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The statistical analysis of random-valued impulse noise detection techniques based on the local image characteristic: ROAD, ROLD and RORD

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ABSTRACT

Advances in local image statistical analysis have made possible the random-valued impulse noise detection but the current noise detections based on ROAD (Rank-Ordered Absolute Differences), ROLD (Rank-Ordered Logarithmic Differences) and RORD (Rank-Ordered Relative Differences), which are the most three effective and practical detections using the local image statistical characteristic, operates effectively on different noise density and different image statistical characteristic. To address these issues, this paper proposes the comparative analysis on the noise detections based on ROAD, ROLD and RORD. Therefore, the first contribution is the comparative statistical distribution of these three noise detections. By comprehensive experiment at each noise density, the optimized detected threshold is later determined from four benchmark data: Lena, Girl, Pepper and Airplane. Moreover, the maximum detection accuracy for each case is comparatively demonstrated by using the noise detections based on ROAD, ROLD and RORD with the optimized detected threshold.

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1. INTRODUCTION

Because of communication errors, memory located faulty, malfunctioning CCD sensors, and ADC synchronizing errors, impulse noise [1-4] traditionally contaminates captured digital images. The primary property of this noise [5-21] is that only some group of the pixels is contaminated and another group of the pixels are noiseless. In real implementation, the noise detection [7-21], which is one of the main processes of the image denoising process, is elementary process for forthcoming and advance image process [22-24] such as object classification, face hallucination, car license plate detection, etc. The main objective of noise detection is to classify noisy pixels and noiseless pixels. This section introduces some research documents from the noise detection based on the local image statistical characteristic point of view because the noise detection is one of the most primary processes of the image denoising process and directly impact to the image denoising performance. First, the median filtering (MF) technique [5-7] is used to detect the impulsive noise. Later, the AMF (Adaptive Median Filter) [14, 25] is developed from MF to be noise detected process. Next, the ROAD (Rank-Ordered Absolute Differences) [26], which is the first local image statistical characteristic technique that is used to be image denoising process, has been proposed in 2005. Subsequent, the ROLD (Rank-Ordered Logarithmic Differences) [27], which is developed from ROAD to improve its performance in high noise density, has been proposed in 2007. Finally, the ROAD (Rank-Ordered Relative Differences) [28], which is developed from ROAD and ROLD to improve its performance in low noise density, has been proposed in 2008. Consequently, these three noise detected techniques operates effectively on different noise density and different image statistical characteristic. To address these issues, this paper proposes the comparative analysis on the noise detections based on ROAD, ROLD and RORD from the comparative statistical distribution point of view and, moreover, the optimized detected threshold is later determined from four benchmark data: Lena, Girl, Pepper and Airplane by experimenting on several noise density. Furthermore, with the optimized detected threshold, the maximum detection accuracy for each case is comparatively demonstrated by using the noise detections based on ROAD, ROLD and RORD.

2. RELATED THEORY

2.1. Mathematical of Random-Valued Impulse Noise

Support that the original image is $\mathbf{x}$ where $x_{i,j}$ is the original image pixel at location (i,j) that is $s_{\min} \le x_{i,j} \le s_{\max}$ where $[s_{\min}, s_{\max}]$ is the intensity range of this image. Support that the noisy image is $\mathbf{y}$ where $y_{i,j}$ is the contaminated image pixel at location (i,j), which can be mathematically expressed as following (1):

$$y_{i,j} = \begin{cases} s_{\min} & \text{at probability } p \\ s_{\max} & \text{at probability } q \\ x_{i,j} & \text{at probability } (1-p-q) \end{cases} \quad \text{where } (p-q) \text{ is the noise level.} \tag{1}$$

2.2. ROAD (Rank-Ordered Absolute Differences) Statistic

Support that the computed image pixel $y_{i,j}$ at location (i,j) and $\Omega_N = \{(s,t) | -N \le s,t \le N\}$ is its group of neighborhood pixels (with the window size at $(2N+1)\times(2N+1)$), which is centered at location (i,j). The ROAD (Rank-Ordered Absolute Differences) Statistic [26] can be mathematically defined as:

$$\text{ROAD}_m(\mathbf{i}) = \sum_{i=1}^{m} r_i(\mathbf{i}) \tag{2}$$

where $r_i(\mathbf{i}) = i^{th} \text{ smallest } D(y_{i,j}), \forall (s,t) \in \Omega_N$ and $D(y_{i,j})$ is defined as the absolute difference between the gray-level intensity $y_{i+s,j+t}$ and $y_{i,j}$ or can be mathematically defined as:

$$D(y_{i,j}) = |y_{i+s,j+t} - y_{i,j}|, \quad \forall (s,t) \in \Omega_N \tag{3}$$

