Proceedings of the International MultiConference of Engineers and Computer Scientists 2011 Vol I,
IMECS 2011, March 16 - 18, 2011, Hong Kong

Random-valued Impulse Noise Reduction by MST-based Method for Color Image

Takanori Koga *, Noriaki Suetake †

Abstract— **In this paper, noise reduction performance of a switching vector median filter with a random-valued impulse noise detector for color images is evaluated. As a random-valued impulse noise detector, a method utilizing the minimum spanning tree (MST) is employed. In the switching vector median filter, the impulse noise detector is employed before filtering, and the detection result is used to control whether a pixel should be filtered or not. By applying the method to color images, it is expected that the impulse noise is reduced pointedly while preserving detailed structures such as thin lines, sharp corners, and so on. Through some experiments, for color images, the effectiveness of the combination of the MST-based random-valued impulse noise detector and the switching vector median filter is verified. Particularly, the present method is compared to some powerful switching vector median filters which had been proposed so far from a view point that the impulse noise reduction while preserving edges and details of an image is realized or not.**

Keywords: ***image denoising, impulse noise detector, random-valued impulse noise, minimum spanning tree, switching vector median filter***

1 Introduction

Color images are corrupted frequently by noises due to degrading factors such as defection of image sensor, thermal noise from electric circuits around the image sensor, aging of data storage, and data transfer error and so on. Particularly, impulse noise is generated by bit error in the data transfer process, and may be broadly defined as the corruption that is random, sparse and high or low amplitude relative to local pixel values. Generally, in the impulse noise reduction, it is important to suppress the noise while preserving the integrity of edge and detail information.

In order to realize detail-preserving impulse noise reduction, a switching median filter is used frequently. Before the filtering by median filter, in the switching median filter, an impulse noise detector previously detects pixels to be processed. The conventional impulse noise detector can detect the salt-and-pepper noise relatively well [1, 2]. However, thin lines and corners of edges in an input image to be fed to filter are regarded wrongly as noises by the detector, thus those structures are ruined in median filtering process. This ruin of the structures due to misdetection of noises is unavoidable fundamentally. This is because the noise detector uses the output image of the median filter for the noise detection. And then, it can be said that the conventional detector is not also suitable for the detection of the random-valued impulse noise having similar amplitude to values of neighboring pixels.

On the other hand, an impulse noise detector which preserves the detailed-structures well had been proposed [3]. This detector employs a minimum spanning tree (MST) of graph theory for noise detection. By using MST-based detector, it had been verified that the random-valued impulse noise elimination and the detail-preserving filtering had been achieved with a perfect balance for gray-scaled images. However, the performances of the MST-based noise detector for color images have not been proved yet.

In this paper, the performance of the combination of random-valued impulse noise detection algorithm with MST [3] and a switching vector median filter (SVMF) for color image is evaluated. In the present method, the MST based on the Euclidian distance among neighboring pixels is employed to estimate probability of being noised-pixel. After that, the switching vector median filter is applied selectively to remove the random-valued impulse noises. The effectiveness of the present algorithm for color image is verified quantitatively and qualitatively by some experiments using an artificial image and natural one.

2 Noise Detection and Filtering Process

Here, let $\boldsymbol{I}(x,y)$ be a vectorized pixel value of an input image with 8-bit in R, G, and B channels. In this paper, suppose that the random-valued impulse noise model as follows:

$$\boldsymbol{I}(x,y) = \begin{cases} (I_R, I_G, I_B) & 1 - p_R - p_G - p_B \\ (d, I_G, I_B) & p_R \\ (I_R, d, I_B) & p_G \\ (I_R, I_G, d) & p_B, \end{cases} \quad (1)$$

*Department of Computer Science and Electronic Engineering, Tokuyama College of Technology, Gakuendai, Shunan 745-8585, JAPAN, Tel/Fax: +81-834-29-6319, Email: koga@tokuyama.ac.jp

†Graduate School of Science and Engineering, Yamaguchi University, 1677-1 Yoshida, Yamaguchi 753-8512, JAPAN, Tel/Fax: +81-83-933-5703, Email: suetake@sci.yamaguchi-u.ac.jp

ISBN: 978-988-18210-3-4
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

$$p = p_R = p_G = p_B, \tag{2}$$

where d represents the value of impulse noise. Supposing that bit error can occur with equal probability for all bits, the value of d is given by uniform random numbers ranged from 0 to 255. I_R, I_G, and I_B are pixel values correspond to R, G, and B channels, respectively. The impulse noise is replaced with equal probability p for each channel.

