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Simulated evaluation of new switching based median filter for suppressing SPN and RVIN

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ABSTRACT

In the past two decades, the SPN (salt and pepper noise) suppressing method is worldwide interested researches on computer vision and image processing hence many SPN suppressing methods have been proposed. In general, the primary goal of SPN removal method is the suppressing of SPN in digital images thereby one of the recent effective and powerful SPN suppressing methods is a new switching-based median filtering (NSMF), which is innovated for suppressing high density SPN. Consequently, this paper thoroughly examines its efficiency and constrain of a new switching-based median filtering when this filter is used for contaminated image, which is synthesized by SPN and RVIN (random-value impulsive noise). In these simulations, six well-known images (Lena, Mobile, Pepper, Pentagon, Girl, Resolution) with two impulsive noise classes (SPN and RVIN) are used for measuring the its efficiency and constrain. An evaluation of the efficiency is conducted with many previous methods in forms of subjective and objective indicators.

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1. INTRODUCTION OF NSMF (NEW SWITCHING-BASED MEDIAN FILTERING)

Digital images [1]-[4] are generally contaminated by impulsive noise [5]-[23] due to communicating unsuccess, improper operating of CCD sensor, ADC synchronized erroneous and memory site erroneous hence noise suppressing method is one of the most vital process for sophisticated digital image process [24]-[26] for instant, face identification, license plate identification, remote sensing, etc. Even through the original Median Filter (SMF) [5]-[7] and Adaptive Median Filter (AMF) [14], [27] are known as the practical noise suppressing method [5]-[23] for SPN, one of the recent effective and powerful SPN suppressing methods is a NSMF (new switching-based median filtering) [28], which is proposed for suppressing only SPN, especially high density. From some results [28], it can conclude that NSMF has good efficiency while the NSMF has low computational complexity however there are no research of the NSMF for SPN at all density and random-value impulsive noise. Consequently, this paper thoroughly examines its efficiency and constrain of a novel modified median filtering based switching technique.

2. STATISTICAL THEORY OF NSMF

The NSMF comprises of four modified processes (*Process 1- Process 4*) as showing in Figure 1 instead of three processes (for previous proposed method), namely, detection, estimation, and replacement.

a) *Process 1*: Detecting the processed pixel as noisy pixel or noiseless pixel. If the processed pixel is 0 or 255 then the processed pixel is classified as contaminated noise otherwise the pixel is noiseless.
b) *Process 2*: Substituting the processed input pixel by using 1st order linear predictor.
c) *Process 3*: Estimating the expected original image by using a median filtering based on L-estimators.

d) *Process 4*: Replacing contaminated pixels by the estimated pixels.