From the simplicity and computational experimental analysis reason [26], this paper defines $m = 4$ therefore the ROAD can be mathematically simplified as:

$$\text{ROAD}_4(\mathbf{i}) = \sum_{i=1}^{4} r_i(\mathbf{i}) \tag{4}$$

In this paper, the normalized ROAD, which is used for analyzing, can be mathematically defined as:

$$\text{ROAD}_m(\mathbf{i}) = \tfrac{1}{m}\sum_{i=1}^{m} r_i(\mathbf{i}) \quad \text{or} \quad \text{ROAD}_4(\mathbf{i}) = \tfrac{1}{4}\sum_{i=1}^{4} r_i(\mathbf{i}) \tag{5}$$

2.3. ROLD (Rank-Ordered Logarithmic Differences) Statistic

In order to detecting noisy pixel and noises pixel under the noise density levels as high as 60%, ROLD statistic technique [27] is desired and developed from ROAD statistic technique and the ROLD (Rank-Ordered Logarithmic Differences) Statistic can be mathematically defined as:

$$D(y_{i,j}) = 1 + \max\left\{\log_a |y_{i+s,j+t} - y_{i,j}|, -b\right\} / b, \forall (s,t) \in \Omega_N \tag{6}$$

From the simplicity and computational experimental analysis reason [27], this paper defines $a=2$ and $b=5$ therefore the ROLD can be mathematically simplified as:

$$D\left(y_{i,j}\right)=1+\max\left\{\log_2\left|y_{i+s,j+t}-y_{i,j}\right|,-5\right\}\Big/5,\forall\left(s,t\right)\in\Omega_N \tag{7}$$

In this paper, the normalized ROLD, which is used for analyzing, can be mathematically defined as:

$$\mathrm{ROLD}_m\left(\mathbf{i}\right)=\tfrac{1}{m}\sum_{i=1}^{m}r_i\left(\mathbf{i}\right) \quad \text{or} \quad \mathrm{ROLD}_4\left(\mathbf{i}\right)=\tfrac{1}{4}\sum_{i=1}^{4}r_i\left(\mathbf{i}\right) \tag{8}$$

2.4. ROAD (Rank-Ordered Relative Differences) Statistic

The absolute difference $D\left(y_{i,j}\right)$ between the gray-level intensity $y_{i+s,j+t}$ and $y_{i,j}$ can be usually used for defining whether a computed image pixel $y_{i,j}$ is contaminated by impulse noise. In general, if the absolute difference $D\left(y_{i,j}\right)$ is large then the impulse noise likely contaminates the computed image pixel $y_{i,j}$ however If their neighbor image pixels $y_{i+s,j+t}$ are contaminated but the computed image pixel $y_{i,j}$ is noiseless then the absolute difference $D\left(y_{i,j}\right)$ is large or if the computed window contains a sharp edge texture then the absolute difference $D\left(y_{i,j}\right)$ is large. In order to improve the performance of noisy/noiseless detected rate, the RORD statistic technique [28], which is desired and developed from ROAD statistic technique by using a reference image, can be mathematically defined as:

$$D\left(y_{i,j}\right)=\left|\hat{y}_{i+s,j+t}-\hat{y}_{i,j}\right|,\quad \forall\left(s,t\right)\in\Omega_N \tag{9}$$

$$\hat{\mathbf{y}}=\mathbf{y}-\alpha\times\mathbf{y}_{\mathrm{ref}} \tag{10}$$

From the simplicity and computational experimental analysis reason [28], the reference image $\mathbf{y}_{\mathrm{ref}}$ in this paper is computed from the contaminated image by filtering by MF (median filter) denoising process and α is usually set to be 0.5.

