Digital Image Denoising by Adaptive Median Filtering and Wavelet Transform

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Abstract. Digital image processing is an important area of preservation and representation of cultural and historical objects. Part of it is the task of cleaning images corrupted by noise. Many different methods and approaches have been successfully implemented, but still filtering and denoising techniques are developing and improving intensively. Herein, we report numeric simulations of 2D image filtering. Effects of impulse noise are very efficiently reduced by adaptive median filtering. The situation of additive noise, which itself depends on the intensity of the original image, is more complicated. However, we demonstrate that in this case the use of wavelet transforms in the denoising procedure is very productive and promising.

Keywords: Digital image processing, adaptive median filter, wavelet denoising.

1 Introduction

One of the principle areas of digital image processing methods is related to an improvement of pictorial information for human interpretation [1]. It includes preservation and representation of cultural and historical objects. Image enhancement and image restoration no doubt are related to denoising images with certain degradation. Many different methods and techniques have been successfully implemented, but still filtering and denoising are developing and improving intensively. That is due to the fact that there is no such thing as the ‘best’ or the ‘ultimate’ filter. Restoration techniques are based on mathematical models of image degradation [1]. Thus denoising (a particular case of restoration) uses certain á priori knowledge of the degradation phenomena. It develops a probabilistic model of the noise and by a variety of numeric approaches, then solves the so-called inverse problem i.e. recovers the original.

Herein, we report numeric simulations of 2D image filtering. The original image is assumed to be without noise, and then it is corrupted by certain degradation. In Section 1 we consider the so-called ‘impulse noise’, which is widespread in many image deteriorations. In this case, we have implemented the adaptive median algorithm [1]. The denoising software is ‘friendly’ and effective, so it can be used by non-IT specialists. Section 2 is addressed to image processing specialists. There, the situation of additive noise, which itself depends on the intensity of the original image, is treated. We demonstrate that in this case the use of wavelet transforms [1, 2] in the denoising procedure is very productive and promising.

2 Impulse Noise: Adaptive Median Filtering

Impulse noise is also called shot noise, binary noise or 'salt and pepper' noise. It is easily identified in grayscale images because its appearance has randomly scattered white ('salt') and black ('pepper') dots (pixels) over the image [1]. In color images, the noisy pixels bear no relation to the color of the surrounding pixels. It is known [1, 2, 3] that Median Filtering (MF) is effective and widely used technique for reducing such noise. The main idea of MF is to scan the 2D image with a window (mask) of smaller size, and replace the value of each pixel in the image by the median of the neighboring pixels. A significant drawback of this nonlinear filter is that it does not preserve all details (edges) while removing noise [1, 3, 4]. As a result, the denoised image appears blurred. That is why we implemented the so-called Adaptive Median Filter (AMF). ADF main feature is that the size of the mask is changing during the processing. The filter adapts its behavior on the characteristics of the image in the mask region [1, 4]. So, details are preserved and distortion is reduced. In our implementation there is one additional parameter: the size of the mask. In the modeling, we use another additional parameter: noise density. It gives the number of noise affected pixels (randomly selected over the image).

Fig. 1. Original image.

In Fig.1 we present the original image that will be corrupted with impulse noise. It is a 19-th century icon and its grayscale image has 988 x 768 pixels. We have affected 7% of pixels with impulse noise. In Fig.2 a detail of the 'degraded' image is shown, so that salt and pepper dots are clearly visible.

The AMF used in the denoising procedure has maximum window size of 11 x 11 pixels. The processing is robust and effective. In fact, AFM can smooth other noises that may be not impulsive [1, 4, 5].

Fig. 2. Detail of the original image, contaminated with impulse ‘salt and pepper’ noise.

Fig. 3. Detail of the denoised image.

In practice, visual control of the AMF denoised images is quite enough. However, for evaluation of the denoising procedure, we apply the Figure of Merit (FM) criterion, defined below in Section 2. The lower FM value, the better - when FM = 0, the de-noised image is ‘equal’ to the original. The FM before the processing of the de-graded image gives the starting point of the filtering. In this case FM = 0.036. After AMF processing, FM = 0.002 and we can consider the denoising as very effective. We have compared this result to the ‘classical’ median filtering, which results in FM = 0.02. Detail of the denoised image is shown in Fig.3.