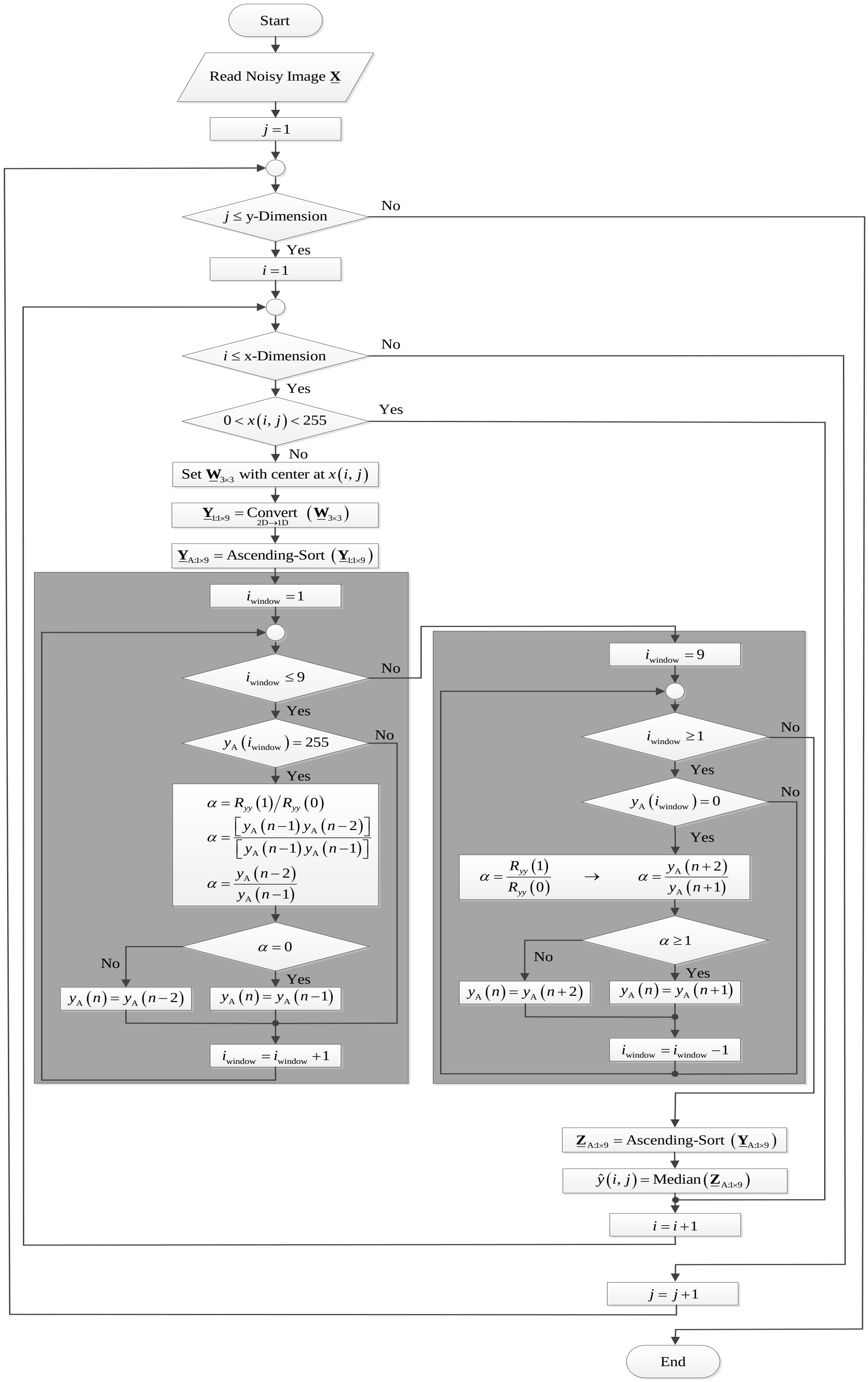

Figure 1. The flowchart of overall method of new switching-based median filtering (NSMF)

2.1. Statistical Theory of Estimating Process

Let $X=\{x_1,x_2,x_3,\ldots,x_j,x_{j+1},x_{j+2},\ldots,x_n\}$ is the original image, which is noiseless, and $Y=\{y_1,y_2,y_3,\ldots,y_j,y_{j+1},y_{j+2},\ldots,y_n\}$ is the contaminated image, which is comprised of a set of noiseless pixels $\{y_1,y_2,y_3,\ldots,y_j\}$ and a set of noisy pixels $\{y_{j+1},y_{j+2},\ldots,y_n\}$. Let $Z=\{y_1,y_2,y_3,\ldots,y_j,z_{j+1},z_{j+2},\ldots,z_n\}$, which is comprised of a set of noiseless pixels $\{y_1,y_2,y_3,\ldots,y_j\}$ and a set of substituted pixels for the noisy pixels $\{z_{j+1},z_{j+2},\ldots,z_n\}$, and z_{med} be the median of Z.

Let $x_i[n]$ is the i^{th} order statistic of the original image and $\hat{x}[n]$ is the expected original image, which can be defined from set of original noiseless pixels ($x_i[n]$). By linear prediction, Finite Impulse Response (FIR) linear predictor of order $(p-1)$ can be statistically defined as:

$$\hat{x}[n+1]=\sum_{k=0}^{P-1}h[n]x[n-k] \tag{1}$$

where $h[k]$ are the prediction filter coefficients.