In this paper, the normalized RORD, which is used for analyzing, can be mathematically defined as:

$$\mathrm{RORD}_m\left(\mathbf{i}\right)=\tfrac{1}{m}\sum_{i=1}^{m}r_i\left(\mathbf{i}\right) \quad \text{or} \quad \mathrm{RORD}_4\left(\mathbf{i}\right)=\tfrac{1}{4}\sum_{i=1}^{4}r_i\left(\mathbf{i}\right) \tag{11}$$

3. COMPARATIVE EXPERIMENTAL RESULTS

3.1. The Simulated Estimation of Optimized Noise Threholds

First, this experiment investigates the statistical distribution of the noisy and noiseless pixels of the ROAD, ROLD and RORD by using four benchmark data: Airplane, Girl, Lena, and Pepper under many impulse noise densities (from 5% to 90%) as shown in Figure 1 to Figure 4, respectively. Then, the optimized thresholds for classifying noisy and noiseless pixels are estimated for each image at each noise density from the maximum detection accuracy perspective. The noise detection accuracy is defined as:

$$\text{Accuracy}=\tfrac{1}{2}\left(\frac{\text{number of estimated noisy pixels}}{\text{number of noisy pixels}}\right)+\tfrac{1}{2}\left(\frac{\text{number of estimated noiseless pixels}}{\text{number of noiseless pixels}}\right) \tag{12}$$

3.2. The Simulated Results of Noise Detection Accuracy

Later, by using the optimized thresholds for classifying noisy and noiseless pixels, this experiment investigates the noise detection accuracy of the ROAD, ROLD and RORD by using four benchmark data: Airplane, Girl, Lena, and Pepper under many impulse noise densities (from 5% to 90%) as shown in Table 1 to Table 4, respectively. From this experimental result, the RORD has the highest noise detection accuracy under low impulse noise densities (< 40%) but the ROLD has the highest noise detection accuracy under high impulse noise densities (> 60%). The ROAD usually has lower noise detection accuracy than ROLD and RORD in almost all cases because both ROLD and RORD are developed and modified from ROAD. Compared to AMF (Adaptive Median Filter) [14, 25], the ROAD, ROLD and RORD has higher noise detection accuracy because the AMF is desired for Salt&Pepper noise.

Table 1. The Noise Detection Performance: Airplain

Noise Detection Tech.	Impulse Noise Density (%)																	
	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
AMF	0.8154	0.7831	0.7511	0.7274	0.7061	0.6847	0.6617	0.6449	0.6282	0.6183	0.6075	0.5957	0.5870	0.5783	0.5697	0.5628	0.5583	0.5525
ROAD	0.9190	0.9173	0.9171	0.9178	0.9141	0.9109	0.9068	0.8992	0.8928	0.8847	0.8759	0.8668	0.8570	0.8487	0.8433	0.8388	0.8351	0.8298
ROLD	0.9197	0.9164	0.9166	0.9179	0.9146	0.9114	0.9085	0.9021	0.8971	0.8901	0.8842	0.8779	0.8679	0.8583	0.8512	0.8463	0.8416	0.8370
RORD	0.9301	0.9263	0.9252	0.9233	0.9185	0.9118	0.9060	0.8957	0.8892	0.8776	0.8694	0.8577	0.8463	0.8369	0.8307	0.8247	0.8208	0.8170

Table 2. The Noise Detection Performance: Girl

Noise Detection Tech.	Impulse Noise Density (%)																	
	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
AMF	0.7363	0.6910	0.6558	0.6209	0.5880	0.5632	0.5381	0.5217	0.5021	0.4827	0.4677	0.4516	0.4378	0.4241	0.4096	0.3955	0.3831	0.3712
ROAD	0.9381	0.9357	0.9384	0.9383	0.9362	0.9302	0.9247	0.9196	0.9127	0.9033	0.8957	0.8857	0.8759	0.8693	0.8604	0.8524	0.8467	0.8420
ROLD	0.9385	0.9349	0.9387	0.9378	0.9367	0.9315	0.9265	0.9237	0.9206	0.9132	0.9076	0.8986	0.8894	0.8826	0.8742	0.8662	0.8609	0.8560
RORD	0.9460	0.9399	0.9403	0.9384	0.9337	0.9262	0.9181	0.9115	0.9019	0.8886	0.8788	0.8622	0.8478	0.8361	0.8223	0.8107	0.8002	0.7943

