Efficient Removal of Impulse Noise from Digital Images

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**Abstract — ***A new impulse noise removal technique is presented to restore digital images corrupted by impulse noise. The algorithm is based on fuzzy impulse detection technique, which can remove impulse noise efficiently from highly corrupted images while preserving image details. Extensive experimental results show that the proposed technique performs significantly better than many existing state-of-the-art algorithms. Due to its low complexity, the proposed algorithm is very suitable for hardware implementation. Therefore, it can be used to remove impulse noise in many consumer electronics products such as digital cameras and digital television (DTV) for its performance and simplicity*[1].

Index Terms — Signal processing, image enhancement, impulse noise, impulse detection.

I. INTRODUCTION

The acquisition or transmission of digital images through many consumer electronics products such as digital cameras and digital television (DTV) is often interfered by impulse noise. For example, impulse noise can be added to still images in digital cameras or video sequences of DTV in various steps such as image acquisition, recording, and transmission. The standard television broadcast signals are often contaminated with impulse noise arising from various sources such as household electrical appliances and atmospheric disturbances. In order to get images and video sequences of high quality in digital cameras and DTV, it is very important to eliminate impulse noise in the images.

A large number of algorithms have been proposed to remove impulse noise while preserving image details. Among them, the median filter and its modifications [5] are used widely because of their effective noise suppression capability. However, most of the median filters are implemented uniformly across the image and thus tend to modify both noisy and noise-free pixels. Consequently, the effective removal of impulse noise is often accomplished at the expense of blurred and distorted features, thus removing fine details in the image [9]. To avoid the damage of good pixels, the switching strategy was introduced by some recently published papers [1]-[15], where an impulse detector was used to determine whether a pixel should be modified. The switching median filters [2][9] have been shown to be simple and yet more effective than uniformly applied methods, such as median filter.

The existing detection schemes are based on various techniques, for example, weighted median [2][9], rank-order thresholding [1], local signal statistics [4], and fuzzy techniques [8], etc. In addition, some methods, such as those in [1], are based on previous training. A rank-order thresholding-based and a soft-switching impulse detector were shown work well under high noise corruption but at the cost of significantly increasing computational complexity [1][3]. The iterative procedure in [11] and the variational method in [12] involve the very time-consuming minimization of complicated functional.

In this paper, a new impulse noise removal algorithm based on fuzzy impulse detection technique is proposed, which exhibits better impulse removal ability than many other more complicated detectors, and requires no previous training. In particular, it can successfully remove impulse noise from highly corrupted images very efficiently while preserving image details. The experimental results show that the proposed method performs significantly better than many other well-known techniques.

The remainder of this paper is organized as follows. In Section II, the new impulse noise removal technique is proposed. Experimental results are presented in Section III. Finally, Section IV concludes the paper.

II. A NEW EFFICIENT IMPULSE REMOVAL TECHNIQUE

In this section, the proposed novel approach for the efficient removal of impulse noise from digital images is presented. The noise considered in this paper is only salt-pepper impulsive noise with uniform distribution as practiced in [3], [4], and [9]. That is, each image pixel has equal probability of being corrupted to either a positive impulse (with value 255) or a negative impulse (with value 0). In this paper, noise ratio is used to represent how much an image is corrupted. For example, if an image is corrupted by impulse noise with noise ratio 20%, then 10% of the pixels in the image are corrupted by positive impulses and 10% of the pixels by negative impulses.

A. Fuzzy Impulse Detection

The goal of the fuzzy impulse detection is to generate a fuzzy flag map which gives each pixel a fuzzy flag indicating how much it looks like an impulse pixel.