The $h[k]$ is statistically defined by the Wiener-Hopf [5] equation as

$$R_x[k]h[k]=r_x[k] \tag{2}$$

where $R_x[k]$ is an autocorrelation matrix, $h[k]$ is predictor coefficient vector, and $r_x[k]$ is autocorrelation vector. The autocorrelation $R_x[k]$ can be statistically defined as

$$E\left[x[l-k]x[n-k]\right]=R_x[k-1] \tag{3}$$

where $k=0 \text{ to } (p-1)$ and $l=0 \text{ to } (p-1)$

By Auto Regressive Moving Average (ARMA) in time domain, the causal Infinite Impulse Response (IIR) predictor is given by $H[z]=z\left(1-1/Q[z]\right)$, which can be statistically defined as

$$\hat{x}[n+1]=\sum_{k=0}^{N-1}a_k\hat{x}[n-k]+\sum_{k=0}^{N-1}b_k\hat{x}[n-k] \tag{4}$$

Let $\hat{x}[n]$ is an expected original image from one or more noiseless pixels and $\hat{x}[n]=d[k]$

$$E\left[\hat{x}[n]x[n+1]\right]=E\left[d[n]x[n+1]\right]=\hat{r}d[k] \tag{5}$$

2.2. Statistical Theory of Replacing Process

If the processed input pixel is 0 or 255 then the pixel is defined as a noisy pixel and is replace by the replacing process, which comprises of 10 processing step as following:

1) *Processing Step 1*: Setting the 3×3 window with center at the processed pixel $x(i,j)$.
2) *Processing Step 2*: If $0<x(i,j)<255$ then the processed input pixel is classified as noiseless pixel and it is left unchanged and, then, the processed pixel $x(i,j)$ moves to the next position.
3) *Processing Step 3*: If $x(i,j)=0$ or $x(i,j)=255$ then the processed input pixel is classified as noisy pixel and go to *Processing Step 4*.
4) *Processing Step 4*: Converting the 3×3 window (2D) to the vector Y_A (1D)
5) *Processing Step 5*: Sorting to the vector Y_A (1D) in ascending order
6) *Processing Step 6*: If $x[n]=255$ then replacing $x[n]$ from left to right by following equation

$$x[n]=\alpha\cdot x[n-1] \text{ with } \alpha=\left(R_{xx}[1]/R_{xx}[0]\right), 0<\alpha<1 \tag{6}$$

$$R_{xx}[1]=x[n-1]\cdot x[n-2] \tag{7}$$

$$R_{xx}[0]=x[n-1]\cdot x[n-1] \tag{8}$$

If $\alpha=0$ then $x[n]=x[n-1]$

a) *Processing Step 7*: If $x[n]=0$ then replacing $x[n]$ from right to left by following equation

$$x[n]=\alpha\cdot x[n+1] \text{ with } \alpha=\left(R_{xx}[1]/R_{xx}[0]\right), 0<\alpha<1 \tag{9}$$

$$R_{xx}[1]=x[n+1]\cdot x[n+2] \tag{10}$$

$$R_{xx}[0]=x[n+1]\cdot x[n+1] \tag{11}$$

If $\alpha\geq 1$ then $x[n]=x[n+1]$

b) *Processing Step 8*: Estimating the vector Z_A(1D) by the predicted value, Sort the vector Z_A(1D), and Determine the median value.
c) *Processing Step 9*: Replace the processed pixel $x(i,j)$ with its median value.
d) *Processing Step 10*: Reprocess the Processing Steps 1 to Processing Steps 3 until the entire image is processed completely.

3. ILLUSTRATION OF NSMF

In this NSMF calculation example, the processed pixel intensity is 255 therefore the processed pixel is noisy and the processed pixel is suppressed by NSMF as shown in Figure 2. From the NSMF process, the denoised pixel is suppressed and the output pixel is replaced to be “200”.

4. SIMULATION OUTCOMES

In this simulation section under both SPN and RVIN, six tested images (Lena (256x256), Mobile (704x480), Pepper (256x256), Pentagon (512x512), Girl-Tiffany (256x256) and Resolution (128x128)) are employed to analytically simulate the upper bound of NSMF efficiency. This simulation analyses the noise suppressing efficiency of the NSMF by first applying the SPN and the RVIN on tested images. Subsequently, the NSMF processes for suppressing the noisy images, which are used to compute the PSNR with the known original images. From the simulation outcomes in Table 1 for SPN (salt&pepper noise), the NSMF algorithms have the better quality outcomes than SMF (Standard Median Filter) and GMF (Gaussian Mean Filter) at all cases however the NSMF algorithms have the better quality outcomes than AMF for high noise density.

