AN ADAPTIVE CONTROL OF LUM SMOOTHER

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Abstract

In this paper is presented a new design of LUM smoother. The LUM smoother, a subclass of lower-upper-middle (LUM) filters is used in smoothing image and signal applications. This filter very well can suppress impulsive noise and preserve signal details, simultaneously. It is achieved by simply varying the filter parameter for smoothing. However, the tuning parameter for smoothing is fixed for whole image. A new design is based on adaptive controlled level of the smoothing. The analysis of a new method is presented. Performance of the proposed methods is evaluated through subjective and objective criteria and compared with the traditional LUM smoother and the well-known median.

Keywords

LUM filters, median, impulsive noise, adaptive, smoothing

1. Introduction

A class of rank-order-based filters, lower-upper-middle (LUM) filters were described in detail [2]. The name of these filters follows since a lower- and upper-order statistics are compared with the middle sample in the filter window to determine the output. These filters can be designed for smoothing, sharpening, and outlier rejection. This wide range of characteristics can be obtained from a single filter structure by simply varying the filter parameters. By the type of characteristics, the class of LUM filters is divided to four subclasses [1] such as LUM smoother, LUM sharpener [5], general LUM filter and asymmetric LUM filter.

In smoothing applications, the median is still the most widely used. However, the median introduces too much smoothing. The blurring introduced may be more objectionable than the original noise. When the LUM filter is used as smoothers, it can take on a range of smoothing characteristics. The level of smoothing done by LUM smoother can range from no smoothing to that of the median. Thus, by desirable level of smoothing can be achieved the best balance between noise suppression and detail preservation.

However, the tuning parameter for smoothing is fixed for whole image. Thus, the excessive or insufficient smoothing can be performed. This problem is solved by a new method based on the adaptive controlled level of smoothing. A new method has excellent performance of noise reduction in the environments corrupted by an impulsive noise with variable random value. In addition, similar approach can be expanded to LUM sharpener or others subclass of LUM filters.

The remainder of this paper is organised as follow. In Section 2, the traditional LUM smoother is defined. In Section 3, the new method is presented and the detailed description is provided. Experimental results are presented in the Section 4, the pictures and tables are included. In this section, noise models and the objective criterions are described. This section contains a number of filtered images and comparisons with the traditional LUM smoother and the median. Properties of the methods are summarised in the conclusion, where the directions of next research are mentioned.

2. LUM Smoother

Nonlinear filters based on order statistics have excellent robustness properties. The best-known order statistics filter is a simple median of the points within a filter window.

The output of median filter is given by

$$y^{*} = med\{W\} = x_{((N+1)/2)}, \qquad (1)$$

where y^{*} is an estimate of the processed sample x^{*}, W is a set of observations determined by the filter window, $x_{((N+1)/2)}$ is a central sample of ordered set defined by (2). Note, that W is a set of N samples centered about the sample x^{*} and *med* is a median operator.

$$x_{(1)} \le x_{(2)} \le \ldots \le x_{(N)} \qquad (2)$$

In many applications, the median introduces too much smoothing. The LUM smoother, a subclass of a lower-upper-middle (LUM) filters [1,2], achieves the best balance between noise smoothing and signal-detail preservation. A structure of LUM smoother is based on tuning parameter k for the smoothing. Varying this parameter changes the level of the smoothing from no smoothing (i.e. identity filter for k=1, where $y^{*}=x^{*}$) to the maximum amount of smoothing (i.e. median, $k=(N+1)/2$).

Thus, the smoothing function is created by a simply comparing of processed sample x^{*} to the lower- and upper-order statistics. If x^{*} lies in a range formed by these order statistics it is not modified. If x^{*} lies outside this range it is replaced by a sample that lies closer to the median.

The output of LUM smoother is given by

$$y^{*} = med\left\{x_{(k)}, x^{*}, x_{(N-k+1)}\right\}, \qquad (3)$$

where $x_{(k)}$ and $x_{(N-k+1)}$ are lower and upper order statistics of the ordered set.

This definition is equivalent to center-weighted median that is given by the median over a modified set of observations containing multiple processed samples. However, implementation of the LUM smoother as shown in (3) requires fewer operations than that of (4), since fewer elements must be sorted.

$$y^{*} = med\left\{W \cup \{\underbrace{x^{*}, x^{*}, \ldots, x^{*}}_{w-1}\}\right\} \qquad (4)$$

In (4) w is the weight of the central sample and is assumed to be an odd positive integer. The relationship between the parameter w in the center-weighted median and the parameter k in the LUM smoother is

$$w = N - 2k + 2\,. \qquad (5)$$

3. New Method

The traditional approach of 3x3 LUM smoother is based on the fixed level of smoothing for whole image. Thus, the excessive or insufficient smoothing can be performed. By the adaptive change of the level of smoothing is reduced deviation from the desired estimate and the better result can be achieved. The blurring introduced may be more objectionable than the original noise.