2.1 Minimum Spanning Tree (MST) by Kruskal's Greedy Algorithm

Let $G = (V, E, W)$ be a connected graph. Here V, E, and W are a set of vertices, that of edges, and that of edge weights, respectively. Each edge $(u, v) \in E$ has an associated weight $W(u, v)$. Here, by regarding each pixel in an input image as a vertex, the graph associated with the input image is constructed. In this regard, edges exist exclusively between a pixel and its neighboring pixel on the left, right, top and bottom. In this study, the edge weight between pixels (x_1, y_1) and (x_2, y_2) is given by $\| \boldsymbol{I}(x_1, y_1) - \boldsymbol{I}(x_2, y_2) \|$. Under such definition, a spanning tree for G is a subgraph of G that is a tree connecting all vertices in V. The weight of a spanning tree is the sum of weights on its edges. A minimum spanning tree (MST) of G has a minimum weight. The Kruskal's greedy algorithm [4], which is a MST finding algorithm, is used here. The process is explained briefly as follows:

Let a state be a set of edges $S(\subset E)$. In the initial state, $S = \emptyset$.

Step 1 (Sorting) : Make a queue E in ascending weight by using sorting algorithm such as merge sort.

Step 2 (Verifying admissibility) : While $E \neq \emptyset$, a condition, "$S \cup \{e\}$ does not contain any cycle," is verified for the head edge e in the queue E. If the condition is satisfied, the state and the queue are updated as follows: $S \leftarrow S \cup \{e\}$, $E \leftarrow E - \{e\}$. Otherwise, the state is not updated and the queue is updated as follows: $S \leftarrow S$, $E \leftarrow E - \{e\}$. If the queue is empty, the state S represents the MST.

An example of an MST of a graph obtained from a gray-scaled image is shown in Fig.1. If there are edges with the same weight, theoretically, the MST may not be constructed uniquely. In this case, note that the edge found in first among them in a raster order in the input image is queued in line on ahead.

2.2 Impulse Noise Detector Using MST

In the present method, a partial image corresponding to a local region of an input image is expressed as a graph, and then its MST is constructed by using the Kruskal's greedy algorithm. In the MST, the end-vertex, which is a vertex connected to another vertex by unique edge, tends to be a pixel corrupted by the impulse noise. In the MST-based detector, by using this characteristic, impulse noises are detected by the following procedures (see Fig.2):

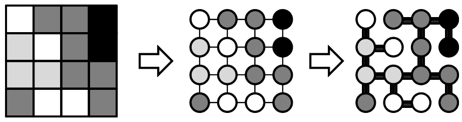

Figure 1: MST of a graph obtained from an image.

Step 1 : Arrange zero matrices A and B as counters which have the same size to the input image. Start the following process from the upper left of the input image. $A(x, y)$ stores the processed times by the MST-based detector for each pixel, and $B(x, y)$ stores detected times as the end-vertex for each pixel.

Step 2 : Increment values of counter matrix $A(x, y)$ corresponding to all pixels within the local processing window of size $r \times r$ pixels.

Step 3 : Create a MST of a graph expressed by using the partial image consisting of pixels in the window, and increment values of counter matrix $B(x, y)$ corresponding to all end-vertices in the MST.

Step 4 : Repeat **Step 2** and **Step 3** in a raster order for the input image.

Step 5 : Calculate all pixels' probabilities of being noise $q(x, y) = B(x, y)/A(x, y)$.

Step 6 : Create a zero matrix C which has the same size to the input image as a noise map. If $q(x, y)$ is larger than or equal to a threshold θ, then set $C(x, y)$ to 1. This means that $\boldsymbol{I}(x, y)$ is corrupted by the impulse noise. Otherwise, $\boldsymbol{I}(x, y)$ is a noise-free pixel.