Let I denote the corrupted, noisy image of size $l_1 \times l_2$, and x_{ij} is its pixel value at position (i, j), i.e., $I = \{x_{ij} : 1 \le i \le l_1, 1 \le j \le l_2\}$. It is well-known that a natural, noise-free image is locally smoothly varying, and is

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separated by edges [9]. A noisy pixel (an impulse) is usually located near one of the two ends in the interval of possible pixel values [16]. As an example, the histogram of the noisy image (see Fig. 6(a)) of *Lena* corrupted by 30% impulse noise is given below. From Fig. 1, it is clear that there are two peaks at both ends of the histogram, which identifies the locations and values of impulse noise, especially when the images are highly corrupted.

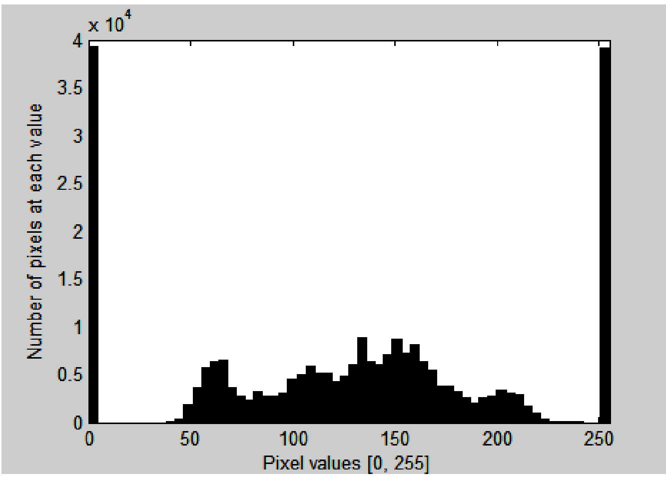


Fig. 1. The histogram of the noisy image of Lena corrupted by 30% impulse noise.

Let W_{ij} denote the 3x3 window centered about x_{ij}, i.e., $W_{ij} = \{x_{i-1,j-1}, \cdots, x_{ij}, \cdots, x_{i+1,j+1}\}$. In order to judge whether x_{ij} is an impulse pixel, the proposed impulse detection algorithm consists of the following steps.

Step 1: Detect the locations and values of impulse noise based on the histogram of the noisy image as is shown in Fig. 1.

Step 2: Test to see if the pixel value x_{ij} matches one of the peak locations in the histogram of the noisy image.

Step 3: If it does not match, then x_{ij} is a noise-free pixel. Otherwise, calculate the minimum value M_{ij} of $| x_{ij} - s_{ij} |$ for all $s_{ij} \in W_{ij}$ and $s_{ij} \neq x_{ij}$. The value of M_{ij} provides us with a simple and effective measure for detecting impulses.

Step 4: To give the pixel x_{ij} a fuzzy flag indicating how much it looks like an impulse pixel, the following two-parameter membership function is used:

$$f_{ij} = \begin{cases} 0 & \mathrm{M}_{ij} \leq T_1 \\ \dfrac{\mathrm{M}_{ij} - T_1}{T_2 - T_1} & T_1 \leq \mathrm{M}_{ij} \leq T_2 \\ 1 & \mathrm{M}_{ij} \geq T_2 \end{cases} \qquad (1)$$

where T_1 and T_2 are two pre-determined parameters. Extensive experiments indicate that restored images with high quality can be obtained with the proposed algorithm when $10 \leq T_1 \leq 20$ and $22 \leq T_2 \leq 32$. For all noise-free pixels, f_{ij} is set to zero.

B. Impulse Noise Cancellation

After the membership function f_{ij} for each pixel x_{ij} is calculated, the pixel value of x_{ij} is replaced by a linear combination of its original value x_{ij} and the median m_{ij} of W_{ij}. That is,

$$y_{ij} = (1 - f_{ij}) * x_{ij} + f_{ij} * m_{ij} \qquad (2)$$

where y_{ij} is the restored value of x_{ij}.