A new method is based on similar approach as a LUMsm impulse detector [6]. This detector is characterised by the all desired properties of LUM filters such as detail preservation, noise reduction and achieves the best performance of impulse detection in comparison with others method [3,7,8].

The decision rule of LUMsm detector is given by

$$\textbf{IF}\ \ crit \geq Tol\ \ \textbf{THEN}\ \ \textit{filter} \qquad (6)$$
$$\textbf{ELSE}\ \ \textit{not filter},$$

where Tol is predetermined threshold (optimal value 60 or 90 for various types of the noise [6]) and $crit$ is a reduced sum of absolute differences d_k between the processed sample x^{*} and the outputs of LUM smoothers for each possible value of tuning parameter k.

The absolute difference d_k is determined by

$$d_k = \left|x^{*} - y_k\right|, \qquad (7)$$

where k=1,2,...,5 is tuning parameter for smoothing and y_k is output of LUM smoother corresponding to k.

The principle scheme of LUM smoother with adaptive controlled level of the smoothing is shown on a Fig.1. The algorithm of this method is presented in Fig.2. The set of observation is sorted in first step. Then, the outputs of LUM smoothers and absolute differences are computed for each k. Obtained absolute differences d_k are compared with

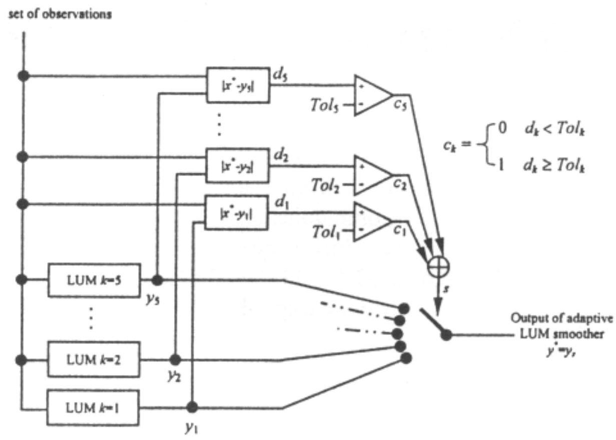

Fig.1 Principle scheme of adaptive LUM smoother

predetermined thresholds Tol_k for k=2,3,...,5. The outputs of comparators is determined by

$$\textbf{IF}\ \ d_k \geq Tol_k\ \ \textbf{THEN}\ \ c_k = 1 \qquad (8)$$
$$\textbf{ELSE}\ \ c_k = 0,$$

where k=2,3,...,5 and c_k are the outputs of comparators. Note, that c_1=1 or Tol_1=0 (identity filter). Finally, in every location of running window the output of adaptive LUM smoother is equal to smoothing level y_k corresponding to sum of comparator outputs (see Fig.1). Then, the outputs of adaptive LUM smoother is given by

$$y^{*} = y_s\,, \qquad (9)$$

where s is a sum of c_k and $y_1, y_2, \ldots y_5$ are the outputs of traditional LUM filters.. Note, that $1 \leq s \leq 5$.