From the simulation outcomes in Table 2 for RVIN, the NSMF algorithms have the better quality outcomes than SMF (Standard Median Filter), GMF (Gaussian Mean Filter) and AMF at all cases. However, the NSMF algorithms have the worst quality outcomes than AMF for all noise density in Resolution image because this image pixel intensity are “0” or “255”.

$\underline{\mathbf{W}}_{3\times 3}$

$y(i-1, j+1) = 200$	$y(i, j+1) = 205$	$y(i+1, j+1) = 188$
$y(i-1, j) = 169$	$y(i, j) = 255$	$y(i+1, j) = 255$
$y(i-1, j-1) = 255$	$y(i, j-1) = 255$	$y(i+1, j-1) = 255$

$y_1(i, j)$ is an impulsive noisy image

$\longrightarrow \underline{\mathbf{Y}}_{1:1\times 9} = \underset{2D\to 1D}{\text{Convert}}\left(\underline{\mathbf{W}}_{3\times 3}\right)$

$\longrightarrow \underline{\mathbf{Y}}_{1:1\times 9} = \underset{2D\to 1D}{\text{Convert}}\left(\begin{bmatrix} 200 & 205 & 188 \\ 169 & 255 & 255 \\ 255 & 255 & 255 \end{bmatrix}\right)$

$\longrightarrow \underline{\mathbf{Y}}_{1:1\times 9} = [200 \;\; 205 \;\; 188 \;\; 169 \;\; 255 \;\; 255 \;\; 255 \;\; 255 \;\; 255]$

$\longrightarrow \underline{\mathbf{Y}}_{A:1\times 9} = \text{Ascending-Sort}\left(\underline{\mathbf{Y}}_{1:1\times 9}\right)$

$\longrightarrow \underline{\mathbf{Y}}_{A:1\times 9} = \text{Ascending-Sort}\left([200 \;\; 205 \;\; 188 \;\; 169 \;\; 255 \;\; 255 \;\; 255 \;\; 255 \;\; 255]\right)$

$\longrightarrow \underline{\mathbf{Y}}_{A:1\times 9} = [169 \;\; 188 \;\; 200 \;\; 205 \;\; 255 \;\; 255 \;\; 255 \;\; 255 \;\; 255]$

$y_A(i_{window}) = 255$

For $i_{window} = 1, y_A(1) = y_A(1) \rightarrow y_A(1) = 169$

$\longrightarrow \underline{\mathbf{Y}}_{A:1\times 9} = [169 \;\; 188 \;\; 200 \;\; 205 \;\; 255 \;\; 255 \;\; 255 \;\; 255 \;\; 255]$

For $i_{window} = 2, y_A(2) = y_A(2) \rightarrow y_A(2) = 188$

$\longrightarrow \underline{\mathbf{Y}}_{A:1\times 9} = [169 \;\; 188 \;\; 200 \;\; 205 \;\; 255 \;\; 255 \;\; 255 \;\; 255 \;\; 255]$

For $i_{window} = 3, y_A(3) = y_A(3) \rightarrow y_A(3) = 200$

$\longrightarrow \underline{\mathbf{Y}}_{A:1\times 9} = [169 \;\; 188 \;\; 200 \;\; 205 \;\; 255 \;\; 255 \;\; 255 \;\; 255 \;\; 255]$

For $i_{window} = 4, y_A(4) = y_A(4) \rightarrow y_A(4) = 205$

$\longrightarrow \underline{\mathbf{Y}}_{A:1\times 9} = [169 \;\; 188 \;\; 200 \;\; 205 \;\; 255 \;\; 255 \;\; 255 \;\; 255 \;\; 255]$

For $i_{window} = 5, \alpha = y_A(n-2)/y_A(n-1) = 200/205$

$, y_A(5) = y_A(3) \rightarrow y_A(5) = 200$

$\longrightarrow \underline{\mathbf{Y}}_{A:1\times 9} = [169 \;\; 188 \;\; 200 \;\; 205 \;\; \mathbf{200} \;\; 255 \;\; 255 \;\; 255 \;\; 255]$

