Efficient Removal of Impulse Noise from Digital Images

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Abstract

- New impulse noise removal technique
  - Fuzzy impulse detection
    - Generating a fuzzy flag map
  - Impulse noise cancellation
    - Preserving image details
  - Suitable for hardware implementation
    - Due to the low complexity

Introduction

- Digital camera or digital TV (DTV)
  - Often interfered by impulse noise
    - Image acquisition, recording, and transmission
    - Household electrical appliances and atmospheric disturbances
  - To get high quality images
    - Important to eliminate impulse noise

- Algorithms to remove impulse noise
  - Median filter and its modifications
    - Tend to modify both noisy and noise-free pixels
      - Removing fine details in the image
  - Using impulse detector to determine whether a pixel should be modified
    - Switching (weighted) median filter
    - Rank-order threshold
    - Local signal statistics
    - Fuzzy technique

Working well but increasing computational complexity

A new efficient impulse removal technique

- Assumptions in this paper
  - Impulse noise
    - Only salt-pepper noise with uniform distribution
    - Equal probability of being corrupted to either a positive impulse or a negative impulse for each pixel
  - Noise ratio
    - How much an image is corrupted
    - Noise ratio is 20% → 10% positive impulses and 10% negative impulses

◆ Fuzzy impulse detection

– The purpose

- To generate a fuzzy flag map: Indicating how much it looks like an impulse pixel

– Corrupted and noisy image, I

$$I = \{x_{ij} : 1 \le i \le l_1,\ 1 \le j \le l_2\}$$

$$l_1 \times l_2 : \text{Image size}$$

$$x_{ij} : \text{Pixel value at position } (i, j)$$

– The location of noisy pixels near one of the two ends

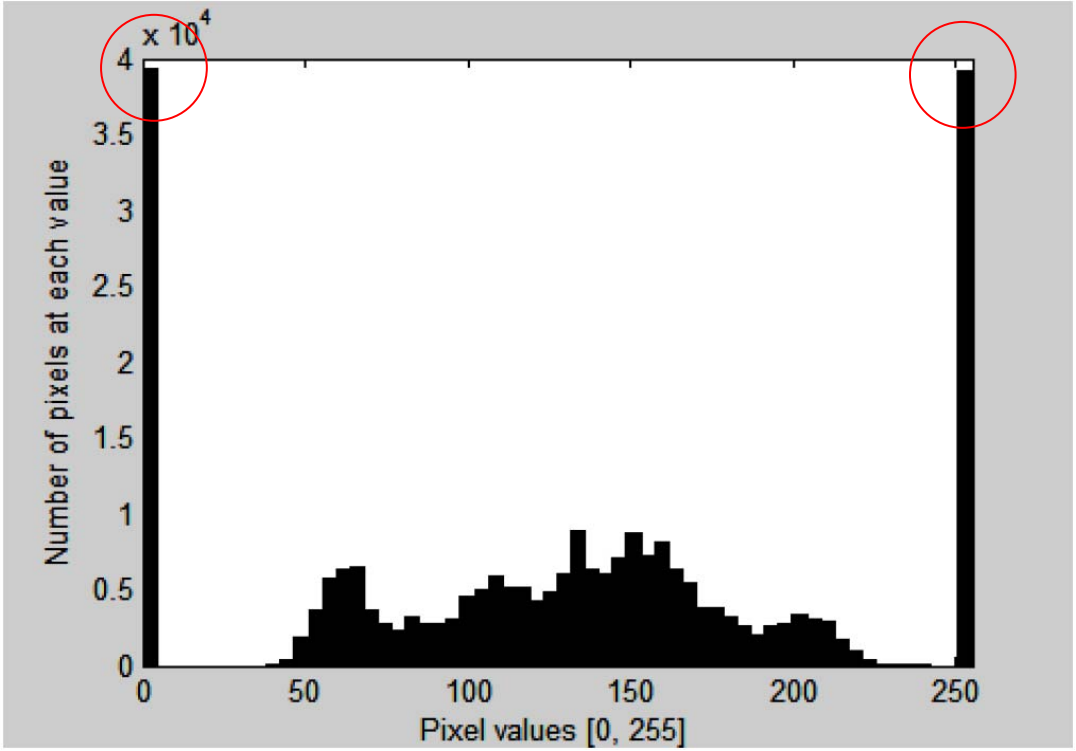

Fig. 1. The histogram of the noisy image of Lena corrupted by 30% impulse noise.