From (2), it is clear that for a**Error! Bookmark not defined.** noise-free pixel, i.e., $f_{ij} = 0$, its value is unchanged, i.e., $y_{ij} = x_{ij}$. For a heavily corrupted pixel, i.e., $f_{ij} = 1$, its value is replaced by the median m_{ij}. For all other pixels ($0 < f_{ij} < 1$), the restored pixel value y_{ij} is a linear combination of x_{ij} and m_{ij} as in (2).

Fig. 2 shows the diagram of the proposed impulse noise removal method.

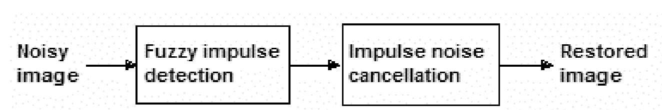


Fig. 2. Block diagram of the proposed impulse noise removal technique using fuzzy impulse detection.

III. EXPERIMENTAL RESULTS

In this section, extensive experimental results with multiple commonly used gray-scale test images of size 512x512 are presented to assess the performance of the proposed impulse noise removal technique. The standard gray-scale test images used in the computer simulations have distinctly different features, including *Lena*, *Bridge*, and *Baboon* as shown in Fig. 3. For simplicity, the parameters T_1 and T_2 are set to 15 and 25, respectively, in the following experiments. In order to further improve the restoration results, the proposed algorithm is applied iteratively.

Peak signal-to-noise ratio (PSNR) [1]-[15] is used to assess the restoration results, which measures how close the restored image is to the original image. The PSNR (dB) is defined as

$$\mathrm{PSNR} = 10\log_{10}\frac{255^2}{1/(l_1 * l_2)\sum_{i=1}^{l_1}\sum_{j=1}^{l_2}(o_{ij} - t_{ij})^2} \quad (3)$$

where $l_1 \times l_2$ is the size of the image, and o_{ij} and t_{ij} are the pixel values at position (i, j) within the original image and the test image, respectively.

In Table 1, the performance of the proposed method is compared with that of many other well-known algorithms. The test image used for this comparison is *Lena*, which is corrupted by 20% impulse noise. The results of several existing algorithms are listed in Table I, along with the result of the proposed algorithm at the end of the table. From Table I, it is clear that the proposed algorithm provides significant improvement over all the other approaches. Similar results are obtained for other standard test images and different noise ratios.

TABLE I
COMPARISON OF RESTORATION RESULTS IN PSNR FOR IMAGE LENA CORRUPTED BY 20% IMPULSE NOISE

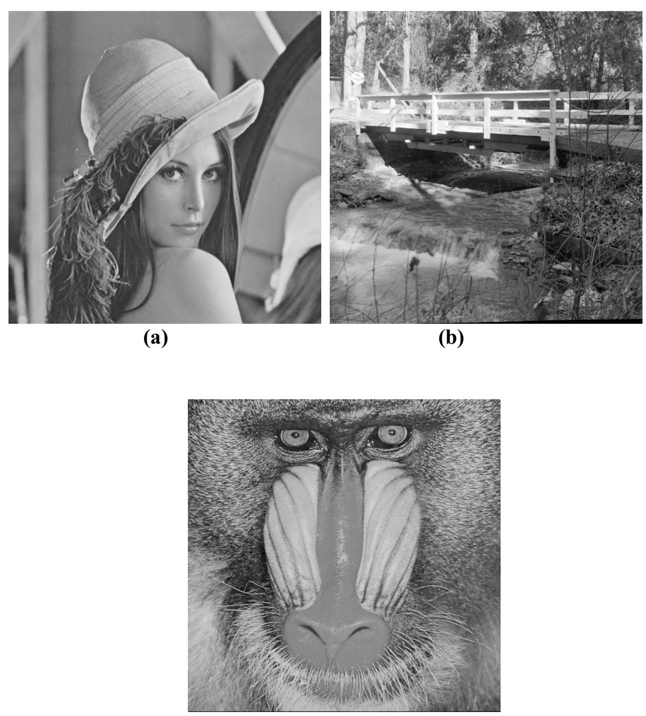
Algorithm	PSNR (dB)
Median filter with adaptive length [5]	30.57
Sun and Neuvo, Switch I median filter [9]	31.97
Sun and Neuvo, Switch II median filter [9]	29.96
Weighted fuzzy mean filters [19][20]	28.60
Fuzzy filter [8]	30.75
TSM filter [2]	30.57
Decision-based median filter [4]	32.02
Abreu et al. (M=2, no training) [1]	33.47
Abreu et al. (M=1296, outside training set) [1]	34.65
Abreu et al. (M=1296, inside training set) [1]	35.70
CSAM filter [17]	36.44
Long-range correlation [18]	36.95
The proposed algorithm	37.62