For $i_{window} = 6, \alpha = y_A(n-2)/y_A(n-1) = 205/200$

$, y_A(6) = y_A(4) \rightarrow y_A(6) = 205$

$\longrightarrow \underline{\mathbf{Y}}_{A:1\times 9} = [169 \;\; 188 \;\; 200 \;\; 205 \;\; 200 \;\; \mathbf{205} \;\; 255 \;\; 255 \;\; 255]$

For $i_{window} = 7, \alpha = y_A(n-2)/y_A(n-1) = 200/205$

$, y_A(7) = y_A(5) \rightarrow y_A(7) = 200$

$\longrightarrow \underline{\mathbf{Y}}_{A:1\times 9} = [169 \;\; 188 \;\; 200 \;\; 205 \;\; 200 \;\; 205 \;\; \mathbf{200} \;\; 255 \;\; 255]$

For $i_{window} = 8, \alpha = y_A(n-2)/y_A(n-1) = 205/200$

$, y_A(8) = y_A(6) \rightarrow y_A(8) = 205$

$\longrightarrow \underline{\mathbf{Y}}_{A:1\times 9} = [169 \;\; 188 \;\; 200 \;\; 205 \;\; 200 \;\; 205 \;\; 200 \;\; \mathbf{205} \;\; 255]$

For $i_{window} = 9, \alpha = y_A(n-2)/y_A(n-1) = 200/205$

$, y_A(9) = y_A(7) \rightarrow y_A(9) = 200$

$\longrightarrow \underline{\mathbf{Y}}_{A:1\times 9} = [169 \;\; 188 \;\; 200 \;\; 205 \;\; 200 \;\; 205 \;\; 200 \;\; 205 \;\; \mathbf{200}]$

$\longrightarrow \underline{\mathbf{Y}}_{A:1\times 9} = [169 \;\; 188 \;\; 200 \;\; 205 \;\; 200 \;\; 205 \;\; 200 \;\; 205 \;\; 200]$

$\longrightarrow \underline{\mathbf{Z}}_{A:1\times 9} = \text{Ascending-Sort}\left(\underline{\mathbf{Y}}_{A:1\times 9}\right)$

$\longrightarrow \underline{\mathbf{Z}}_{A:1\times 9} = \text{Ascending-Sort}\left([169 \;\; 188 \;\; 200 \;\; 205 \;\; 200 \;\; 205 \;\; 200 \;\; 205 \;\; 200]\right)$

$\longrightarrow \underline{\mathbf{Z}}_{A:1\times 9} = [169 \;\; 188 \;\; 200 \;\; 200 \;\; 200 \;\; 200 \;\; 205 \;\; 205 \;\; 205]$

$\longrightarrow \hat{y}(i, j) = \text{Median}\left(\underline{\mathbf{Z}}_{A:1\times 9}\right) = 200$

Figure 2. The example of overall calculation of new switching-based median filtering (NSMF)

