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A novel image noise reduction technique based on hysteresis processing

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ABSTRACT

In this paper a new method based on hysteresis phenomena for image noise suppression has been presented. First, the basic procedures of hysteresis processing are described and then two new proposed approaches namely, local hysteresis smoothing (LHS) and local adaptive hysteresis smoothing (LAHS) procedures are presented. In these procedures, we attempted to propose a principled way to compute the best setup of the proposed hysteresis smoothing method in the presence of Additive White Gaussian Noise (AWGN).

The results of the proposed approaches are compared in both objective and subjective manners with the other noise suppression methods in the presence of different levels of noise. The experimental results showed the feasibility of the proposed approaches denoising ability.

1. Introduction

Noise suppression is one of the most important issues in the field of image processing. The methodologies of noise reduction are varied and usually dependent on the nature of noise existing in the under-processed image. With regard to the physical properties of image grabbing systems, Additive White Gaussian Noise (AWGN) is commonly observed in the images and therefore many of the proposed image noise reduction methods have been developed to removing this kind of noise. The major challenge of these methods is distinguishing main features such as edges, smooth areas and fine details from each other or adapting the proposed method for better image content preservation. Some successful noise reduction methods for AWGN are as follows: Adaptive Gaussian filter [1], Signal Adaptive Wiener (SAW) [2], Total Variation (TV) [3], and Wavelet Thresholding (WT) [4].

In the Adaptive Gaussian filter, the filter variance is adapted to the noise characteristics and the local variance of the signal. This method is only useful for edge detection applications [1].

The purpose of processing with SAW filters is to differentiate the maximum likelihood estimation of the main signal from its noisy pattern. In this method, the output of the signal contains two components; high frequency and low frequency. By exploiting these components, edge regions and smooth areas can be discriminated [2].

The TV technique uses the bounded variation norm for regularization, and tries to maintain a balance between image consistency and total variation. The preservation of the image's fine details along with the noise reduction process is the most significant advantage of this method [3].

DWT is a simple non-linear technique which operates on the wavelet's coefficient. Each coefficient will be compared with a threshold. If the coefficient is smaller than the threshold it will be set to zero, otherwise the value of the coefficient will remain the same. Finally the image will be reconstructed by applying the inverse linear wavelet transform to the result [4].

Bilateral filter (BL) smooths images while preserving edges, by means of a nonlinear combination of nearby image values. It combines gray levels or colors based on both their geometric closeness and their photometric similarity [5].

The NL-means algorithm tries to take advantage of the high degree of redundancy of any natural image. The aim of the non-local filtering is to search the full image to find the similar region to estimate each pixel. Each pixel is obtained as a weighted average of pixels centered at regions that are similar to the region centered at the estimated pixel [6].

The Locally Adaptive Regression (Steering) Kernel (LARK) technique, uses the dominant orientation of the local gradients in the image to adapt the shape and size of a canonical kernel. With these locally adapted kernels, the denoising is effected most strongly along the edges, rather than across them, resulting in strong preservation of details in the final output [7].

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The main idea of BM3D is based on an enhanced sparse representation of image blocks in transform-domain. The enhancement of the sparsity is achieved by grouping similar 2D image fragments (e.g. blocks) into 3D data arrays. Then collaborative filtering is applied to deal with these 3D groups [8].

A dictionary based method was introduced in K-SVD [9]. The proposed method is based on local operations and involves sparse decompositions of each image block under one fixed over-complete dictionary, and a simple average calculations.

The main concept of the noise reduction approach in this paper is based on the hysteresis process. There are two conventional methods, standard hysteresis smoothing (SHS) and complex hysteresis smoothing (CHS), which are also based on the hysteresis concept. These methods use a cursor as the principal of their noise removing approach [10]. By altering the procedure by which the cursor moves between pixels [10] and applying this new procedure in local windows, a contrast adjusting approach called local hysteresis process (LHP) is created [11]. In this paper, we tried to apply the LHP characteristics of these processes to the field of image enhancement to improve the image quality.

In Section 2, SHS and CHS procedures will be completely introduced and LHP, the basic platform for our proposed methods, will be described. In Section 3, our two proposed methods for image noise reduction, local hysteresis smoothing (LHS) and local adaptive hysteresis smoothing (LAHS), will be explained. In Section 4, the proposed approaches will be compared with some well-known noise reduction methods from an objective and subjective point of view. Finally, the advantages of using the proposed methods and a general conclusion will be discussed in Section 5.