In the MST-based detection algorithm, it can be said that the pixel, whose value is stood out in comparison with those of neighboring pixels, can be detected as the noisy pixel independently of the amplitude of the noise. Furthermore, pixels constituting line structures tend to be not detected as noises because edges of the MST creep on the line structures and thus noise probabilities of them are dispersed, and become small.

2.3 Switching Vector Median Filter

Here, let a filter window size, a multi-channel signal in the filter window, and a distance between vector $\boldsymbol{I}_i$ and $\boldsymbol{I}_j$ be $n+1$, $\boldsymbol{I}_j (j = 0, 1, ..., n)$, and $\eta(\boldsymbol{I}_i, \boldsymbol{I}_j)$, respectively. A scalar R_i is obtained as follows:

$$R_i = \sum_{j=0}^{n} \eta(\boldsymbol{I}_i, \boldsymbol{I}_j). \tag{3}$$

ISBN: 978-988-18210-3-4
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

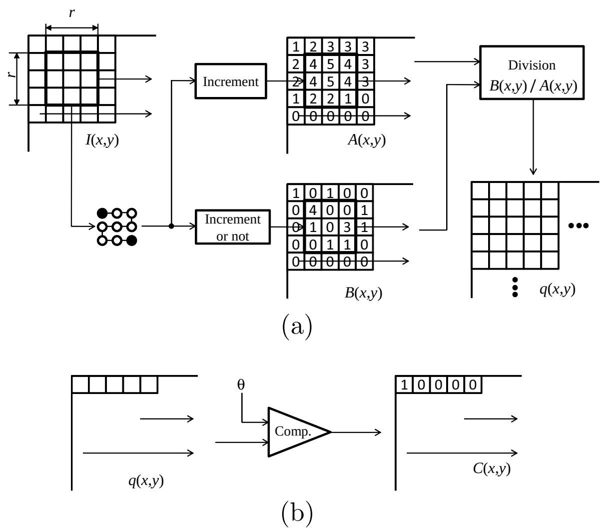

Figure 2: Schematic of the procedures. (a) Noise probability calculation. (b) Noise map generation.

This equation represents a sum of the distance between an arbitrary vector $\boldsymbol{I}_i$ and the other vector $\boldsymbol{I}_j$ in the filter window.

By letting R_i arrange in ascending order as $R_{(0)} \leq R_{(1)} \leq \cdots \leq R_{(n)}$, and letting $\boldsymbol{I}_{(i)}$ be the corresponding multichannel (vector) signal to $R_{(i)}$, the ordering of the multichannel signal is represented as $\boldsymbol{I}_{(0)} \leq \boldsymbol{I}_{(1)} \leq \cdots \leq \boldsymbol{I}_{(n)}$.

The output of vector median filter (VMF) $\boldsymbol{I}^*$ satisfies the following condition.

$$\sum_{j=0}^{n} \eta(\boldsymbol{I}^*, \boldsymbol{I}_j) \leq \sum_{j=0}^{n} \eta(\boldsymbol{I}_i, \boldsymbol{I}_j), \quad i = 0, ..., n, \tag{4}$$

where $\eta(\cdot)$ represents L1 norm. Thus, the output of VMF is a vector which makes the sum of distance for the other vectors in the filter window minimum.

In the switching vector median filter (SVMF), by employing pre-obtained noise map $C(x,y)$, an output $\boldsymbol{I}'(x,y)$ is given as follows:

$$\boldsymbol{I}'(x,y) = \begin{cases} \boldsymbol{I}^*(x,y) & C(x,y) = 1 \\ \boldsymbol{I}(x,y) & \text{otherwise.} \end{cases} \tag{5}$$

3 Experiments and Results

At first, in the experiment, noise reduction for a simple artificial image in order to show obviously the fact that the MST-based SVMF can preserve the thin lines and corners compared to other methods. Then, by considering practical situation, a natural image of the standard image database (SIDBA) is used for evaluation of the algorithm.