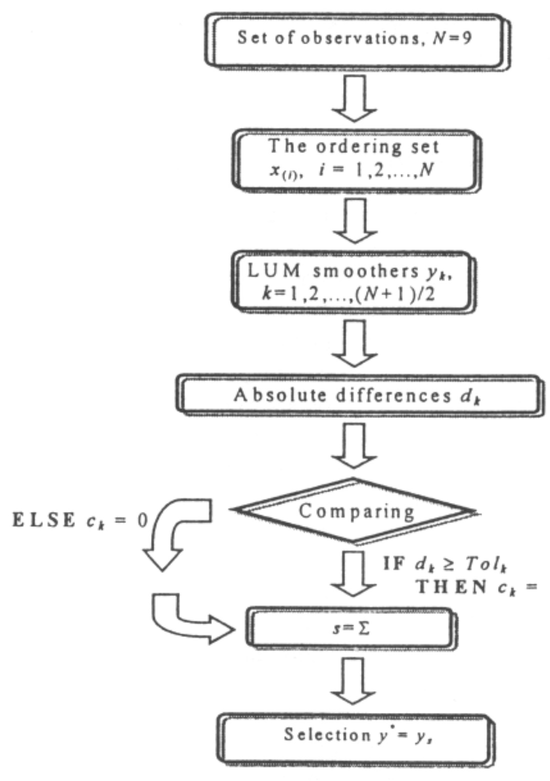

Fig.2 Algorithm of adaptive LUM smoother

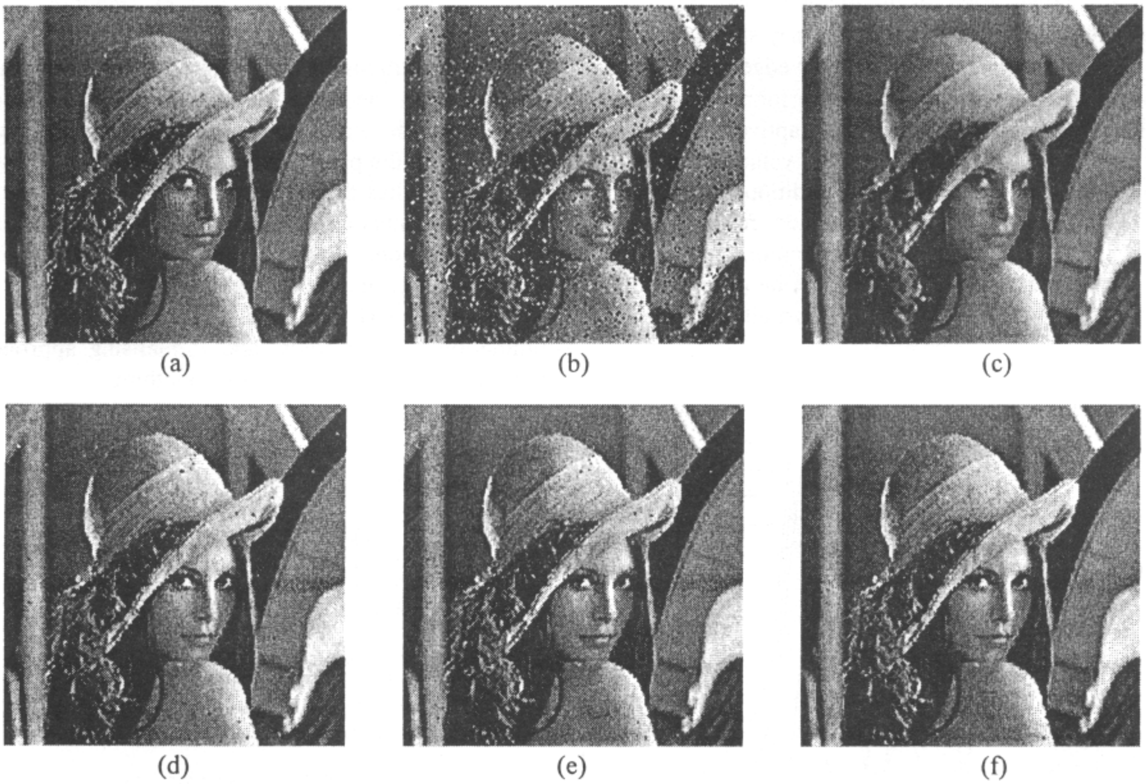

Fig.3 (a) Original image (b) Noisy image (10% impulsive noise) (c) Median filter (d) LUM k=3 (e) New method – adaptive LUM smoother (1st iteration) (f) New method – adaptive LUM smoother (2nd iteration)

Thus, the output of adaptive LUM smoother is given by most appropriate value determined by output of traditional LUM smoother.

4. Experimental Results

To demonstrate the performance of the proposed methods were used various test images, but the results are presented for image Lena, only. Fig.3(a) shows original test image, that has a resolution of 256 x 256 pixels with 8 bits/pixel grey-scale quantization. This image contains monotonous fields and problem areas (eyes, hair and other image details), too. Two types of variable impulsive noise were used (5% and 10%). Fig.3(b) shows the original image corrupted by the I10 noise. For objective comparison the well-known mean absolute error (MAE) and mean square error (MSE) are used. The results obtained by new method are compared to the median and traditional LUM smoother.

Fig.3(c) is the result of 3x3 median filter (LUM smoother for k=5). This image is very blurred, small structures and high frequency elements were distorted, a reconstruction process is not good performed. Through this result, it can be noticed that the median filter smoothes out the noise as well as the image details. This results in a blurred image.

