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An Intelligent Impulse Noise Detection and Elimination Algorithm

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Abstract

The algorithm presented in this paper uses fuzzy logic techniques in order to detect impulse noise and emphasises on the reduction of the computational complexity required in the noise suppression scheme. The algorithm is applicable to both greyscale and colour images and outperforms similar reported techniques.

Keywords - image restoration, fuzzy logic, colour, impulsive noise filtering

1. INTRODUCTION

The need to obtain a noise free image after transmission through a noisy channel or because of image capture devises malfunction is important for its further process. Several impulse detection algorithms that utilise fuzzy logic have been presented in the literature. An indeed efficient technique suitable for impulse noise detection and removal using fuzzy techniques has been reported in [1]. This first detects possible noise contaminated pixels in the image and then it uses a special kind of information redundancy-long range correlation within different parts of the image in order to suppress noise. The algorithm proposed in this paper uses more advanced fuzzy techniques in the noise detection part. Each pixel is characterised by a fuzzy flag that indicates the degree of noise presence by a more effective membership function. Furthermore, the shape of the function is modified, leading to a better discrimination against impulse noise affected pixels. The noise elimination part that follows operates only on the pixels that have been detected previously and its function is to add or subtract an appropriate value from the noisy pixels and restore them to their former state before noise contamination. According to the PSNR (Peak-signal-to-noise-ratio) and MSE (Mean-squared-error) indexes, the proposed algorithm is effective and outperforms previous presented methods. Furthermore, the application of the algorithm has been extended to colour images. This paper substantially

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expands the work of [2], containing both computational aspects issues and extensive comparative experimental results.

2. PRELIMINARIES

The efficient algorithm in [1] firstly detects impulse noise pixels and then it applies the noise cancellation algorithm only to those pixels. The noise detection is achieved by applying a median filter to the image. The image after the application of the median filter is subtracted from the original noisy image and the absolute differences are the degree of noise presence in each pixel in the image. The classification of the pixels according to the noise presence is performed by a proper membership function that assigns membership values to each one of them by means of specific fuzzy logic rules. In the second step, the noise cancellation scheme is applied only to the pixels that have been regarded as noise pixels according to their membership value. In particular, the function of the noise suppression algorithm is summarised as follows: two windows of the same size are defined, the one as the local window centred on the impulse pixel (i,j) and the second one as the remote window, located at a different position (k,l). The remote window must be completely covered by a larger window called the searching range window and this must not be the same with the local window (Fig. 1).

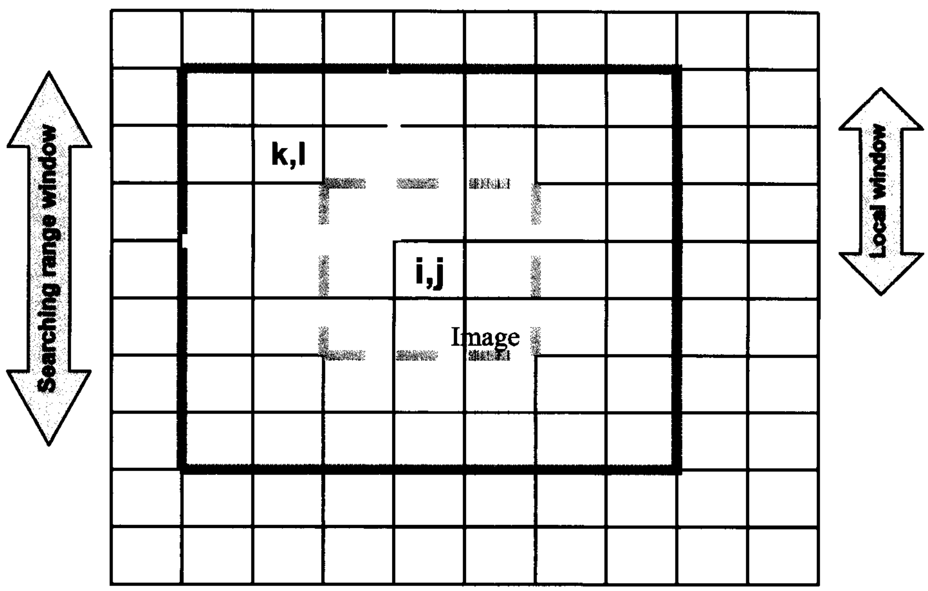

Figure 1. The local, remote and the searching range windows according to [1].