Table 3. The Noise Detection Performance: Lena

Noise Detection Tech.	Impulse Noise Density (%)																	
	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
AMF	0.8395	0.8133	0.7896	0.7650	0.7428	0.7233	0.7049	0.6920	0.6773	0.6624	0.6486	0.6373	0.6302	0.6192	0.6115	0.6040	0.5973	0.5909
ROAD	0.9495	0.9106	0.9126	0.9097	0.9045	0.9020	0.8971	0.8901	0.8834	0.8769	0.8667	0.8605	0.8547	0.8462	0.8405	0.8338	0.8305	0.8263
ROLD	0.9515	0.9098	0.9128	0.9087	0.9045	0.9036	0.9000	0.8954	0.8899	0.8856	0.8753	0.8681	0.8606	0.8512	0.8454	0.8384	0.8333	0.8287
RORD	0.9539	0.9233	0.9202	0.9165	0.9088	0.9040	0.8998	0.8929	0.8859	0.8788	0.8672	0.8591	0.8528	0.8448	0.8387	0.8341	0.8305	0.8264

Table 4. The Noise Detection Performance: Pepper

Noise Detection Tech.	**Impulse Noise Density (%)**																	
	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
AMF	0.8550	0.8189	0.7893	0.7638	0.7368	0.7191	0.7002	0.6819	0.6653	0.6539	0.6411	0.6263	0.6176	0.6073	0.5982	0.5907	0.5863	0.5803
ROAD	0.9169	0.9128	0.9126	0.9072	0.9065	0.9024	0.8995	0.8904	0.8815	0.8728	0.8688	0.8593	0.8523	0.8443	0.8366	0.8290	0.8283	0.8246
ROLD	0.9153	0.9115	0.9124	0.9075	0.9071	0.9037	0.9022	0.8939	0.8883	0.8800	0.8761	0.8675	0.8595	0.8505	0.8416	0.8334	0.8317	0.8278
RORD	0.9299	0.9217	0.9193	0.9139	0.9096	0.9035	0.8989	0.8900	0.8816	0.8716	0.8656	0.8536	0.8450	0.8364	0.8278	0.8212	0.8205	0.8182

4. EXPERIMENTAL SUMMARY

This paper presents the comparative analysis on the noise detections based on ROAD, ROLD and RORD. Therefore, the first contribution is the comparative statistical distribution of these three noise detections. By comprehensive experiment at each noise density, the optimized detected threshold is later determined from four benchmark data: Lena, Girl, Pepper and Airplane. Seond, the maximum detection accuracy for each case is comparatively demonstrated by using the noise detections based on ROAD, ROLD and RORD with the optimized detected threshold.