Fig.3(d) corresponds to the LUM smoother with tuning parameter k=3. Although, some impulses are presented in the image, signal details are preserved excellent and no blurring is observed. Thus, the best balance between noise smoothing and detail preservation was achieved.

Table 1 Traditional LUM smoother

Noise	5%		10%	
Filter	***MAE***	***MSE***	***MAE***	***MSE***
Identity	3.540	374.3	7.018	759.1
LUM k=2	1.443	73.3	3.051	202.9
LUM k=3	1.640	35.4	2.254	64.3
LUM k=4	2.711	48.3	3.059	59.6
Median	4.563	85.4	4.888	94.3

Table 2 A new method – the adaptive LUM smoother

Noise	5%		10%	
Iteration	***MAE***	***MSE***	***MAE***	***MSE***
1	0.806	28.0	1.445	54.5
2	0.852	28.5	1.381	44.6

Previous results are summarised in Table 1. From this quantitative evaluation it can seen that LUM smoother with tuning parameter k=3 achieved the best results under the MAE criteria. It means that this filter preserves signal details better than others. The LUM smoother with k=4 suppresses impulsive noise very well, but on the other hand it introduces a little blurring. However, these results are better in comparison with median.

Fig.3(e) shows the result obtained by proposed method. A simple visual comparison clearly shows that the adaptive LUM smoother preserves better edges and details in image than previous methods. The performance of new method is evaluated in Table 2. The adaptive LUM filter achieved excellent MAE value and MSE value is markedly less than traditional approaches. In addition, the second iteration (Fig.3(f)) can improve obtained result. Unlike traditional LUM smoother, the restoration process is excellent performed. From Fig.3(f) it can be observed that details were preserved very well and almost all impulses are removed.

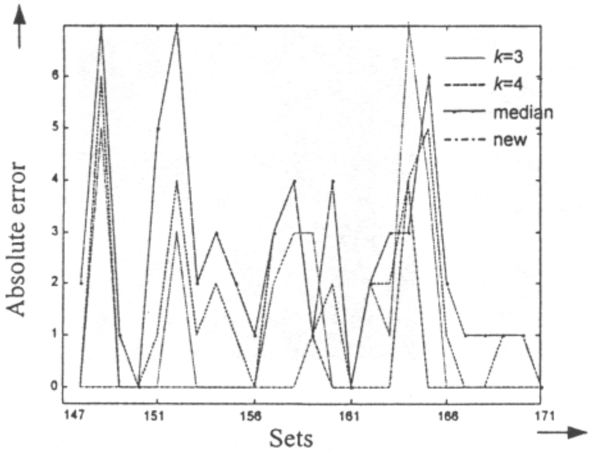

Fig.4 Error curves for 10% impulsive noise

Fig.4 shows the visual comparison of error curves between the traditional approaches of LUM smoother and the proposed method. The horizontal plot axis corresponds to the sets of column pixels. This analysis was performed for 95th row and 147-171 column pixels. The vertical axis shows the absolute error between origin and used filter estimates. This picture shows that the proposed method is characterised by minimal error. As illustrated in Fig.4, the median filter performs more smoothing than is desired.

The optimal filter thresholds for single levels of smoothing were obtained from a number of experiments. From principle of the proposed method is resulting that control threshold for LUM smoother with tuning parameter k=1 (identity filter) is Tol_1=0. Let $Tol = \{Tol_1, Tol_2, ..., Tol_5\}$ is the set of control thresholds. Then the set of optimal control thresholds obtained from a number of experiments can be described as $Tol = \{0,10,15,30,30\}$. This set was used to obtain results to this paper.

5. Conclusion

A new method for impulsive noise filtering has been developed, presented and compared to the well-known median and the traditional LUM smoothing filters. A new method has excellent performance of noise reduction in the environments corrupted by an impulsive noise with variable random value. The proposed adaptive LUM smoother is simple and successful in smoothing application. By the simple adaptive controlled level of smoothing achieved excellent results.

The traditional LUM smoother performs the noise reduction with the fixed level of smoothing for the whole image. Thus, the excessive or insufficient smoothing can be performed. In the proposed method, such constraints do not exist. This makes the proposed method more preferable in the environments corrupted by variable impulsive noise.

In addition, similar approach can be expanded to LUM sharpener or others subclass of LUM filters.

Future work in this area will concentrate on elimination of thresholds, and formalising approach with better decision for the levels of smoothing.

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