Table 1. Denoising Performance Result of SPN

SPN	PSNR (dB)					
Tested Images	Noise Density	Observed Image	Denoising Algorithm			
			SMF	GMF	AMF	NSMF
Lena (256x256)	10	15.6564	30.7076	19.3812	**35.3032**	31.3470
	20	12.6389	27.6257	16.3208	**32.1558**	30.2476
	30	10.8971	23.6811	14.5829	27.9141	**29.6058**
	40	9.6481	19.0080	13.2479	23.7903	**28.5528**
	50	8.6553	15.4758	12.2146	20.5725	**27.0119**
	60	7.7813	13.6792	11.2939	18.4727	**25.7010**
	70	7.1697	11.0400	10.6509	17.0517	**25.2202**
	80	6.5846	8.8975	10.0057	16.5452	**23.6491**
	90	6.0604	7.1223	9.4356	17.1346	**21.7870**
Mobile (704x480)	10	15.1637	21.3601	18.4448	**25.0280**	21.5039
	20	12.0780	20.1976	15.4276	**23.8172**	20.8137
	30	10.3465	18.3435	13.6485	**21.7980**	20.1805
	40	9.0919	16.1073	12.3414	19.5320	**19.6503**
	50	8.1216	13.4726	11.3057	17.3015	**19.0300**
	60	7.3397	12.6259	10.4380	15.9416	**17.8327**
	70	6.6636	10.2402	9.6946	14.5107	**16.9717**
	80	6.1003	8.1954	9.0778	13.6481	**16.5924**
	90	5.5706	6.4911	8.4680	13.1971	**15.5046**
Pepper (256x256)	10	15.3798	30.6116	19.0677	**36.0391**	32.0762
	20	12.3593	26.5888	15.9804	**31.6485**	30.3296
	30	10.6242	22.0663	14.1748	26.7650	**29.3512**
	40	9.3998	18.4321	12.9076	23.4995	**28.4487**
	50	7.9930	14.8506	11.8117	20.2203	**26.6461**
	60	7.6189	12.0128	10.9563	18.3003	**24.8222**
	70	6.9246	9.7704	10.2039	16.8667	**24.1151**
	80	6.3710	8.0166	9.5853	16.3827	**22.7764**
	90	5.8582	6.5767	9.0214	16.7617	**20.8912**
Pentagon (512x512)	10	15.7999	28.7784	19.5038	**32.8245**	29.2477
	20	12.7934	26.5128	16.5198	**30.5509**	28.4111
	30	11.0668	22.8646	14.7790	27.1212	**27.8224**
	40	9.8125	18.9056	13.5122	23.3677	**27.0890**
	50	8.8227	15.4225	12.5108	20.4567	**25.9327**
	60	8.0450	12.6240	11.7138	18.3989	**24.7612**
	70	7.3650	10.3040	10.9953	17.0422	**24.2225**
	80	6.7914	8.4840	10.4099	16.4737	**22.9866**
	90	6.2778	6.9876	9.8698	16.8647	**21.4828**
Girl-Tiffany (256x256)	10	13.6890	31.5583	17.2530	**36.8900**	32.9954
	20	10.6567	25.5153	13.9593	**32.0377**	30.9499
	30	8.8677	20.7738	11.9599	27.6911	**29.1071**
	40	7.5798	16.5146	10.4543	23.3733	**28.6836**
	50	6.5712	13.0319	9.2367	20.1711	**27.6182**
	60	5.8609	10.4981	8.3590	18.5314	**26.9544**
	70	5.13`11	8.0463	7.4271	17.1068	**25.7710**
	80	4.5674	6.2520	6.6881	16.7480	**24.2522**
	90	4.0573	4.7465	5.9986	17.1560	**22.3078**
Resolution (128x128)	10	13.4819	17.9425	16.3688	**18.3302**	12.9262
	20	10.1271	16.2124	13.0706	**17.1273**	12.8794
	30	8.4430	14.4548	11.1807	**15.7907**	12.4083
	40	7.3308	12.6223	9.9457	**14.7904**	11.6991
	50	6.2938	10.4851	8.7005	**13.8816**	10.6690
	60	5.4436	8.5925	7.6865	**14.0392**	10.2361
	70	4.6795	6.6295	6.7002	**12.6150**	10.4634
	80	4.1940	5.3585	6.0922	**10.9746**	9.7668
	90	3.7113	4.2234	5.4638	**9.3116**	8.4931