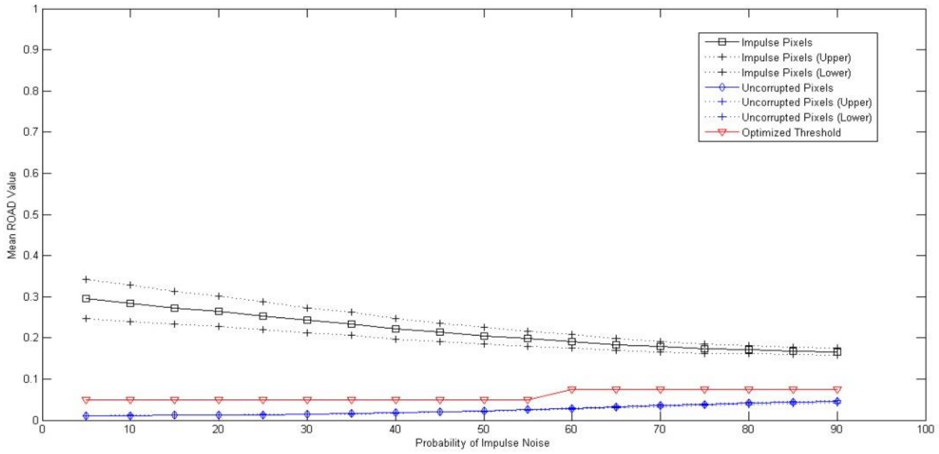

Figure 1(a). Mean ROAD of noisy/noiseless pixels: Airplane

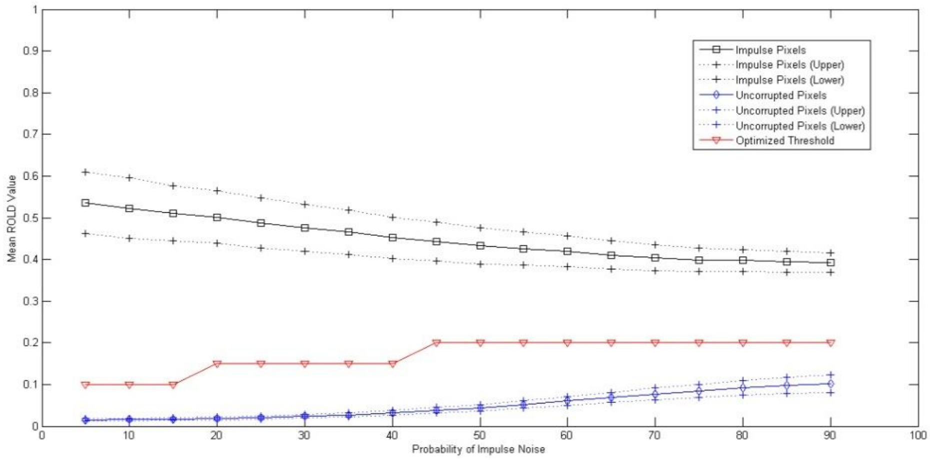

Figure 1(b). Mean ROLD of noisy/noiseless pixels: Airplane

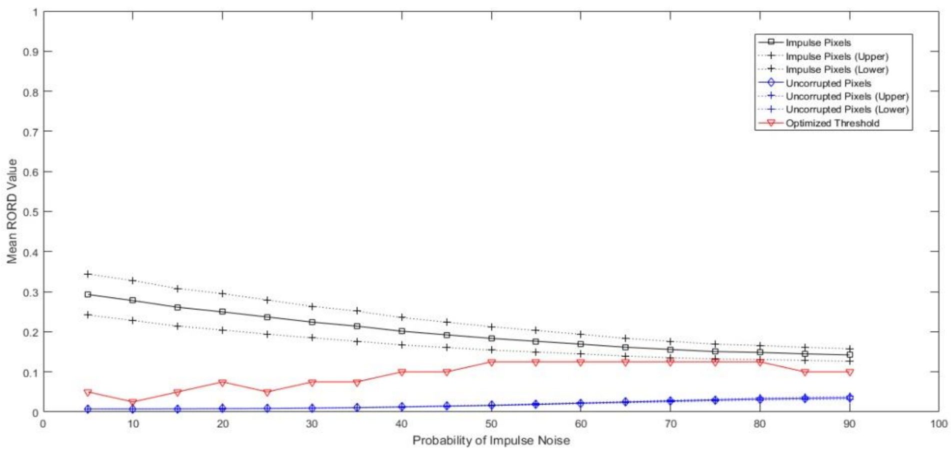

Figure 1(c). Mean RORD of noisy/noiseless pixels: Airplane

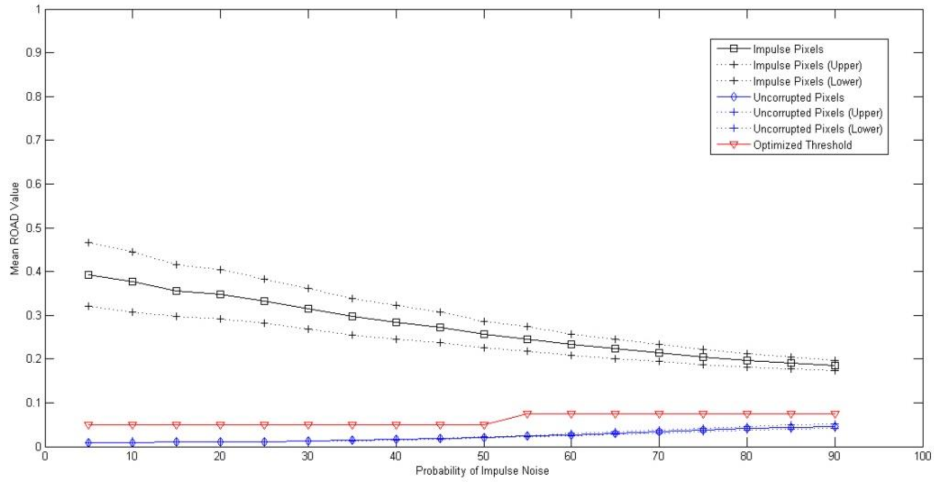

