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A Review of Image Denoising Methods

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Abstract

Image Denoising is one of the fundamental and very important necessary processes in image processing. It is still a challenging and a hot problem for researchers. Images are one of essential representations in every field like education, agriculture, geosciences, aerospace, surveillance, entertainment etc by means of electronic or print media. Images can get corrupted by noise, there has been a great research effort which made solutions for this problem, a number of methods have been proposed. An overview of various methods is given here after a brief introduction. These methods have been categorized on the bases of techniques used.

Keywords: Derivative Based Denoising, Fuzzy Based Denoising, Mathematical Morphology Based Denoising, Median Based Denoising, Nonlinear Denoising methods, s Statistical Modeling Based Denoising

1. Introduction

Various sources let the digital images to be corrupted by poor contrast and noise, theses sources include image transmission, acquisition, compression [1-5], quantization, illumination conditions [6], malfunctioning instruments, ill positions etc. These sources directly degrade the visual quality of image during processing of image [7]. Process of image denoising or image restoration is targeted to estimate the original image from corrupted image. It is still the most fundamental, largely unsolved and widely studied problem [8]. Image has important information and certain details, as communication through visual images is an integral part of modern life. Images and videos are used everywhere to communicate as a visual source. Noise affects image features seriously like edges, thin lines, and loss of image details provides degradation of spatial resolutions. Therefore noise removal from corrupted images is very important and necessary before further processing on them like segmentation [9-12], feature matching, edge detection, feature extraction [13-15], feature detection [16] of image details used for face recognition [17-38] etc, These denoised images can be used for face detection [39-41], content based image retrieval [42-48], medical image reconstruction [49], understanding Morphology of medical images [50] with its applications [51], medical image enhancement [52], image rendering [53] etc.

A huge number of methods have been proposed in this context over the past decades in image processing. A review of these methods has been given here covering the representative methods which gave better performance in this area. These methods have been categorized on the bases of their natures of techniques used in. These categories are Median Based, Statistical Modeling Based, Derivative Based, Fuzzy Logic Based and Mathematical Morphology Based image denoising methods. These categories are discussed one by one in upcoming section of rest of the paper and conclusion is given at the end.

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2. Median Based Image Denoising Methods

Median Based Filters or Denoising Methods are the corner stones of image cancellation methods in modern image processing. Tukey [54] first introduced the Median Filter, after its inception, tremendous efforts have been made for optimization, improvement and refinement over the years. Standard median filters presented in [55] treated all the pixels of the image whether corrupted or uncorrupted. [56] To overcome this drawback Weighted Median Filters (WMF) [57] and Switching Median Filter (SMF) [58] were proposed. WMF reduced the smoothing effect, preserved the image sharpness and treated the entire pixels like standard median filter by giving higher weights to the central pixel [59-60]. Weighted Order Statistics Median Filters (WOSFs) were proposed in [61]. Design of WMF admitting negative and complex weights presented in [62-65]. Steerability concept was introduced in [66] and its application found in [67]. Recently Dimitrios Charalampidis [68] proposed steerable WMF inheriting the noise robustness and edge preserving capabilities of WMF.

SMF reduced the number of pixels subjected to filtration by identifying the corrupted and uncorrupted pixels and leaving the uncorrupted pixels unchanged. In [69-80] extensions of median filter and SMF have been presented. Recent examples of noise adaptive approaches can be found in [81-83]. The parameters that can be used for as input function to adaptive approach can be window size, shape or rank [84]. It created blurred images when applied to mix or Gaussian Noise, Directional Weighted Median (DWM) [85] presented an iterative filtering approach to overcome this drawback. Hsing [86] proposed switching bilateral filter based on median based detection scheme and to address the problems presented in [87]. Partition based techniques comprising linear combination; made with current pixel value and output of nonlinear median filter has been studied in [88]. Some hybrid techniques of linear and non linear filters can be investigated in [89]. Wang and Lu [90] proposed LOFBDND an efficient SMF based on combination of Local Outlier Factor (LOF) [91], Boundary Discriminative Noise Detection (BDND) and Directional Weighted Median Filter.