For each pair of respective pixels in the remote and local windows a certain fuzzy value is calculated by means of fuzzy logic techniques. All the above fuzzy values of each pair of remote and local windows are appropriately combined and lead to a value that indicates the degree of resemblance between the two windows. By searching and comparing within the entire searching area window, the most suitable window is found and its central pixel is utilized in the next step. The impulse noise pixel value is substituted by a linear combination of itself and the pixel value found with the previous method. As it can be easily inferred the complexity of the algorithm is significantly high, since it utilizes information within a large area of the image and the algorithm is repeated for each noise affected pixel. The method described in this paper is an effort to overcome such a complexity without degrading the quality of results achieved in [1].

3. PROPOSED IMPULSE NOISE DETECTION TECHNIQUE

Let $x_{i,j}$ be the pixel value at position (i,j) of the noisy image. In order to detect the impulse pixels we apply a median filter with dimensions $N_d x N_d$ to the noisy image. The output of the median filter $u_{i,j}$ when subtracted from the noisy image provides a good measure of how much the pixel looks like an impulse pixel. A large difference value indicates possible presence of an impulse value at the corresponding pixel, whereas a small difference value indicates a possible noise free pixel. In order to fuzzify the absolute difference between $x_{i,j}$ and $u_{i,j}$ we use a sigmoid membership function, that provides each pixel with a fuzzy flag $f_{i,j}$ between 0 and 1 that indicates the degree of noise in the pixel:

$$f(x_{i.j}) = sig|x_{i,j} - u_{i,j}| \tag{1}$$

The selection of the sigmoid membership function has been made since its characteristic "s" shape has the ability to spread the small differences and make them more distinguishable. It can be understood that both very large and very small values of the absolute difference $|x_{i,j}-u_{i,j}|$ can easily indicate the presence or the absence of an impulse pixel, whereas all values in between cannot provide us with a direct measurement of noise presence. The specific membership function when applied to the differences $|x_{i,j}-u_{i,j}|$ is expected to correspond all pixels of the image to a 0 to 1 scale according to the noise presence. In addition we apply the following intensity modification operator μ^i [3] in order to further enhance the differences $|x_{i,j}-u_{i,j}|$

$$\mu^i(x) = \begin{cases} 2\mu^2(x) & if \quad 0 \le \mu(x) \le 0.5 \\ 1 - 2[1 - \mu(x)]^2 & otherwise \end{cases} \tag{2}$$

The above operator is applied to the membership values $f(x_{i,j})$ that have been calculated through the sigmoid membership function. Its purpose is to distinguish membership values that have values close to 0.5 which is the value containing the most imprecise and fuzzy information. Membership values are shifted away from the critical and vague value 0.5 and, therefore, further inferences can be more easily derived. By selecting the above membership function and a proper threshold T_d between 0 and 1 we can judge whether a pixel having a fuzzy value over the threshold will be replaced by another value in the noise cancellation procedure.

4. NOISE CANCELLATION SCHEME

In the second step of the proposed method, the noise cancellation scheme is applied only to the pixels that have been characterised as noise pixels. In other words, if $f(x_{i,j})>T_d$ then the noise cancellation part of the algorithm is applied. By subtracting the median value $u_{i,j}$ from $x_{i,j}$ the result can be either a positive number, if $x_{i,j}$ has an impulse value close to 255, or a negative number, if $x_{i,j}$ has an impulse value close to 0. If the difference $x_{i,j}-u_{i,j}$ is positive which means that the pixel that has been regarded as "impulse" has a large value, then the median value $u_{i,j}$ is subtracted from the noise value, leading to a smaller value close to the original. On the other hand if the difference $x_{i,j}-u_{i,j}$ is negative, which means that the pixel that has been regarded as "impulse" has a small value, then the median value $u_{i,j}$ is added to the noise pixel value in the corrupted image, leading to a larger value closer or perhaps identical to the original one. Let $y_{i,j}$ be the pixel value at position (i,j) at the output of the noise cancellation algorithm.