3 Intensity Dependent Noise: Wavelet Transform Filtering

In digital image processing Wavelet Transforms (WT) are successfully used for edge detection, image enhancement and restoration, signal compression, denoising, etc. [1, 6, 7]. WT are often compared to the Fourier transform. WT have the advantage over

Fourier transform because they provide insight into both image spatial and frequency characteristics [7, 8]. That is why WT are more efficient in image restoration. However, WT efficiency in denoising depends on the type of disturbance in the image. If we have in the preprocessing activity some information on the type of noise, which is to be expected, we can choose the most appropriate denoising method. If no such information is available, several WT should be explored [1, 7]. For 2D images usually discrete wavelet transformations are applied and the wavelet is discretely sampled.

In general, the procedure includes several steps: 1) Compute signal WT. 2) Alter the transform coefficients. 3) Compute the inverse transform. 4) Evaluate the result.

In what follows we consider an image model (O) with additive intensity dependent noise. The 'degraded' image (J) can be described by the equation: J = O + N*O, where N is uniformly distributed random noise with zero mean and certain variance V. In the numeric modeling we have chosen the variance to be V = 0.02.

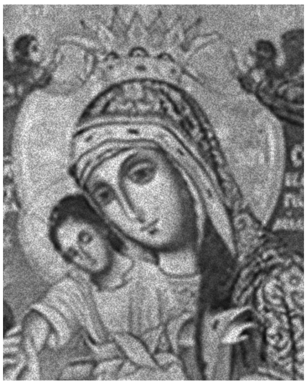

Fig. 4. Detail of the original image, contaminated with intensity dependent noise.

In Fig.3 we present a detail of the model (original) image from Fig.1, contaminated with intensity dependent noise. We have tried to denoise the image J by the adaptive median filtering, but the results were not satisfactory. Much better results were obtained when the denoising was performed with orthonormal wavelet "db4-2" (Daubechies wavelet of order 4, level of decomposition - 2).

In order to evaluate the efficiency of the filtering, we define a Figure of Merit (FM) as the ratio of the Euclidean norm of the difference between the original image and the processed image, to the Euclidean norm the original image. The norm of the difference between the original and the noisy image gives the starting point of the processing. In this case FM = 0.0612.

After the denoising, the figure of merit FM is equal to 0.0087. This is a 7 fold improvement, even without optimization of the process. We compared the denoising with "db4-2" wavelet to processing with "haar", "symlet" and "gauss" wavelets, using one and the same threshold strategy. We found that "db4-2" is most effective. Furthermore, the level of the Daubechies wavelet plays an important role and an optimum has to be found. We continue the investigations in this field and results will be published elsewhere. Detail of the denoised image with "db4-2" wavelet is shown in Fig.5.

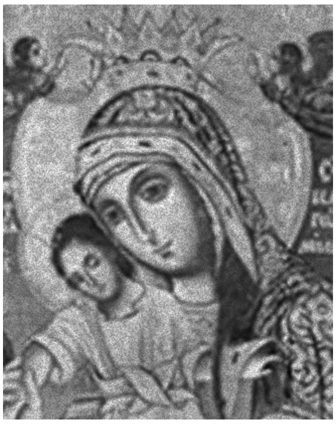

Fig. 5. Detail of the denoised image.

4 Conclusion

We have demonstrated that 2D images can be efficiently denoised by the help of adaptive median filtering and wavelet transforms. In the numeric modeling presented here, only the case of additive noise was considered. The impulse noise is cleared by AMF, while intensity dependent noise is better removed by WT. Both filtering approaches are found to be very robust and effective. The correlation between noise and filter characteristics indicates that we need a variety of filtering procedures and that the filtering process should be optimized over several different approaches. We intend to develop a set of diverse filters in order to attack the problem of multiplicative noise, which is of high practical importance.

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