Figure 2(a). Mean ROAD of noisy/noiseless pixels: Girl

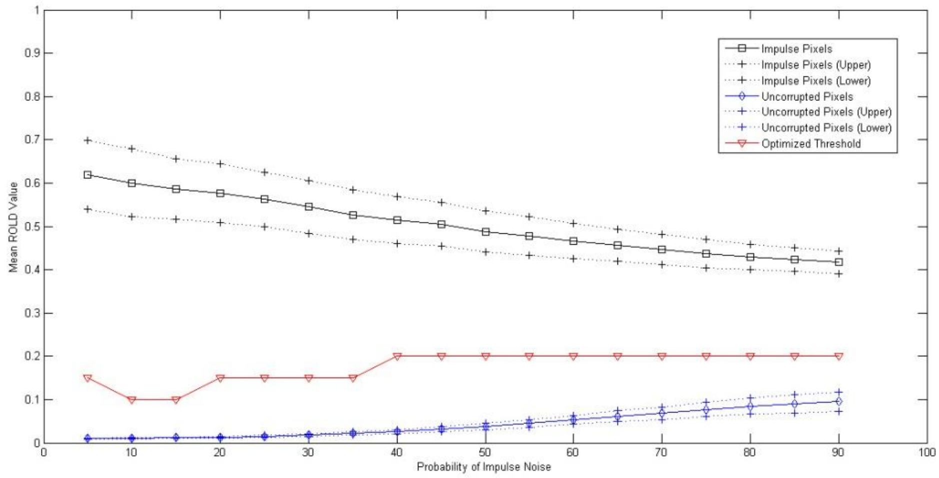

Figure 2(b). Mean ROLD of noisy/noiseless pixels: Girl

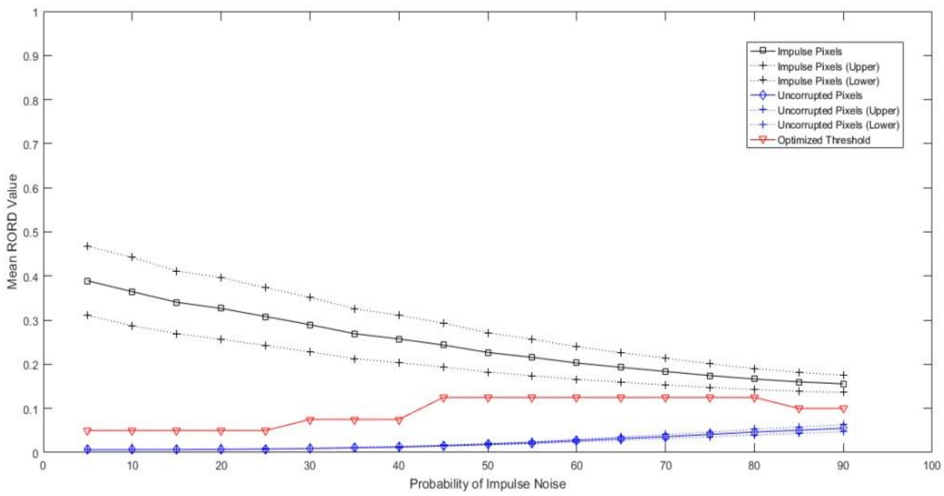

Figure 2(c). Mean RORD of noisy/noiseless pixels: Girl

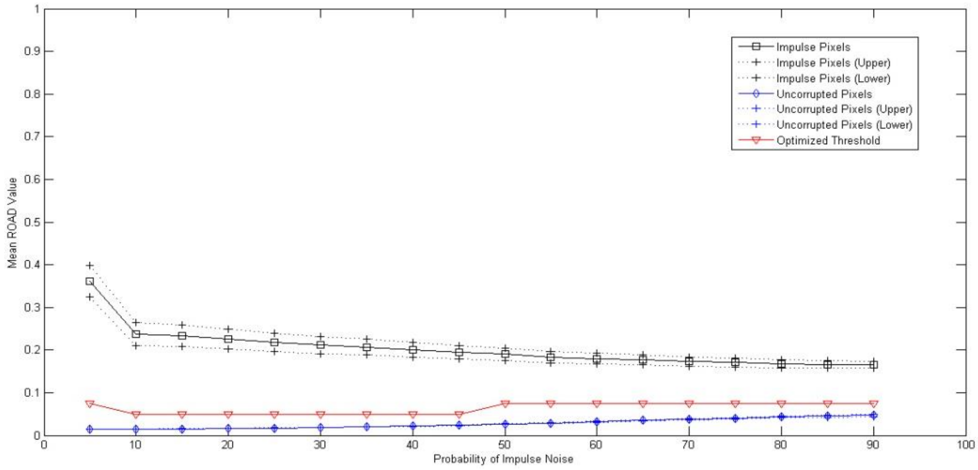