In Figs. 4 and 5, the noisy images and the corresponding restored images are given for the test images corrupted by 20% and 30% impulse noise, respectively, to show how the proposed algorithm performs on different kinds of image details. From Figs 4 and 5, it is easy to see that excellent restoration results are obtained by the proposed algorithm. It can remove almost all of the noise pixels while preserving image details very well. The visual qualities of the restored images are very good considering the abundance of image details and the high noise probabilities.

As a final remark, it is worth noting that the weighted fuzzy mean filters (WFM) proposed in [19][20] used the histogram of a reference image to derive a number of fuzzy sets contained in the knowledge base, which was used by WFM. The key difference between WFM and the proposed algorithm is as follows. First, WFM uses the histogram of a noise-free reference image while the proposed algorithm uses the histogram of the noisy image itself. Therefore, the proposed algorithm does not require a noise-free reference image. Second, because the proposed algorithm performs without reference images, its set-up time, i.e., the training or learning time, is zero. However, a 1-10 min set-up time is initially required for WFM's knowledge base [19][20]. Finally, the proposed algorithm first detects the noisy pixels and then replaces only the values of noisy pixels with their estimated values. On the other hand, WFM does not detect the noisy pixels. Instead, it replaces the values of all pixels (both noisy and good pixels) with the outputs of the weighted fuzzy mean filters. As it was discussed in the introduction, the switching schemes, which use impulse noise detection, have been shown to be simple and yet more effective than uniformly applied methods, such as WFM. The experimental results in Table 1 support the analysis above.

IV. CONCLUSION

In this paper, a new efficient impulse noise removal technique is presented. Extensive computer simulations indicate that it outperforms significantly many other well-known algorithms. The proposed technique can be used in digital cameras and digital television (DTV) to remove impulse noise due to its performance and low complexity.



(a) (b) (c)

Fig. 3. The original noise-free images: (a) *Lena*, (b) *Bridge*, and (c) *Baboon*.