Table 2. Denoising Performance Result of RVIN

RVIN	PSNR (dB)					
Tested Images	Noise Density	Observed Image	Denoising Algorithm			
			SMF	GMF	AMF	NSMF
Lena (256x256)	10	19.7193	31.1555	23.2638	28.4992	**31.2960**
	20	16.6527	29.7106	20.1102	23.1270	**29.9009**
	30	14.9222	27.5271	18.2831	20.1302	**28.0652**
	40	13.6990	24.9693	16.9480	18.0338	**27.2951**
	50	12.6883	22.3406	15.8415	16.3540	**25.9716**
	60	11.8913	19.7498	14.9352	14.9043	**24.2453**
	70	11.2184	17.7591	14.1493	13.7787	**22.5265**
	80	10.6422	16.0345	13.4958	12.8356	**20.3198**
	90	10.1515	14.5334	12.9029	12.0228	**17.8884**
Mobile (704x480)	10	18.4574	21.4778	21.1512	22.6605	**21.5601**
	20	15.5151	20.8069	18.3393	19.7674	**20.9019**
	30	13.7727	19.7265	16.5214	17.4115	**19.8296**
	40	12.5299	18.5715	15.1796	15.6813	**18.7463**
	50	11.5304	17.1060	14.0526	14.1777	**18.0061**
	60	10.7497	15.5745	13.1263	12.9999	**16.9705**
	70	10.0875	14.2337	12.3371	11.9870	**15.7658**
	80	9.4794	12.9625	11.5980	11.0907	**14.4949**
	90	8.9565	11.8224	10.9422	10.2919	**13.1973**
Pepper (256x256)	10	19.1143	31.4270	22.6205	27.4518	**31.9058**
	20	16.0921	28.8665	19.4820	22.3782	**29.7204**
	30	14.3745	26.5900	17.6137	19.4227	**27.4882**
	40	13.1825	23.3362	16.2549	17.2699	**26.3846**
	50	12.2029	20.7731	15.1438	15.6064	**24.5452**
	60	11.3328	18.2128	14.0998	14.0825	**22.4280**
	70	10.7068	16.2565	13.3352	13.0203	**20.1256**
	80	10.1086	14.5768	12.5873	12.0629	**17.5477**
	90	9.6144	13.2495	11.9859	11.2712	**15.6818**
Pentagon (512x512)	10	20.2113	29.1520	23.6997	28.2423	**29.2203**
	20	17.2386	28.0433	20.7616	23.8125	**28.2529**
	30	15.4355	26.6678	18.9263	20.7887	**26.9234**
	40	14.1860	24.9238	17.6449	18.7135	**26.0936**
	50	13.2544	22.9472	16.6548	17.1075	**25.3502**
	60	12.4342	20.9049	15.7838	15.7400	**24.1241**
	70	11.7829	19.0652	15.0817	14.6359	**23.1046**
	80	11.1849	17.3449	14.4326	13.6558	**21.7975**
	90	10.6746	15.8671	13.8673	12.8241	**20.4014**
Girl-Tiffany (256x256)	10	16.4414	**31.6049**	19.9110	25.1339	28.3519
	20	13.4343	28.1774	16.5639	19.5720	**28.4094**
	30	11.6674	23.8175	14.5342	16.4549	**28.0443**
	40	10.3946	19.8213	12.9626	14.1248	**26.7023**
	50	9.4483	16.7201	11.7613	12.3869	**24.4072**
	60	8.6223	14.0847	10.6637	10.9357	**20.5217**
	70	7.9734	12.1107	9.8004	9.8160	**16.6627**
	80	7.3939	10.4710	8.9936	8.7676	**13.1380**
	90	6.8638	9.1560	8.2609	7.9151	**10.6609**
Resolution (128x128)	10	17.7992	18.6254	**20.1134**	18.3074	10.6040
	20	14.6190	**17.9190**	17.1729	17.4171	11.3422
	30	12.7370	**17.1231**	15.3050	16.7349	11.3862
	40	11.3691	**16.2456**	13.8148	15.5071	11.7564
	50	10.5048	**15.5229**	12.8678	14.4871	11.8203
	60	9.7510	**14.3607**	11.9178	13.3621	12.0505
	70	9.1026	**13.6671**	11.1682	12.3620	12.2006
	80	8.4955	12.3904	10.4038	11.1211	**12.4048**
	90	8.0315	11.6735	9.8152	10.2316	**12.3036**

5. CONCLUSION

This in-depth research assesses the efficiency of the noise suppressed method based on NSMF under two impulsive noise classes (SPN and RVIN). These simulations employ on six well-known images (Lena, Mobile, Pepper, Pentagon, Girl, Resolution) under two impulsive noise classes for assessing the highest suppressed images in term of PSNR. Many previous noise suppressed methods, such as SMF (Standard Median Filter), GMF (Gaussian Mean Filter) and AMF, are used to assess the analogy efficiency. From simulation outcomes, the NSMF has a good PSNR for high noise density and this filter can work well for RVIN.

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