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COMMUNICATIONS

THRESHOLD IMPULSE DETECTOR BASED ON LUM SMOOTHER (LUMsm DETECTOR)

Rastislav Lukáč — Stanislav Marchevský *

In this paper we present a new impulse detector based on a LUM smoother (LUMsm detector) for detection of an impulsive type of noise. This detector is controlled by a threshold. Our detection is based on a LUM smoother filter, which is a subclass of a rank-order-based, lower-upper-middle (LUM) filter. A subclass of LUM smoother is used in image-noise smoothing applications. The output of this filter is determined by comparing a lower- and upper-order statistics to the middle of the sample in the observation window. We demonstrate that the proposed algorithm of the LUMsm detector executes the detection operation very well and the performance of impulsive noise removing along with a 3×3 median filter shows excellent capabilities of image-detail preservation. We yield comparisons to other impulsive noise detectors demonstrated by the mean-absolute error (MAE) and mean-square error (MSE). Description of the LUM smoother and impulse detectors is included.

K e y w o r d s: LUM filters, impulsive type noise, impulse detector

1 INTRODUCTION

The idea of impulse detector [3, 4, 5, 8] is most important for noise removing. Noise filtering by a filter alone is disadvantageous because the filter operation window is moved point by point over the whole image. Thus, each pixel is filtered, also in such a case, when the pixel is not corrupted by noise. Non-corrupted point filtration magnifies the error by a blurring or improper replacement of the processed pixel.

The structure of impulse detector and filter system is presented in Fig. 1.

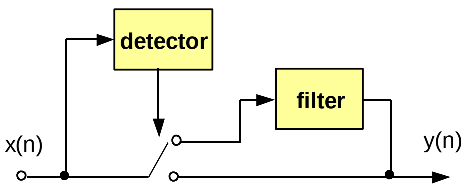

Fig 1 Impulse detector architecture

This system performs impulse noise removing very well and shows excellent capabilities of image-detail preservation.

Experimental results were obtained for various images but in this paper we present experiments on Lena and Bridge images only.

2 NOISE MODELS

Now we describe the noise models used in our experiments.

Fig 2 Original test images; (a) Lena, (b) Bridge.

Table 1. Images corrupted by impulsive type noise

Noise	I10		BW20	
Image	MAE	MSE	MAE	MSE
Lena	7.0181	759.1	23.4016	3438.1
Bridge	7.2212	807.6	23.2214	3157.2

The test images had a resolution of 256×256 pixels with 8 bits/pixel grey-scale quantization. Figures 2a, b show the original test images Lena and Bridge. Figure 2a (Lena) is typical by monotonous fields and Fig. 2b (Bridge) contains a number of details. These images were corrupted with impulsive noise. We differentiate the variable value noise and fixed value (salt and pepper) noise. The percentage denotes the number of corrupted points of the whole image. Figure 3a shows image Lena corrupted with 10 % impulsive noise (I10) and Fig. 3b shows image Lena corrupted with 20 % salt and pepper impulsive noise (BW20). We present MAE and MSE values of the corrupted images in Tab. 1.

* Department of Electronics and Multimedial Communications, Technical University of Koice, Park Komenskho 13, 041 20 Koice, Slovak Republic, lukacr@ccsun.tuke.sk, marchs@ccsun.tuke.sk

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Fig 3 Corrupted image Lena; (a) I10, (b) Bw20.

Fig 4 Output of LUM smoother; (a) I10 filtered by LUM smoother with $k = 3$, (b) Bw20 filtered by median (LUM smoother with $k = 5$).

3 THE LUM SMOOTHER

In this section we describe the LUM smoother [1,2] filter. Consider 2-D signals (*eg* an image) and a window containing a set of N samples centered about the sample x^*. This set of observations will be denoted $W = \{x_1, x_2, \dots, x_N\}$. Let the window be a simple $(2m+1)\times(2m+1) = N$ square (N will always be odd). The rank-ordered set can be written as

$$x_1 \le x_2 \le \dots \le x_N \,. \tag{1}$$

The estimate of the sample will be denoted by y^*.

DEFINITION 1. The output of the LUM smoother with tuning parameter k is given as

$$y^* = \operatorname{med}\{x_k, x^*, x_{N-k+1}\} \tag{2}$$

where $1 \le k \le (N+1)/2$.

Thus, we can achieve different levels of smoothing. For $k = (N+1)/2$, the output of the LUM filter is the median of W and maximum amount of smoothing is performed. As k is decreased, the filter exhibits improved detail-preserving characteristics; when $k = 1$, the LUM smoother becomes an identity filter (*ie*, $y^* = x^*$) and no smoothing is performed.