$$y_{i,j}= x_{i,j}-(x_{i,j}- u_{i,j}) \quad (3)$$

This algorithm can handle both random and fixed valued (salt & pepper) impulse noise since the noise detection part all differences $x_{i,j}- u_{i,j}$ are examined and not only the large or the small ones.

5. COMPUTATIONAL COMPLEXITY

Here we present a comparative analysis of the computational efficiency of the proposed filter and the one described in [1]. The latter, in order to detect impulses, uses a median filter that requires $2N^2 LogN$ compare/pixel operations in the optimal situation, where NxN are the median filter dimensions, using a Quick Sort Algorithm [4]. Additionally, a subtraction/pixel is required to calculate $x_{i,j}-u_{i,j}$ and another compare to threshold T_d is needed. Then at the noise suppression step, if we assume a noise percentage of value p, in order to find the optimal remote window, $p{\cdot}N_c^2$ subtractions/pixel are required between the local and one remote window. This leads to a total number of $p{\cdot}N_c^2{\cdot}(M-N_c+1)^2$ subtractions/pixel if we consider all the remote windows contained inside the large window, where $N_c x N_c$ are the dimensions of the local and remote windows and MxM the dimensions of the large windows centred above the local window. In addition to the total number of subtractions, $p{\cdot}(M-N_c+1)^2$ compare/pixel are required in order to compare to the threshold that finds the optimal remote window. After this procedure, the method in [1] sums all the values of the remote windows that have been calculated previously and therefore requires $p \cdot N_c^2 \cdot (M-N_c+1)^2$ additions/pixel. All the latter values need to be multiplied by a value that is derived from a comparison and is unique for each remote window therefore $p \cdot N_c^2 \cdot (M-N_c+1)^2$ multiplications/pixel and $p \cdot N_c^2 \cdot (M-N_c+1)^2$ comparisons/pixel are also required. The total number of operations is $1+2 \cdot N^2 \cdot \text{Log}N+p \cdot (M-N_c+1)^2 \cdot (1+N_c^2)$ comparisons/pixel, $1+ p \cdot N_c^2 \cdot (M-N_c+1)^2$ subtractions/pixel, $p \cdot N_c^2 \cdot (M-N_c+1)^2$ additions/pixel and $p \cdot N_c^2 \cdot (M-N_c+1)^2$ multiplications/pixel. To calculate the total amount of operations we simply multiply the above figures with the dimensions of the image.

The proposed improvement of the previous method requires exactly the same number of operations at the first step and just px1 subtraction/pixel at the second step. As an illustration let us consider that the dimensions of the median filter, the local window, the remote window and the large window are 3x3, 5x5, 5x5 and 12x12, respectively. Also, the noise percentage is considered 20%. The algorithm of [1] requires 342 compare/pixel, 321 subtractions/pixel, 320 additions/pixel and 320 multiplications/pixel. The proposed method requires 9.6 compare/pixel and 1.2 subtractions/pixel, which is a great improvement.

6. EXPERIMENTAL RESULTS

Many and thorough experiments have been carried out with various greyscale and colour images of different sizes. The noise models in [5] that have been used are salt & pepper (fixed impulse values of 0 and 255 with equal probabilities) and random valued impulse noise (random values uniformly distributed between 0 and 255). In order to obtain an objective quality measure of the denoised image apart from the subjective human eye perception, the PSNR and MSE indexes are used in [6]. The threshold in the noise detection step was T_d=0.4 and the dimensions of the median filter used were 3x3 (N_d=3).