– 3x3 window centered about x_{ij}

$$W_{ij} = \{x_{i-1,j-1}, \ldots, x_{ij}, \ldots, x_{i+1,j+1}\}$$

– Proposed impulse detection algorithm

- Step 1: Detect the locations and values of impulse noise based on the histogram of the noisy image
- Step 2: Test if the pixel value x_{ij} matches one of the peak locations in the histogram of the noisy image

Simple and effective measure for detecting impulses

- Step 3: If it does not match, x_{ij} is noise-free pixel
  Otherwise, calculating minimum value of M_{ij}

$$M_{ij} = \left| x_{ij} - s_{ij} \right| \ , \quad s_{ij} \in W_{ij} \ \text{ and } \ s_{ij} \neq x_{ij}$$

- Step 4: To give the pixel x_{ij} a fuzzy flag

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

T_1, T_2 : Pre-determined parameters

$10 \leq T_1 \leq 20, \quad 22 \leq T_2 \leq 32$

◆ Impulse noise cancellation

– Replacing the pixel value of x_{ij}

- Linear combination of original value x_{ij} and the median m_{ij} of W_{ij}

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

– Diagram of the proposed method

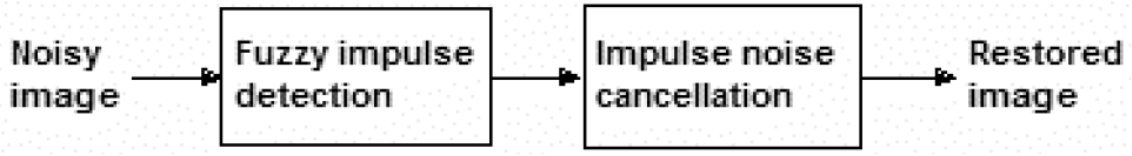

Fig. 2. Block diagram of the proposed impulse noise removal technique using fuzzy impulse detection.

Experimental results

- Test images for proposed algorithm
  - Size of 512 X 512

(a) (b) (c)

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

- The parameter values
  - T_1 and T_2 are set to 15 and 25, respectively
- To assess the restoration results
  - Using PSNR

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

$l_1 \times l_2$: Image size

o_{ij} : Original image

t_{ij} : Test image

– The performance of the proposed method

Table 1. 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

◆ Noisy images and restored images

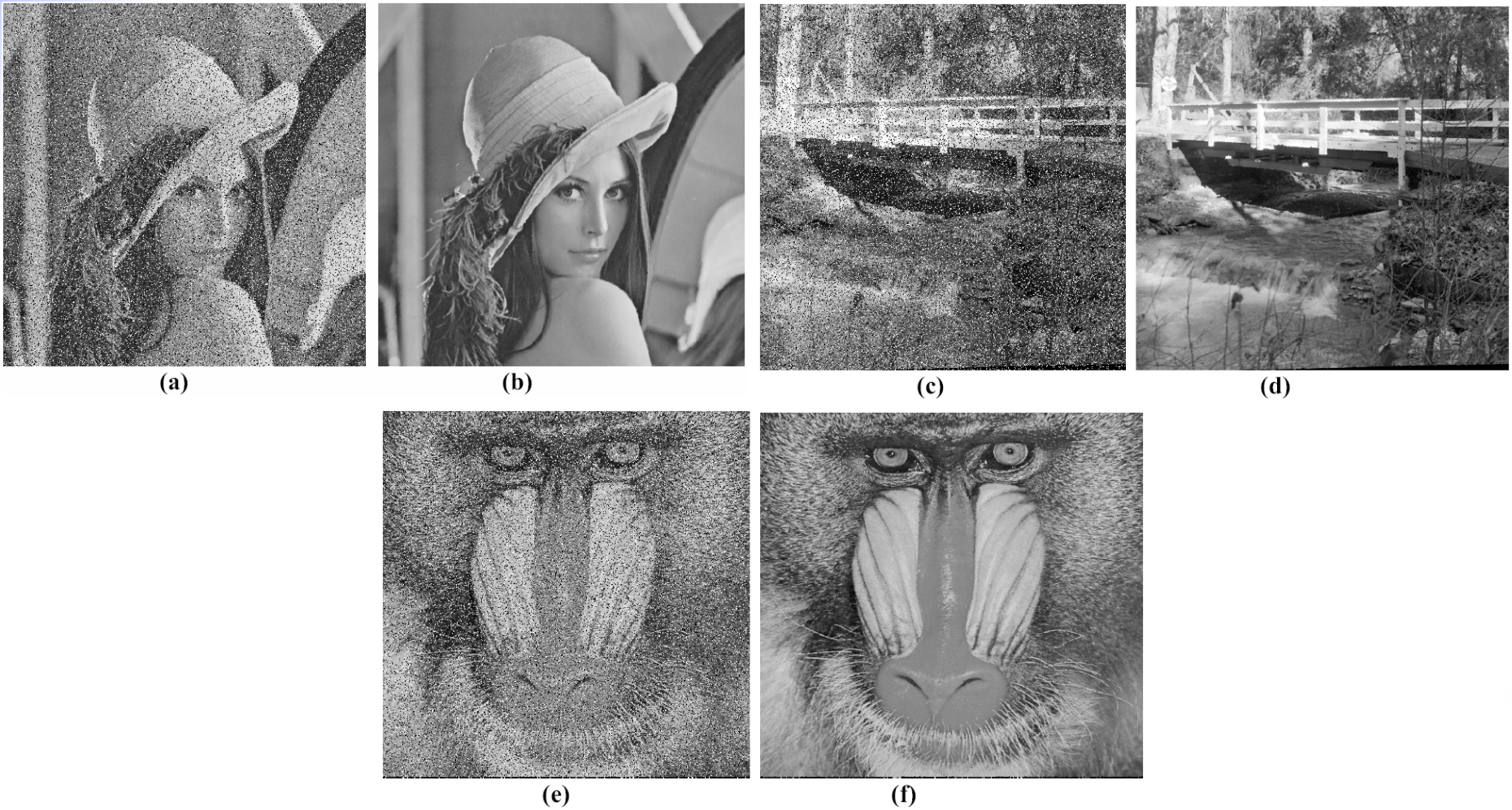

Fig. 4. The noisy images corrupted by 20% impulse noise: (a) Lena, (c) Bridge, and (e) Baboon, and the corresponding restored image: (b) Lena, (d) Bridge, and (f) Baboon.

