Adaptive Impulse Detection Using Center-Weighted Median Filters

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***Abstract*—Previous median-based impulse detection strategies tend to work well for fixed-valued impulses but poorly for random-valued impulse noise, or vice versa. This letter devises a novel adaptive operator, which forms estimates based on the differences between the current pixel and the outputs of center-weighted median (CWM) filters with varied center weights. Extensive simulations show that the proposed scheme consistently works well in suppressing both types of impulses with different noise ratios.**

***Index Terms*—Image processing, impulse noise, median filters.**

I. Introduction

THE corruption by impulse noise is a frequently encountered problem in image acquisition and transmission. Attenuation of noise and preservation of details are usually two contradictory aspects of image processing. Nevertheless, both of them are important to subsequent processing stages [1]. The median filter, as well as its modifications and generalizations (e.g., [2], [3]), has been demonstrated to offer good performance in the removal of impulse noise. However, because these approaches are typically implemented invariantly across an image, they also tend to alter pixels undisturbed by noise. Additionally, they are prone to edge jitter in cases where the noise ratio is high [4]. As a result, the effectiveness in noise suppression is often at the expense of blurred and distorted image features.

One way to circumvent this situation is to incorporate some decision making process in the filtering framework, which is based on a very simple but effective impulse detection and rejecting mechanism. At each pixel location, it is to detect whether the current pixel is contaminated. Then, for the corrupted pixels, some nonlinear filtering is activated, while the noise-free pixels are left unaltered. Since not every pixel is filtered, undue distortion can be avoided. On the other hand, the impulse detection becomes therefore crucial to the subsequent filtering. Recently, such detection based median filtering techniques realized by thresholding operations have been investigated using differently defined impulse detectors [5]–[7]. In those approaches, the output is switched between those of the identity and some median based filters. However, one disadvantage is that the decision rules are typically based on a single threshold for locally obtained statistics. Those strategies tend to work well for large, fixed-valued impulses but poorly for random-valued impulse noise, or vice versa. Differently, the median filter is replaced with a rank-ordered mean (ROM) filter [8] that excludes the current pixel itself from the operation window. In the ROM-based switching scheme [8], multiple thresholds are used in the impulse detection, which operates on the differences between the current pixel and the remaining rank-ordered elements in the filter window. It has been shown to work well in removing both types of impulses.

In this work, we propose a novel adaptive median filter that employs the switching scheme based on the impulse detection mechanism. The objective is to utilize the center-weighted median (CWM) [2] filters that have varied center weights to define a more general operator, which realizes the impulse detection by using the differences defined between the outputs of CWM filters and the current pixel of concern. The ultimate output is switched between the median and the current pixel itself. While still using a simple thresholding operation, the proposed filter yields superior results to other switching schemes in suppressing both types of impulses with different noise ratios. This paper is organized as follows. The new impulse detector is formulated in Section II, where its implementation is also discussed. Section III reports a number of experimental results to demonstrate the performance of the new filter. Finally, conclusions are drawn in Section IV.

II. Formulation and Implementation

Consider a window W defined in terms of the image coordinates symmetrically surrounding the current or origin pixel $W = \{(s, t) | -h \le s \le h, -h \le t \le h\}$. The output of CWM filters [2], in which a weight adjustment is applied to the origin sample X_{ij} within the sliding window, can be described as

$$Y_{ij}^{w} = \mathrm{median}(\boldsymbol{X}_{ij}^{w}) \tag{1}$$

where

$$\boldsymbol{X}_{ij}^{w} = \{X_{i-s,\,j-t},\, w\diamondsuit X_{ij} \mid (s,t) \in W,\, (s,t) \ne (0,0)\}. \tag{2}$$

In the above equations, ($w = 2k+1$ where k is a nonnegative integer) denotes the center weight, and operator $\diamondsuit$ represents the repetition operation. Throughout the following discussion, unless otherwise stated, the window size is assumed to be $2L+1$ ($L>0$). Clearly, the output of standard median filtering is Y_{ij}^{1} (i.e., $k=0$), whereas the identity filter is equivalent to Y_{ij}^{2k+1}, where $k \ge L$.

