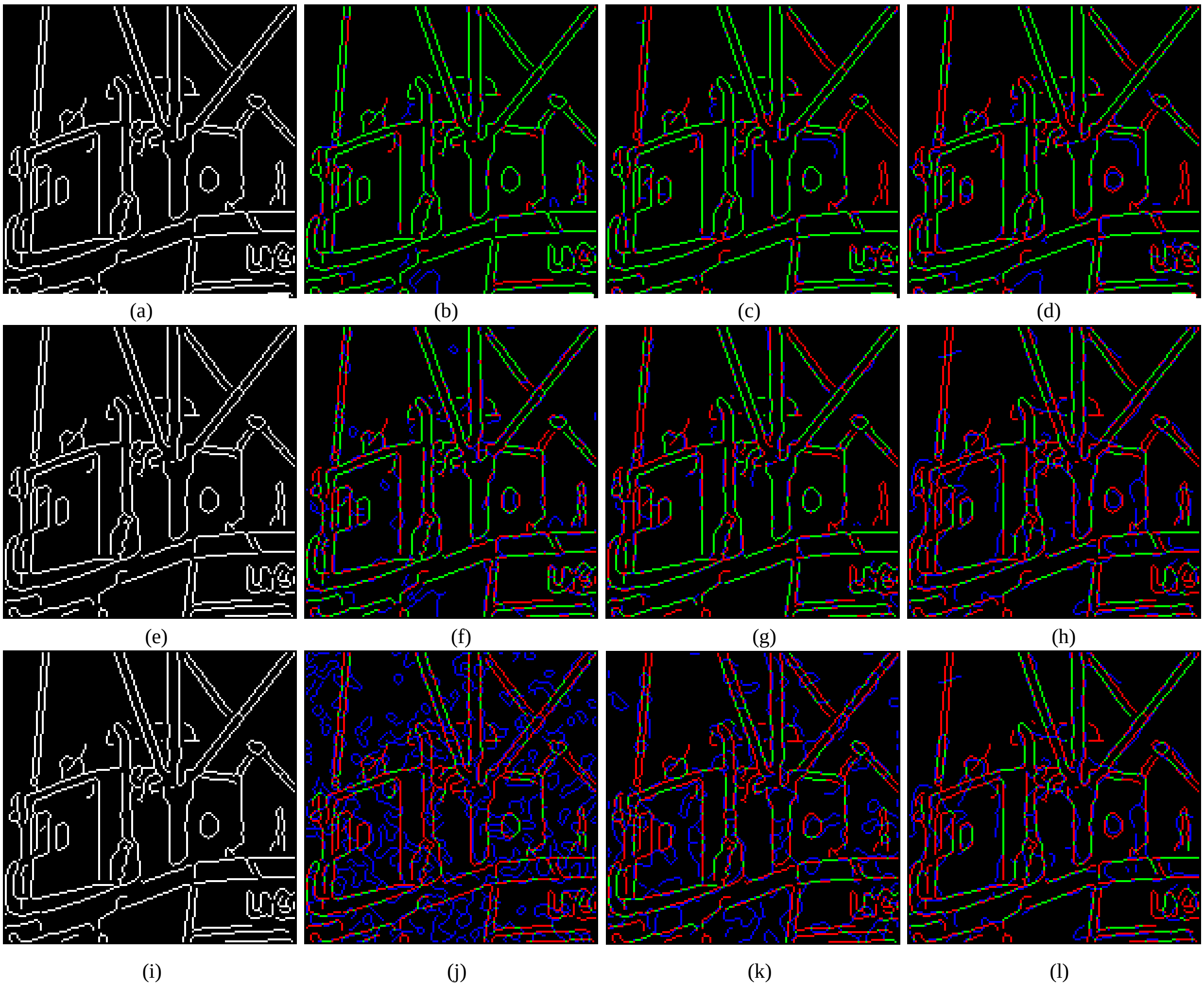

Figure. 8. Canny's Edge images with original, undetected and wrongly detected edge positions from restored outputs of AIDF, DWMF and the Proposed Filter of Boats image respectively from the 2nd column against varied random valued impulse levels ((a) 10%, (f) 40%, (k) 70%)

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Author Biographies

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