Table 2. Image Lena filtered by 3×3 LUM smoother

Noise	I10		BW20	
k	MAE	MSE	MAE	MSE
1	7.0181	759.1	23.4016	3438.1
2	3.0506	202.9	13.9862	1908.3
3	2.2539	64.3	6.4765	659.2
4	3.0586	59.6	4.3338	203.4
5	4.8877	94.3	5.5799	146.9

Table 3. Image Bridge filtered by 3×3 LUM smoother

Noise	I10		BW20	
k	MAE	MSE	MAE	MSE
1	7.2212	807.6	23.2214	3517.2
2	3.8360	245.5	14.5503	1947.8
3	3.5610	108.4	7.8864	701.5
4	5.0970	112.6	6.5610	257.2
5	8.0416	173.7	8.8967	235.9

The output of the LUM smoother is presented in Fig. 4. The output of the LUM smoother with a smoothing level $k = 3$ for image Lena distorted by I10 noise is in Fig. 4a. The output of LUM smoother for smoothing level $k = 3$ (it is the same as median) for image Lena distorted by BW20 noise is in Fig. 4b. These images contain preserved small details, impulses are removed.

In the next sections we show that these results can be improved by a combination of an impulse detector and any filter. We used a median filter (it is the basic or reference filter).

4 LUMsm DETECTOR

Now we present the algorithm of our approach. From Tab. 2–3 we can see that in the case of small noise (*eg* 10 % noise) the LUM smoother works very well for smoothing levels from 2 to 4, where noise is inhibited and details are preserved. For large noise (*eg* 20 % of image elements) larger smoothing levels (from 3 to 5) are appropriate. Our philosophy emanates from this. Assume a 3×3 operation window and $s_1, s_2, \dots, s_5$ are the outputs of the LUM smoother for smoothing levels from 1 to 5, respectively. Now define:

$$\mathrm{crit}_1 = |s_2 - x^*| + |s_3 - x^*| + |s_4 - x^*| \tag{3}$$

$$\mathrm{crit}_2 = |s_3 - x^*| + |s_4 - x^*| + |s_5 - x^*| \tag{4}$$

Fig 5 Our approach (ID_LUMsm + median)
(a) I10 by ID_LUMsm with Tol=60, (b) Bw20 by ID_LUMsm with Tol=90.

Definition 2. The processed pixel is corrupted:

a) Small noise

$$\textbf{IF } \text{crit}_1 > \text{Tol} \quad \textbf{THEN } \textit{filter} \quad \textbf{ELSE } \textit{do not filter} \tag{5}$$

b) Large noise

$$\textbf{IF } \text{crit}_2 > \text{Tol} \quad \textbf{THEN } \textit{filter} \quad \textbf{ELSE } \textit{do not filter} \tag{6}$$

where Tol is predetermined threshold.

From Tab. 4-5 we can see that an appropriate threshold value for small noise is the threshold=60, for large noise the threshold=90, as a default filter a 3×3 median filter was used.

Table 4. Images corrupted by I10 noise filtered by system of LUMsm detector along with 3×3 median for small noise.

Image	Lena – I10		Bridge – I10	
Tol	MAE	MSE	MAE	MSE
40	1.3406	47.0453	2.4103	88.2702
50	1.2411	44.0004	2.1336	81.3757
60	1.2312	44.3590	2.0128	78.7684
70	1.2691	47.5078	1.9427	78.6520
80	1.3290	51.8014	1.9109	79.1880
90	1.3896	55.3175	1.9292	81.7164

Table 5. Images corrupted by BW20 noise filtered by system of LUMsm detector along with 3×3 median for large noise.

Image	Lena – BW20		Bridge – BW20	
Tol	MAE	MSE	MAE	MSE
60	2.3375	105.2853	3.8413	154.6904
70	2.1892	100.4549	3.5557	151.8606
80	2.1001	98.5687	3.3618	146.2609
90	2.0696	98.9380	3.2513	145.3053
100	2.0814	102.2070	3.2029	145.7514
110	2.1151	107.0599	3.2148	151.0863

The system of LUMsm detector and median filter has an excellent property of signal-details preservation. All small details are preserved and small structures are not distorted. Even though some impulses are present in the images, this detector has an excellent performance of impulse detection.

5 OTHER IMPULSE DETECTORS

Now we present other impulse detectors (classificators) and compare their performance with the LUMsm detector.

Definition 3. E-classificator [3,5] is very simple and is based on the following formulas:

$$D = \frac{1}{N}\sum_{i=1}^{N} x_i \tag{7a}$$

$$M = \max_{i \in \{1,\dots,N\}} |x_i - D_i| \tag{7b}$$

$$C = |x_{cent} - D| \tag{7c}$$

where D is the mean value of W, M is the maximum absolute difference of the pixels in W from the mean value D, C is the absolute difference of the central pixel in the operation window from the mean value D, x_i are elements of W, and N is the size of the operation window.