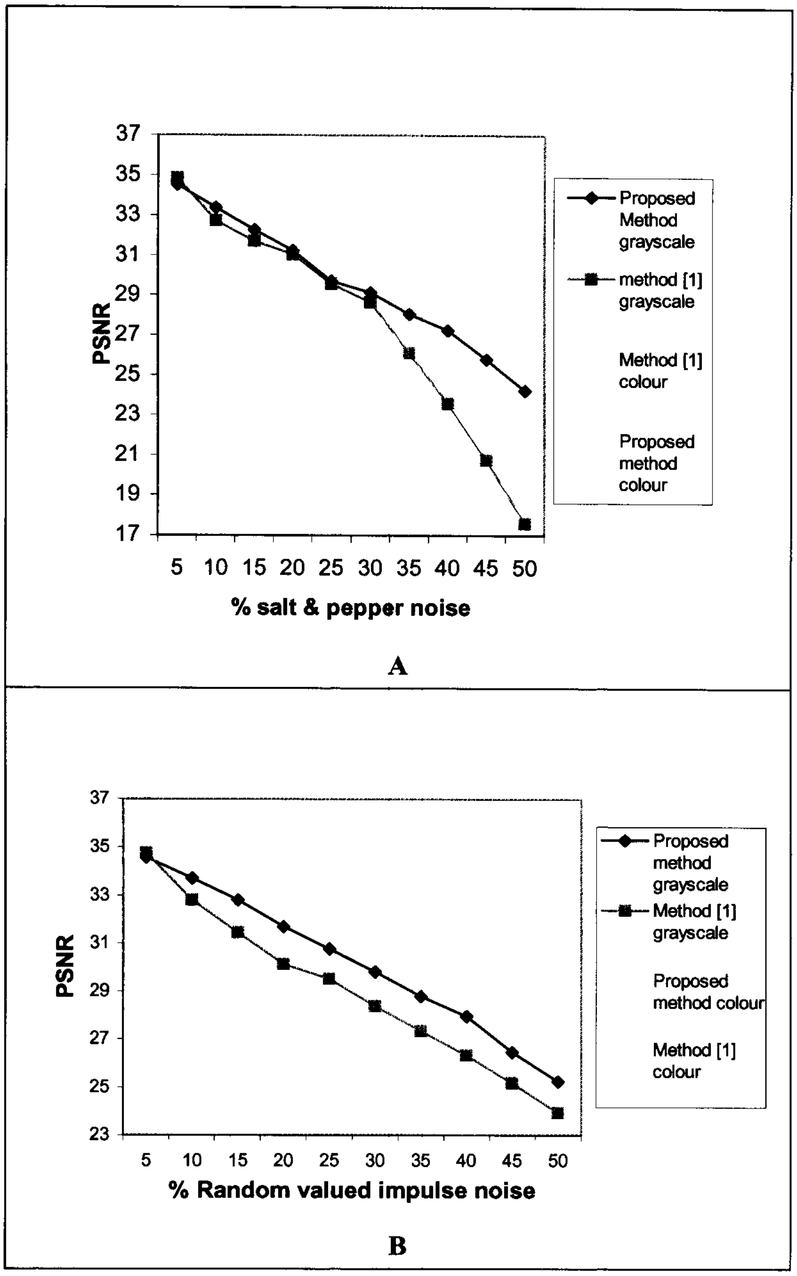

Figure 2. a) PSNR in greyscale and colour (RGB) Lena images contaminated by salt & pepper noise, b) PSNR in greyscale and colour (RGB) Lena images contaminated by random valued impulse noise.