Figure 3(a). Mean ROAD of noisy/noiseless pixels: LENA

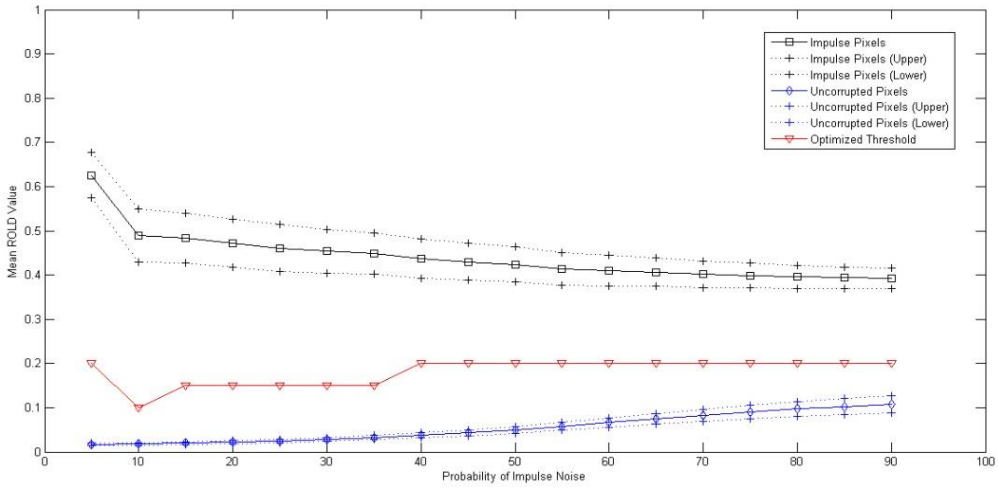

Figure 3(b). Mean ROLD of noisy/noiseless pixels: LENA

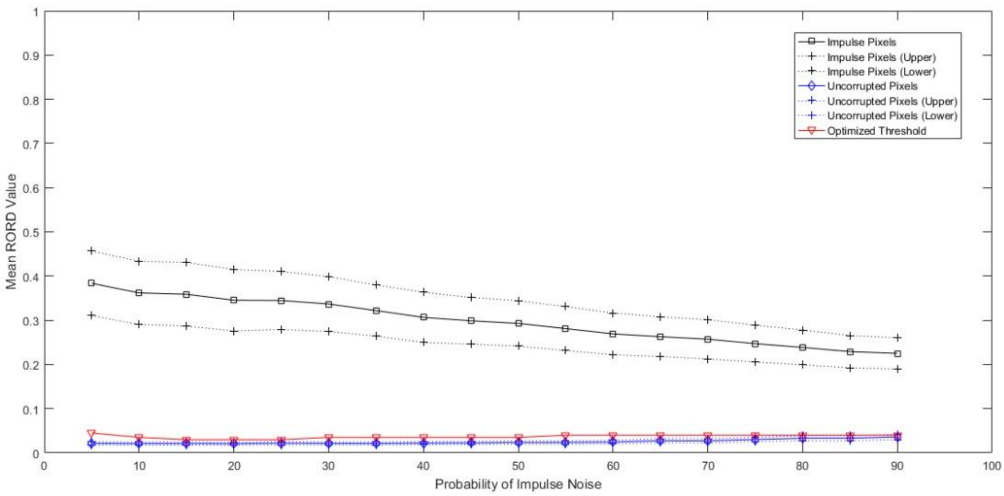

Figure 3(c). Mean RORD of noisy/noiseless pixels: LENA

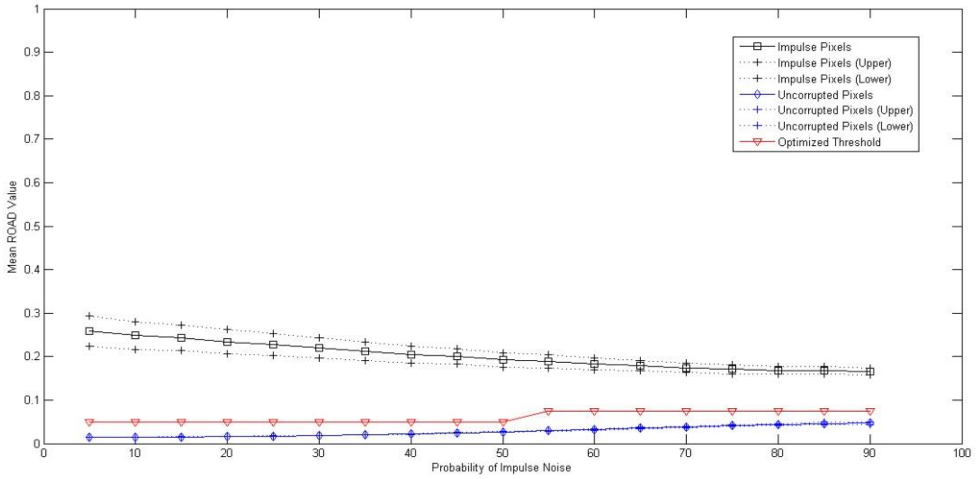

Figure 4(a). Mean ROAD of noisy/noiseless pixels: Pepper