For current pixel X_{ij} under consideration, we first define differences

$$d_k = |Y_{ij}^{w} - X_{ij}| = \left|Y_{ij}^{2k+1} - X_{ij}\right| \tag{3}$$

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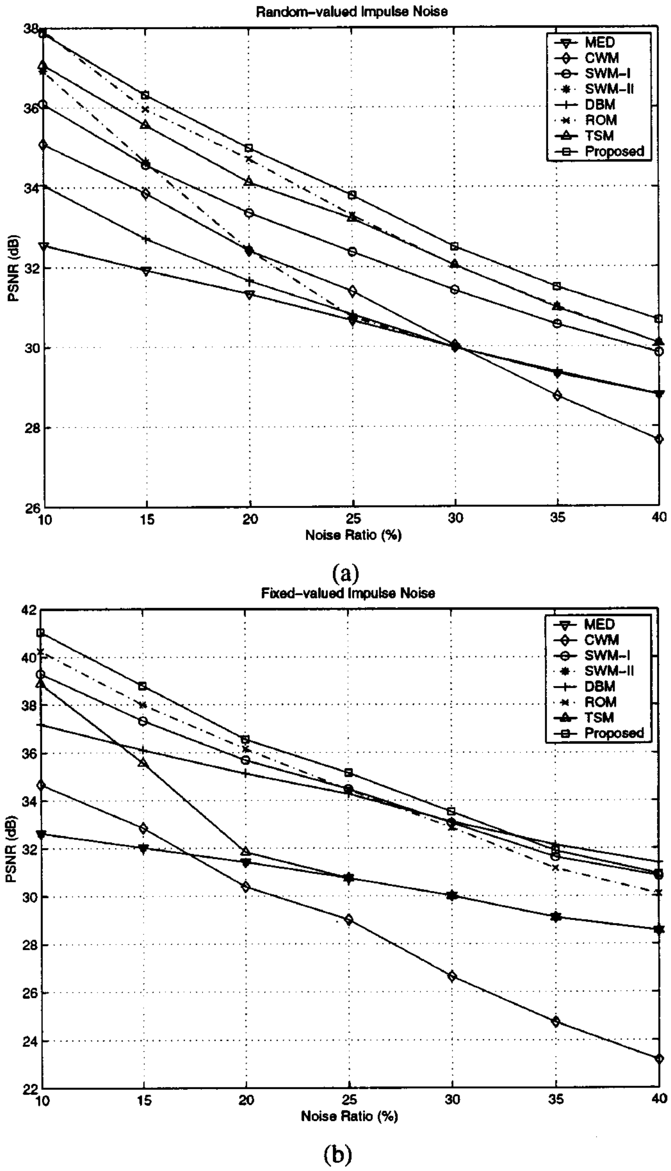

Fig. 1. Performance comparison of different methods for filtering the *Lena* image corrupted by various amounts of (a) random-valued and (b) fixed-valued impulses, respectively.

where $k = 0, 1, \cdots, L-1$. It is readily seen that $d_k \leq d_{k-1}$ $(k \geq 1)$, based upon the derivation shown in [7]. These differences provide information about the likelihood of corruption for the current pixel. For example, consider the difference d_{L-1}. If this value is large, then the current pixel is not only the smallest or the largest one among the observation samples $\boldsymbol{X}_{ij}^1$ within the window, but also very likely contaminated by impulse noise. On the other hand, in the case where d_0 is small, the current pixel may be considered as noise-free and be left unchanged in the filtering. Together, the differences d_0 through d_{L-1} reveal even more information about the presence of a corrupted pixel.

The objective of the impulse detector is to determine whether the current pixel is corrupted. The decision making mechanism is realized by employing a set of thresholds T_k $(k = 0, 1, \cdots, L-1)$, where $T_{k-1} > T_k$ for $k = 1, \cdots, L-1$. Specifically, if any of the inequalities $d_k > T_k$ $(k = 0, 1, \cdots, L-1)$ are true, then pixel X_{ij} is regarded as an impulse. Otherwise, the impulse detector assumes the current pixel as noise-free. In a word, the proposed filter can be realized as follows:

$$\hat{X}_{ij} = \begin{cases} Y_{ij}^1, & \text{if } \exists k,\, d_k > T_k \\ X_{ij}, & \text{otherwise} \end{cases} \tag{4}$$

where $\hat{X}_{ij}$ denotes the final estimate of current pixel X_{ij}.

The primary difficulty associated with the proposed approach is the selection of the thresholds, which influences the performance of the new filter. In our experiments, a 3×3 window (i.e., $h = 1$ and $2L + 1 = 9$) is applied. Therefore, four thresholds, T_k $(k = 0, \cdots, 3)$, are employed. The median of the absolute deviations from the median (MAD), which is defined as

$$\text{MAD} = \text{median}\left\{\left|X_{i-s,\,j-t} - Y_{ij}^1\right| \mid (s,\, t) \in W\right\}$$

is a robust estimate of dispersion [9], [1], and its scaled forms can be used here. Specifically, the thresholds are described as $T_k = s \cdot \text{MAD} + \delta_k$. From the simulations conducted on a broad variety of images, it has been observed that the selection satisfying $[\delta_0, \delta_1, \delta_2, \delta_3] = [40, 25, 10, 5]$ yields satisfactory results in filtering random-valued impulse noise, while the setting of $[\delta_0, \delta_1, \delta_2, \delta_3] = [55, 40, 25, 15]$ consistently performs well in removing fixed-valued impulses. Here, parameter $s(\geq 0)$ varies for different images degraded with different noise ratios, and it is also observed empirically that good results could be obtained using $0 \leq s \leq 0.6$ in suppressing both types of impulse noise for various images. Hence, due to the robustness of the algorithm, the determination of the thresholds is simplified to the adjustment of parameter s.