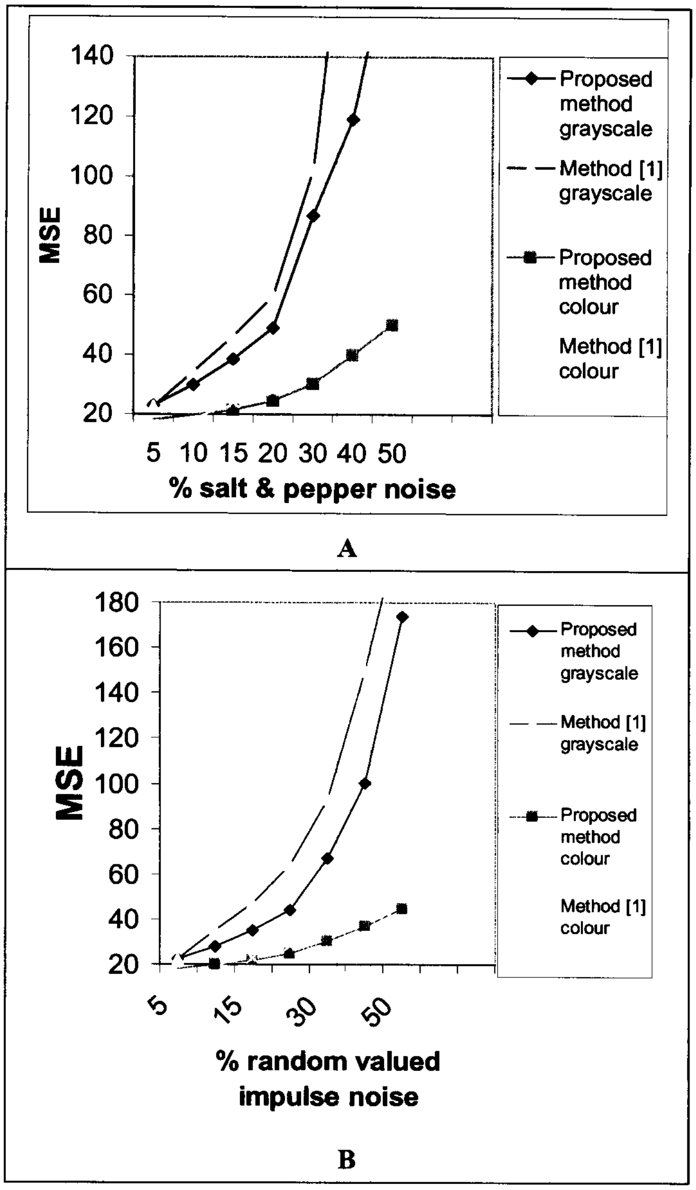

Figure 3. a) MSE in greyscale and colour (RGB) Lena images contaminated by salt & pepper noise, b) MSE in greyscale and colour (RGB) Lena images contaminated by random valued impulse noise.

As it can be seen from Fig. 2 and Fig. 3 the proposed noise removal algorithm outperforms the efficient filter in [1] at a wide range of noise percentages in both greyscale and colour images. Specifically, for noise percentages greater than 5% in greyscale images and greater than 5-10% in colour images. Furthermore, comparative experimental results of the technique reported in [1] to other existing methods such as the Median filter, the Median filter with adaptive length, the Rank conditioned rank selection filter etc. are demonstrated. Table 1 presents these results together with the performance of the filter proposed in this paper.

Table 1. Comparative experimental results.

Algorithm	PSNR with 20% Fixed-valued impulse noise	PSNR with 20% Random-valued impulse noise
Median filter (3X3)	28.57	29.76
Median filter (5X5)	28.78	28.59
Median filter with adaptive length [7] (Lin & Wilson, 1988)	30.57	31.18
Rank conditioned rank selection filter [8] (Hardie & Barner, 1994)	31.36	30.78
Abreu et al. (M=1296 and inside training set) [9] (Abreu et al., 1996)	35.70	33.37
[1] Zhang & Wang, 1997	36.46	33.78
Filter presented in this paper	37.12	34.39

The results refer to the Lena image and the superior performance of the proposed filter is obvious if we take into account the significantly lower number of operations required. Finally, it can also be observed that the proposed method preserves image details as well as suppressing noise (Fig. 4).

a

b

c d

Figure 4. a) Original greyscale Lena image, b) Image contaminated by 40% random valued noise, c) Image after 2 iterations of the proposed method, d) Image after 3 iterations of filter in [1].

7. CONCLUSIONS

We have presented an impulse noise removal method applicable to both greyscale and colour images. The method improves the performance of existing efficient methods, both in terms of image quality and computational complexity. Experimental results have confirmed the improvement in terms of the PSNR and MSE indexes.

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