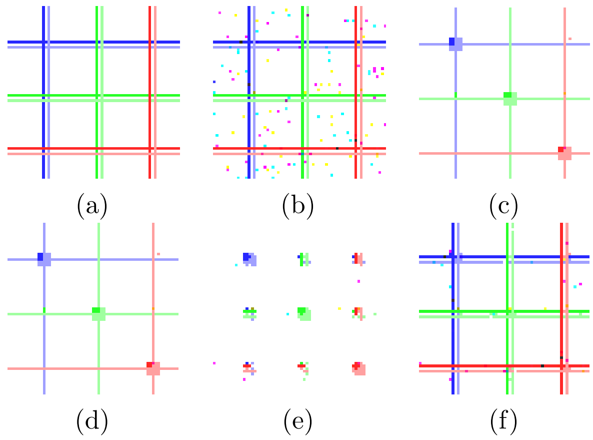

Figure 3: Filtering results for an artificially-generated test image. (a) Original image. (b) Corrupted image with $p=0.01$. (c) VMF ($\rho=3$), (d) SSMF ($\rho=3$). (e) RSVM ($\rho=3$). (f) SVMF-MST ($r=3$, $\theta=0.7$, $\rho=3$).

3.1 Test for Artificial Image

A test image is generated artificially, and is then applied to VMF, to Sun's switching median filter (SSMF) [1], to robust switching vector median filter (RSVM) [5], and to the MST-based method (SVMF-MST). Figure 3(a) shows a color image (65×65 pixels, 8 bit/pixel for each RGB channel) including line structures for testing. In the image, the colors of the line parts are generated from combinations of brightness values {40, 160} for each channel. Figure 3(b) shows a noisy test image corrupted by random-valued impulse noise with $p = 0.01$. Figures 3(c), 3(d), 3(e), and 3(f) show the filtering results by VMF, SSMF, RSVM, and SVMF-MST, respectively. The threshold of SSMF is given by the following equation [6], $\Theta = 0.314P^2 - 5.94P + 57.7$. Here, P represents the percentage of noise generation probability. The parameter α of RSVM is set to be 1.25 [5]. θ of SVMF-MST is experimentally set to 0.7 that gives best performance concerning a mean square error (MSE) in this case. Sizes of filtering window are 3×3 ($\rho=3$) pixels in all methods.

From Figs.3(c), 3(d), and 3(e) it can be seen that VMF, SSMF and RSVM cannot preserve line structures in the image. If a threshold is changed, it can preserve line structures. However, in this case, many impulse noises are not detected, and are not removed well. On the other hand, in SVMF-MST, the superior result is obtained in comparison with the others, as shown in Fig.3(f). However, some impulse noises remained on the lines and beside the lines, moreover, some artifacts are observed in the cross points of lines in this case.

3.2 Test for Natural Image

Here, an image named "Parrots (256×256 pixels, 8 bit/pixel for each RGB channel)," of SIDBA is used. Figures 4(a), 4(b), and 4(c) show a whole image of "Parrots,"