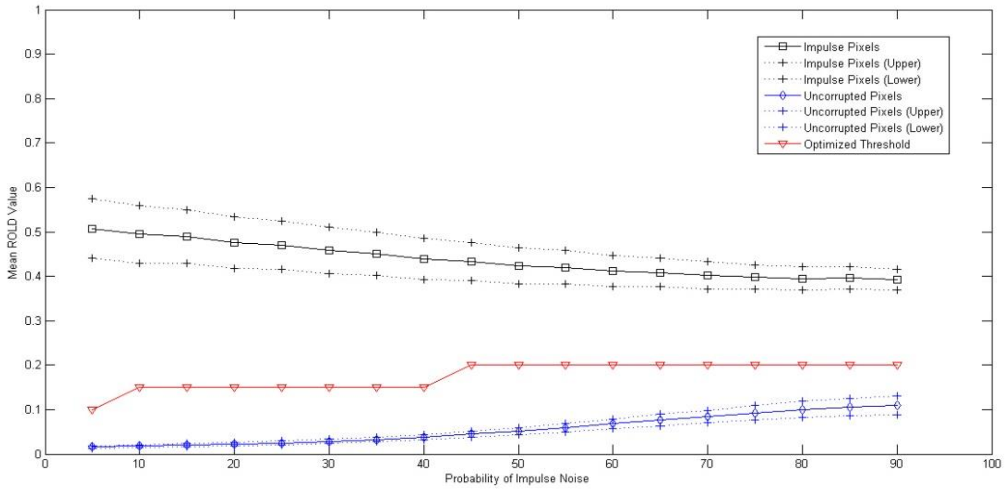

Figure 4(b). Mean ROLD of noisy/noiseless pixels: Pepper

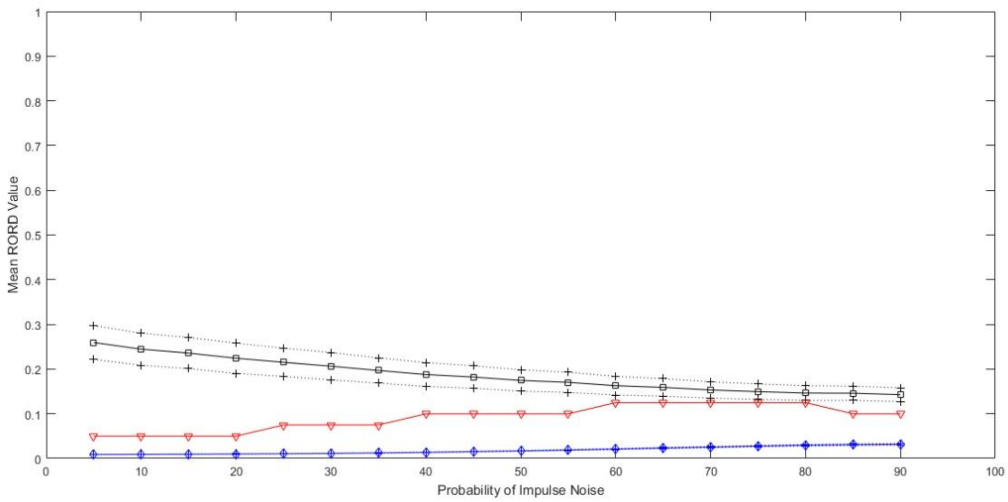

Figure 4(c). Mean RORD of noisy/noiseless pixels: Pepper

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BIOGRAPHIES OF AUTHORS

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