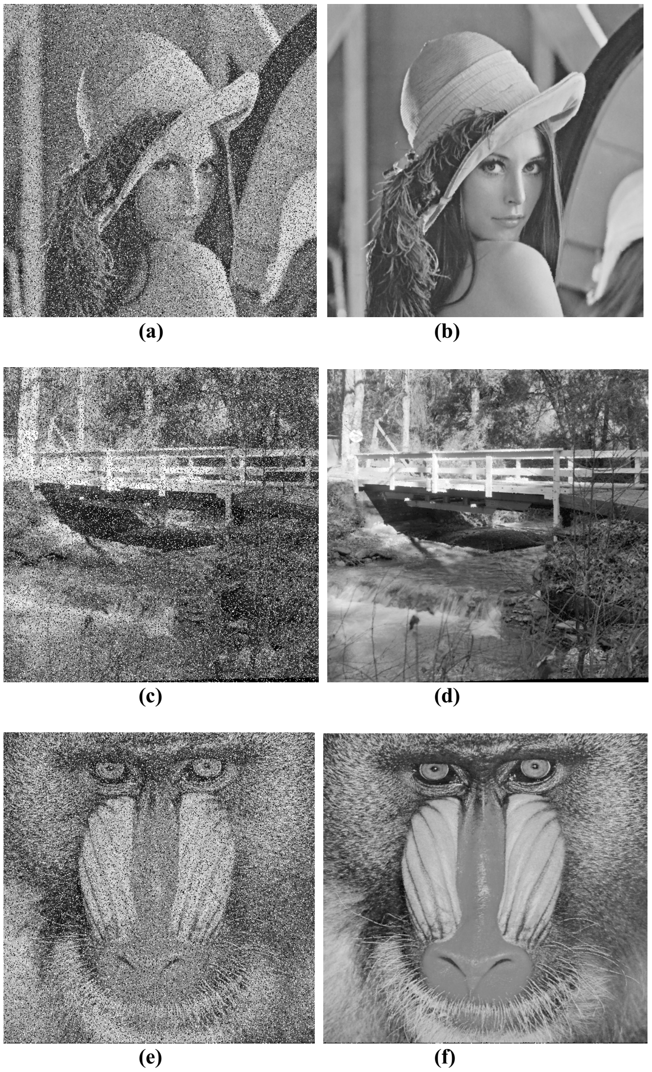
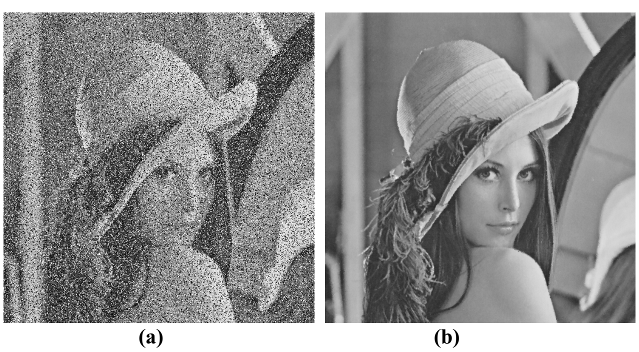


Fig. 4. The noisy images corrupted by 20% impulse noise: (a) *Lena*, (c) *Bridge*, and (e) *Baboon*, and the corresponding restored images: (b) *Lena*, (d) *Bridge*, and (f) *Baboon.*



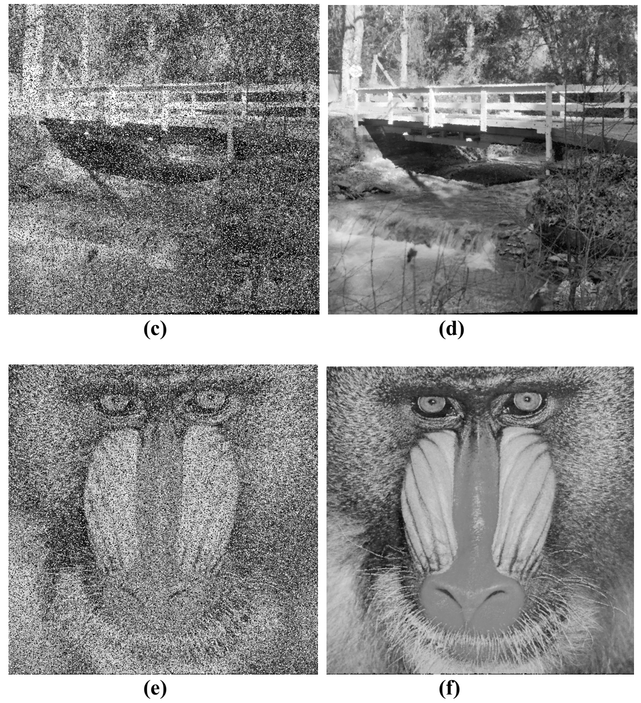


Fig. 5. The noisy images corrupted by 30% impulse noise: (a) *Lena*, (c) *Bridge*, and (e) *Baboon*, and the corresponding restored images: (b) *Lena*, (d) *Bridge*, and (f) *Baboon.*

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