The rule of the E-classificator is given:

$$\textbf{IF } C \geq M \quad \textbf{THEN } \textit{filter} \quad \textbf{ELSE } \textit{do not filter} \tag{8}$$

This detector has many false detections; these are eliminated by a biased E-classificator.

Definition 4. Biased E-classificator [3,5] eliminates E-classificator false detection. This detector is given by:

$$\textbf{IF } C \geq M \textbf{ AND } C \geq \textit{bias} \textbf{ THEN } \textit{filter} \quad \textbf{ELSE } \textit{do not filter} \tag{9}$$

The only problem is to find the optimum value of the bias. In [4] the optimum value was found to be 30.

Definition 5. Standard deviation (SDV) classificator [3] suppresses noise very well. The detector rule is the following:

$$\textbf{IF } C \geq \sigma \quad \textbf{THEN } \textit{filter} \quad \textbf{ELSE } \textit{do not filter} \tag{10}$$

where C is the absolute difference of the central pixel in the operation window from the mean value D and σ is the SDV of the operation window pixels. This detector has a good performance after the 2[nd] or 3[rd] iteration.

Definition 6. Order-statistic detector (OSD) mentioned in [4] is distinguished by its simple structure. A processed pixel is not considered. The observation vector is created from the processed pixel neighbourhoods. The observation vector $x_1, x_2, \dots, x_8$ is sorted, and the detector rule is given by:

$$\textbf{IF } |\mu - x_{cent}| \geq Tol \quad \textbf{THEN} \quad filter \qquad \textbf{ELSE} \quad do\ not\ filter \tag{11}$$

where μ is the mean of four mid-positioned ordered pixels x_3 to x_6 and Tol is the predetermined threshold. This detector achieved best results for $Tol = 40$.

In Tabs. 6–7 we compare the performance of impulse detectors mentioned above with the LUMsm detector. Detectors defined by (8) and (9) have a good performance after the 2nd or 3rd iteration.

Table 6. Comparison of impulse detectors for small noise. The detector – $(\cdot)$ means the number of iterations.

Image	Lena – I10		Bridge – I10	
Type	MAE	MSE	MAE	MSE
identity	7.018	759.1	7.2212	807.6
E – (1)	2.322	140.5	2.967	171.8
E – (3)	1.841	60.6	2.875	98.0
Biased E – (1)	2.244	141.1	2.740	167.9
Biased E – (3)	1.465	58.4	2.130	84.9
SDV – (1)	2.317	71.7	3.876	123.4
OSD – (1)	1.744	62.9	2.455	94.3
LUMsm – (1)	1.231	44.4	1.9	79.2

Table 7. Comparing of impulse detectors for large noise. The detector – $(\cdot)$ means the number of iterations.

Image	Lena – BW20		Bridge – BW20	
Type	MAE	MSE	MAE	MSE
identity	23.402	3438.1	23.221	3157.2
E – (1)	6.563	629.9	6.924	608.4
E – (3)	2.814	140.5	4.054	173.3
Biased E – (1)	6.513	629.7	6.867	607.8
Biased E – (3)	2.333	134.3	3.354	160.7
SDV – (1)	2.676	120.2	3.937	161.4
OSD – (1)	2.527	109.5	3.890	159.0
LUMsm – (1)	2.067	98.9	3.215	151.1

From Tabs. 6–7 we can see that the LUMsm detector provides the best results, *ie* the smallest MAE and MSE values. These results establish the best performance of impulse detection for the LUMsm detector and noise removing and signal-detail preservation by the system of the LUMsm detector and median filter.

6 CONCLUSION

In this paper a new impulse detector was presented, the LUMsm detector, based on a LUM smoother filter. The LUMsm detector is distinguished by its simple structure and excellent performance of impulse detection. The LUMsm detector is controlled by a threshold (bias). The system of the LUMsm detector and median filter excellent performs noise removing, while signal-details remain non-distorted or blurred. Experimental results were performed on several test images and noise models. In this paper, the results are presented for images Lena and Bridge and for I10 and BW20 noise only. By comparing the performance of the LUMsm detector with other impulse detectors we assured that our approach has the best performance in impulse detection. Our future research is oriented to a detector controlled by neural networks [6,7].

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Rastislav Lukáč received the Ing degree from the Technical University of Košice, Slovak Republic, in electronics and multimedial communications in 1998. Currently, he is a PhD student at the Department of Electronics and Multimedial Communications of the Technical University in Košice. His research interests include image filtering, neural networks and permutations.

Stanislav Marchevský received the MSc degree in electrical engineering from the Faculty of Electrical Engineering of the Czech Technical University in Prague in 1976 and the PhD degree in radioelectronics from the Technical University in Koice in 1985. Since 1987 he has been associate professor at FEI TU in Košice.