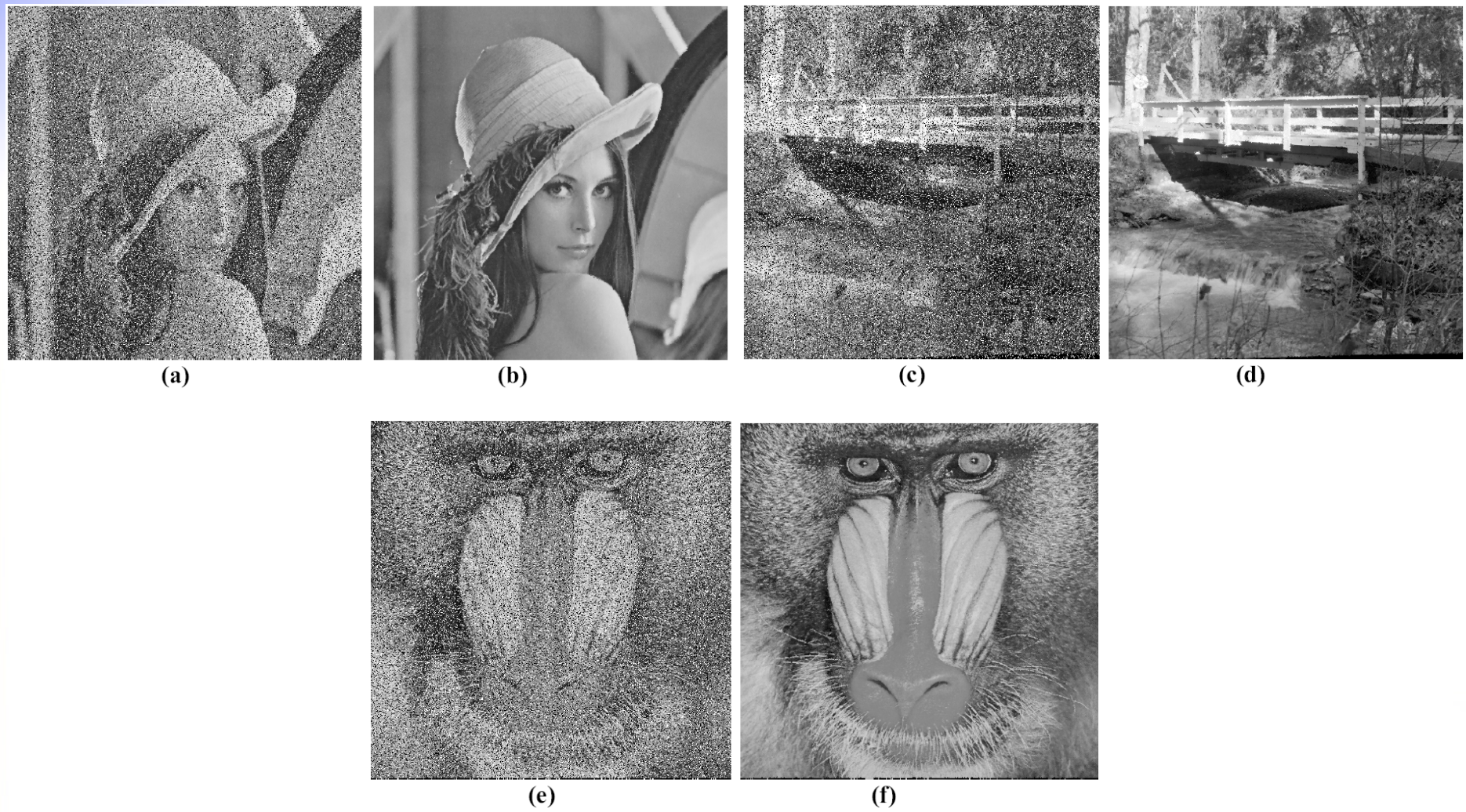

Fig. 5. The noisy images corrupted by 30% impulse noise: (a) Lena, (c) Bridge, and (e) Baboon, and the corresponding restored image: (b) Lena, (d) Bridge, and (f) Baboon.

- Final remark
  - Differences between WFM (weighted fuzzy mean filters) and proposed algorithm
    - Don’t need a noise-free reference image
    - Set-up time (training time or learning time) is zero
    - Replacing only the values of noisy pixels

Conclusions

- To propose a new efficient impulse noise removal technique
  - Outperforming significantly many other algorithms
- Suitable for applying to digital camera and DTV
  - Due to the performance and low complexity