ISBN: 978-988-18210-3-4
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

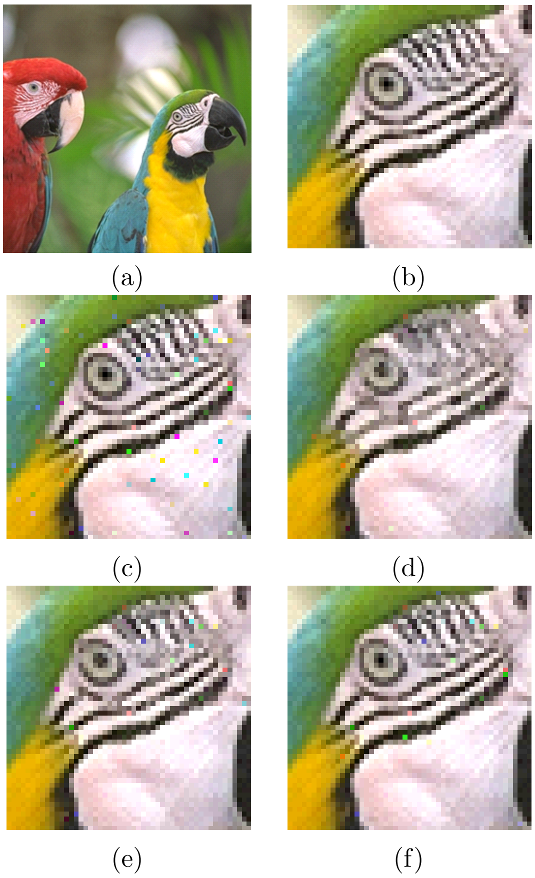

Figure 4: Image "Parrots" and its filtering results. (a) Original image. (b) Partial image with line structures. (c) Corrupted image with $p = 0.01$. (d) SSMF ($\rho=3$). (e) RSVM ($\rho=3$). (f) SVMF-MST ($r=3$, $\theta=0.7$, $\rho=3$).

its magnified partial image including line structures, and a noisy input image corrupted by the random-valued impulse noise with $p = 0.01$, respectively. Figures 4(d), 4(e), and 4(f) show filtering results by SSMF, RSVM and SVMF-MST, respectively. In this experiment, sizes of windows are also 3×3 ($\rho=3$) pixels in all methods. In SSMF and RSVM, the parameters Θ and α are set to be the values mentioned above. And θ giving best MSE is also employed in SVMF-MST.

From Fig.4(d), it is observed that line structures are not preserved, though the noises are removed almost perfectly by SSMF. And from Fig.4(e), it is observed that a part of line structure is ruined slightly. This is caused from the misdetection in the impulse noise detector. On the other hand, as shown in Fig.4(f), it can be said that SVMF-MST performs the impulse noise reduction well while preserving edges and details.

Table 1 shows MSEs of filtering results concerning "Parrots" corrupted by the random-valued impulse noise with p=0.01, 0.02, and 0.03. From Table 1, it is observed that SVMF-MST is best in all cases experimented here.

Table 1: MSE's of filtering results concerning "Parrots" corrupted by random-valued impulse noise.

	p=0.01	p=0.02	p=0.03
Corrupted image	279.5	560.0	842.7
SSMF	117.5	140.2	151.8
RSVM	80.8	91.5	98.0
SVMF-MST	39.5	59.2	87.8

4 Conclusions

In this paper, a combination of the random-valued impulse noise detector based on the minimum spanning tree in graph theory and the switching vector median filter were applied to noise reduction problem in color image. The distinctive feature of the present method is to be able to reduce pointedly the random-valued impulse noise while preserving edges, line structures, and details in an input image. Through some experiments, the effectiveness and the validity of the present method have been verified.

A future work is to develop an automatic parameter-adjusting algorithm that can determine values of parameters appropriately for each input image of concern.

References

[1] T. Sun and Y. Neuvo, "Detail-Preserving Median Based Filters in Image Processing," *Pattern Recogn. Lett.*, V15, pp.341-347, 1994.

[2] Z. Wang and D. Zhang, "Progressive Switching Median Filter for the Removal of Impulse Noise from Highly Corrupted Images," *IEEE Trans. Circuits Syst. II*, V46, N1, pp.78-80, 1999.

[3] G. Tanaka, N. Suetake, and E. Uchino, "Minimum Spanning Tree-based Random-valued Impulse Noise Detection for a Switching Median Filter," *Optics Letters*, V33, N17, pp.1993-1995, 2008.

[4] R. J. Wilson, *Introduction to Graph Theory*, Pearson Education Limited, 1996.

[5] M. E. Celebi and Y. A. Aslandogan, "Robust Switching Vector Median Filter for Impulsive Noise Removal," *Journal of Electronic Imaging*, V17, N4, 9 pages, 2008.

[6] Y. Wakabayasi and A. Taguchi, "Impulse Noise Removal Using Interpolation Technique in Color Images," *IEICE Trans. on Fund.*, VJ89-A, N7, pp.607-618, 2006 (in Japanese).

ISBN: 978-988-18210-3-4
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)