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Adaptive-hierarchical filtering approach for noise removal

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Abstract

In this paper, our contribution is to propose an adaptive-hierarchical filter that can remove the impulse noise while preserving the details in an image. The global image structure, which is estimated from a set of pyramid images, can be used as prior information in order to apply different filters adaptively. The proposed filter outperforms other methods in that it can make use of both local and global information efficiently. Experimental results show that the proposed method produces better performance than many other well-known methods do.
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Keywords: Adaptive filter; Noise removal

1. Introduction

Digital images are often corrupted by impulsive noise due to errors generated in noisy communication channels or sensors [1]. It is essential to remove corrupted pixels before some subsequent processing. Many techniques [2–5] have been proposed to remove impulse noise from the corrupted images. Median filter [4], which exploits the rank order information of the input data, was initially introduced to effectively remove impulse noise. Despite its effectiveness of noise removal, it tends to modify both noisy pixels and uncorrupted good pixels. Weighted median and center weighted median [3] use a set of weighting parameters in order to preserve more image signal details. Ideally, the filtering should be applied to noisy pixels only. Therefore, various switching techniques are introduced [2,5–8] in order to avoid the damage of good pixels by first classifying image pixels as corrupted and uncorrupted and then passed through the noise-removal filters and identify filters, respectively.

Sun and Neuvo proposed impulse detectors, Switching I and Switching II, with a decision rule based on first order statistics by estimating the difference between the current pixel and output of the median filter [5]. Florencio and Schafer introduced a decision measure according to a second order statistic called normalized deviation [8]. Pok et al. proposed the notion of a homogeneity level, which is defined on the basis of the pairwise correlations between neighboring image pixels, to identify the salt and pepper impulse noise [9].

Such kinds of algorithms are proved to be more effective than uniformly applied methods when the noisy pixels are sparsely distributed in the image. However, if images are highly corrupted, a large number of impulse noise may connect into noise blotches. In such cases, it becomes very difficult to detect and eliminate the noise. Additionally, the error will propagate around the nearby regions. Besides, a noise identification scheme is often based on information within a local window so that such an approach is unable to reflect the real global structure of a region. Therefore, the noise cancelation filters are not very effective in preserving the detailed areas.

In this article, our contribution is to propose a novel approach of an adaptive-hierarchical filtering technique to effectively remove the noise while keeping the detailed image information preserved at the same time. The hierarchical filters generate a set of pyramid images. From the

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pyramid structure of an image, the global information of the true image can be effectively differentiated from the noise information. Pixels corrupted by noise in the upper level images will diminish because of the down-sampling process. However, the global information of the image is preserved across all levels of the pyramid.

After estimating the global structure as the prior information, different noise decision filters and error cancelation filters are designed adaptively depending on the global structure of an image. This procedure is applied iteratively to remove noise and preserve the fine detailed information effectively. This iterative reconstruction makes it possible to use partial results as context information to resolve ambiguities in estimating the global structure. The noise pixels processed in the current iteration are used to help better estimate accurate prior information in the subsequent iterations. One main advantage of such an approach is that some impulse pixels located in the middle of large noise blotches can also be properly detected and filtered. Our approach can be illustrated in Fig. 1. Experimental results indicate the proposed algorithm provides better results over many other well-known methods on problems of both uniform random and fixed value (salt-and-pepper) noise.

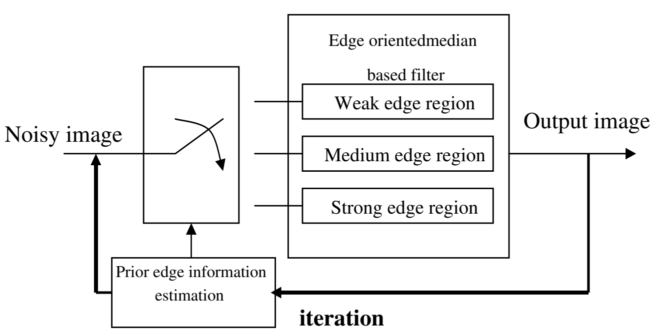

Fig. 1. Adaptive-hierarchical filtering to remove noise iteratively.

2. Prior information estimation: a hierarchical approach

It has been well observed that edges contain the most important information of an image. Estimating the true global edge information from a corrupted image is a challenge. In this paper, we propose a hierarchical approach to effectively estimate the true edge.

Using a simple 2×2 average filter, it is easy to construct a set of pyramid images. It is important to note that the true edge of an image will not disappear in the higher level images while the edges produced by noisy pixels will decrease in the higher level images. Therefore, hierarchical edge detection (HED) scheme shown in Fig. 2 is used to estimate the global true edge information. Sobel edge operators are used [10]. The Sobel operator performs a 2-D spatial gradient measurement on an image and so emphasizes regions of high spatial gradient that correspond to edges. Typically it is used to find the approximate absolute gradient magnitude at each point in an input gray-scale image. Edge value in the upper level image can be set to zero if it is smaller than some predefined values which result from noise. Fig. 3 demonstrates the effectiveness of HED to estimate the structure from a corrupted image. After the estimation, each pixel can be classified as "Weak Edge", "Medium Edge" or "Strong Edge" based on the local statistics. In this paper, we choose to calculate the mean of a 3×3 window centered about each pixel. Namely,

Weak Edge: $HED(i,j) < T1$
Medium Edge: $T1 < HED(i,j) < T2$
Strong Edge: $T2 < HED(i,j)$

The T1 and T2 are the pre-specified thresholds for the above switching operation. T1 and T2 are two thresholds which indicate the fuzziness of the edge information. When the value of HED is greater than T2, it is an indication that the context is a global edge. When the value of HED is in between, it indicates it is median edge. The thresholds are determined based on the statistic data from a lot of images.

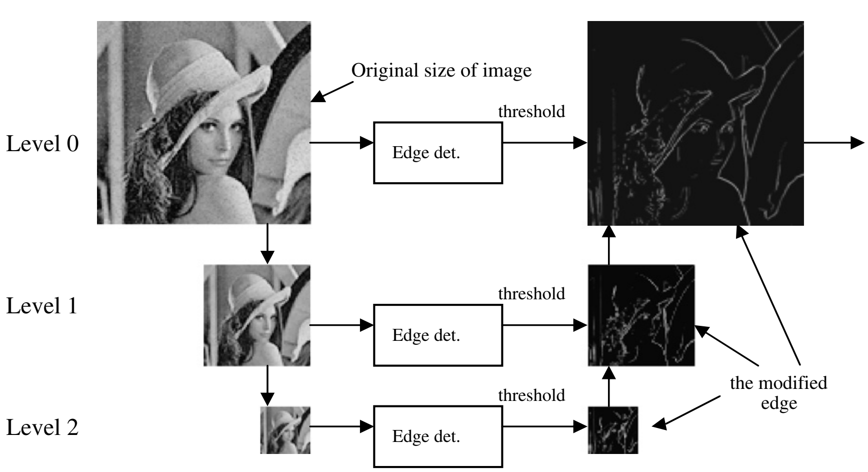

Fig. 2. A hierarchical approach to estimate the image structure.

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