III. Simulations

The performance of the proposed impulse rejecting filter has been evaluated and compared with those of some existing detection based filters. In our simulations, a group of 512×512 gray-scale images corrupted by fixed-valued and random-valued impulses with various noise ratios are used. The noise intensity of fixed-valued impulses corresponds to 0 or 255 with equal probability, while for the random-valued impulses, the noise values are uniformly distributed in the range of [0, 255]. The peak SNR (PSNR) is used to measure the image quality.

For performance comparison, the standard median (MED) filter, CWM filter $(w \geq 3)$, switching median I (SWM-I) [5], switching median II (SWM-II) [5], decision-based median (DBM) filter [6], ROM-based switching scheme [8], and tri-state median (TSM) filter [7] have also been simulated. In all the cases, a 3×3 filtering window slides from pixel to pixel in raster scanning fashion. For the CWM filter, center weights are selected in order to obtain better performances for different cases. Thresholds used in different filtering schemes were tuned, respectively, for different degraded images. Finally, all the algorithms are implemented recursively, that is, the estimate of the current pixel is dependent on the new values instead of the old ones, of previously processed pixels. The output of

TABLE I
COMPARATIVE RESULTS IN PSNR (dB) OF FILTERING DIFFERENT IMAGES CORRUPTED BY 20% IMPULSES

Filters	Random-valued Impulse Noise					Fixed-valued Impulse Noise				
	Boats	*Bridge*	*Flower*	*Goldhill*	*Lena*	*Boats*	*Bridge*	*Flower*	*Goldhill*	*Lena*
MED	29.57	24.60	34.79	29.61	31.33	29.59	24.67	34.79	29.60	31.42
CWM	30.99	26.34	35.27	30.89	32.42	29.81	25.67	32.99	29.87	30.39
SWM-I [5]	31.57	26.76	36.77	31.95	33.37	32.54	27.85	39.47	33.23	35.68
SWM-II [5]	30.99	26.74	34.79	30.90	32.43	29.59	24.67	34.79	29.60	31.42
DBM [6]	30.38	25.91	34.95	30.41	31.66	33.61	28.22	39.01	33.31	35.12
ROM [8]	32.46	27.50	38.65	32.61	34.71	33.89	28.33	39.68	34.18	36.15
TSM [7]	32.29	27.39	37.92	32.44	34.13	31.16	27.65	34.79	31.53	31.84
Proposed	32.84	27.61	38.91	32.76	34.98	33.90	28.40	39.77	34.42	36.54

recursive median filters tends to be much more correlated than that of their nonrecursive counterparts. Nevertheless, the recursive implementation also causes an increase in blurring [10]. Since the proposed algorithm adaptively selects the filtering operation at each pixel location based on locally obtained signal statistics, better noise attenuation and thus generally better results have been obtained without excessive blurring of details when it is applied recursively.

The first experiment is conducted to gauge the efficacy of the proposed technique for filtering images corrupted with different noise ratios. The results for the *Lena* image are shown in Fig. 1, where the noise ratios for the two types of impulses range from 10% to 40%. It is interesting to note that in some cases, several impulse rejecting filters degenerate to the standard median filter by adjusting the employed thresholds in order to achieve a better performance. It is obviously seen that the proposed technique provides superior results to the other methods in removing both types of impulses with different noise ratios.

To assess the effectiveness of the proposed filter in processing different images, Table I presents the comparison results for images degraded by both kinds of impulses, where 20% of the pixels are contaminated in each image. The improvement achieved by the new filter is apparently shown. In addition, it is observed that the proposed filter yields (visually) more pleasing images, providing the best tradeoff between noise suppression and detail preservation.

IV. CONCLUSIONS

With the assistance of differences defined between the outputs of CWM filters and the current pixel under consideration, a more general operator that realizes the impulse detection is formulated. The proposed impulse detector is shown to be robust for a wide variety of images, which therefore simplifies the selection of the thresholds to the adjustment of a single parameter. Compared to other detection-based filtering schemes, the proposed technique consistently yields satisfactory results in suppressing both of the random-valued and fixed-valued impulse noises while still possessing a simple computational structure.

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