2. Hysteresis processing (HP)

2.1. Standard hysteresis smoothing (SHS)

The SHS technique is a one-dimensional smoothing method that relies on cursor characteristics [10]. For a better description, an original waveform and its SHS result are shown in Fig. 1. This process, called HP, assesses the intensity values of neighboring pixels with a "cursor" of the selected intensity range. The cursor represents two intensity values of constant difference which are compared with a pixel's intensity value. The cursor is moved horizontally along lines through the image data using its midpoint as the output intensity value. The cursor's intensity values are compared with each successive pixel's intensity value. If the intensity value of a pixel falls outside the cursor endpoint values, then the cursor follows the data and its top or bottom value assumes the pixel's intensity value thereby changing the cursor's mid-point appropriately with no change in the size of cursor (Δ). However, if a pixel's intensity value falls within the cursor's intensity values, then the cursor maintains its position and the pixel's intensity value is replaced by the cursor's mid-point intensity. In the latter case the read intensity variation has no effect on the output and the represented anon-recognized insignificant intensity changes (hysteresis). Each line is read in both directions and the output values are averaged producing the hysteresis line in one-dimension. There are some blurring disadvantages in this method due to the cursor moving in only one direction.

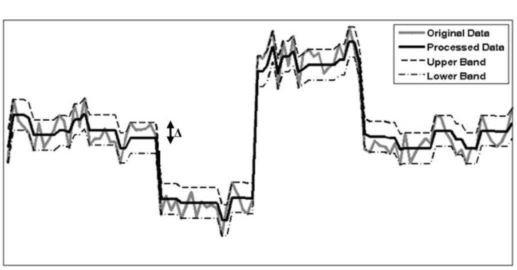

Fig. 1. An original waveform and its output after processing by SHS.

2.2. Complex hysteresis smoothing (CHS)

In complex hysteresis smoothing (CHS) the HP is extended into a two dimensional approach for image noise reduction [10]. With this method a certain amount of contrast variation can be kept in the image, by specifying Δ and utilizing several directions of processing. In this procedure HP with a specific Δ is performed for straight lines in all possible directions extending from a reference pixel to the image border, and applied in reverse in the next step. Then an averaging filter will be used to present a balanced value. In the SHS method this principle is applied for 16 different directions. The CHS is more capable than the SHS in preserving the structural details of the image but it suffers from two defects; (1) It has no way of finding the optimal curser size, and (2) implementation takes a long time to apply the cursor to all the pixels of the image. Achieving optimal curser size and decreasing processing time remain two important issues during implementation of this method [11].

2.3. Local hysteresis process (LHP)

As mentioned before, CHS will be used in smoothing applications. The solution for eliminating CHS drawbacks is inspired by the LHP method, which is not a noise suppression method but instead used for improving contrast.

In the LHP, all processes will be applied in local windows instead of acting on the whole image. In this situation each pixel will be surrounded by a local window then all pixels of the image will be crossed by these windows. The sizes of local windows are usually 3×3 or 5×5 which are more reasonable for achieving better results. Additionally, instead of moving between pixels in straight lines as in the HP method, the LHP method creates new specific patterns which can be utilized through a local window centered on each under-processed pixel [11]. Four possible scanning patterns known as *Classic*, *Spiral*, *Star* and *Ring* have been proposed for LHP [11]. These scanning patterns for 3×3 and 5×5 local windows have been shown in Figs. 2 and 3, respectively. The sequence of digits indicates the order of processing taken to progress for each specific scanning pattern. It is shown that using the proposed LHP method scanning patterns produces feasible results, and significantly decrease redundancy and processing time [12].

3. Proposed methods

3.1. Main structure

The most important part of the hysteresis smoothing process is obtaining the optimal size and position of cursor. can be obtained. Suppose that the *max* and *min* values of the cursor have been shown by a UTL (Upper Trigger Level) and LTL (Lower Trigger Level), respectively, thus the following relations would be reasonable,

$$\mathrm{UTL} = m + \Delta \tag{1}$$

$$\mathrm{LTL} = m - \Delta \tag{2}$$

where Δ is the curser size and m is the center of the cursor located at the middle of the *max* and *min* boundaries of the cursor.

There are three choices for the initial value of m in the under processed local window: (1) the intensity of the central pixel, (2) the mean value of the pixels, and (3) the median of the pixels. In the proposed methods, the mean of the pixels in the current local window has led to the best results. Also, as can be seen in Section 3.2, it is more appropriate for additive noise suppression.