3. Statistical Modeling Based Image Denoising

Due the sparseness property of multiresolution image representation in non-Gaussian statistics for wavelet coefficients, multiresolution image representation gained much attention for probabilistic modeling over the last decade. Moreover, statistical characteristics of image are accurately described in multiresolution and sparse domains like, Discrete Wavelet Transform (DWT) [92], Discrete Complex Wavelet Transform (DCWT) [93], Discrete Contourlet Transform (DCT) [94] and Discrete Curvelet Transform (DCUT) [95]. Sparse domain image denoising consists of three steps (a) transformation of noisy observation into signal (b) estimation of image from transformed coefficients (c) synthesis step that inverse transformation of selected coefficients [96]. Image estimation functions from the transformed coefficients are of multiple types for example hard and soft thresholding [97], firm and garrote thresholding [98]. Marginal histograms of wavelet coefficients are of two characteristics leptokurtic peaked and heavy tailed [99]. Some of image denoising methods are seemed to exploit these characteristics of marginal histograms of wavelet coefficients and follow simple and appropriate shrinkage rules [100-115]. Another characteristic of wavelet coefficients is interscale dependency. This property is characterized by local parameters of probability density function. This is observed that algorithms which use local parameters as outperform as compared with algorithms using global parameters [116-124]. Study of joint histograms of wavelet coefficients has been given in [125-129] additionally.

Recent variations of Gaussian scale mixture (GSM) have been presented in [130-132]. Some statistical models of wavelet coefficients estimation in sparse domain have been presented in [133-139].

4. Derivative Based Image Denoising

There has been a wide use of partial differential equations in edge preservation image denoising over the past decade. These methods can be of two types, nonlinear diffusion and energy functional minimization, the nonlinear diffusion is axiomatic approach of nonlinear scale space and energy functional minimization is variational approach. There has been a large number of PDE models have been presented over the past years; some of representative models are being described here.

4.1 Axiomatic approach

Witkin [140] proposed the original PDE model based on linear heat equation diffusing in all direction and destroying the edges. This limitation enlightened the new ways for researchers like controlling diffusion speed, direction, adding a fidelity term or combination of these. Perona-Malik [141] were pioneers for introducing such scheme by controlling the diffusion speed and proposing a nonlinear adaptive diffusion process named anisotropic diffusion. Catte [142], You and Kaveh [143] proposed PDE image denoising models based on improving controlling speed function by a selective smoothing model and by using Laplacian image of evolving image instead of gradient image respectively. Black [144] proposed new controlling function based on statistical interpretation of anisotropic diffusion called edge stopping function, Chen [145] introduced coupled nonlinear diffusion model in which the controlling function is smoothed by diffusion equation. Sapiro and Ringach [146] used the combination of speed and direction of diffusion for the improvement of controlling function, Tschumperlé and Deriche [147] introduced a unifying expression for vector valued images to regularize PDE to achieve desired smoothing behaviors by summarizing the existing PDE based formalisms. Vosburg [148] proposed speckle noise removal approach from ultrasonic images based on study of numerical scheme of anisotropic diffusion filter and extending it to matrix of anisotropic diffusion. Wang and Zhang [149] used the local variance to control the forward and backward diffusion.

4.2 Variation approach

Rudin [150] introduced Total Variation Denoising (TVD) model by giving the fidelity term a simple form and defining it as dynamic value. [151] set the fidelity term as a constant value and used nonconvex functions as fidelity functions. Nikolova [152] described the usage of nonconvex functions to decrease the goodness of fit to the contaminated data in case of very high noise density to stabilize the denoising Processing Abubakar [153] proposed multiplicative regularization scheme for TV deblurring problems, in which regularization parameter is controlled by an optimization Processing Gilboa [154] presented the pyramidal texture structure-texture decomposition and analysis for preservation of texture and certain image details. Spatially varying fidelity term controlled the denoising process in image regions. Wang [155] combined the pixel and wavelet domain where TV and shrinkage are used as regularizers in both domains respectively. Chartrand [156] presented quasi Newton method for TV regularization. Bae [157] presented the TV minimization based on graph cuts method. Wu and Tang [158] distinguished the pixels as edge, noise and interior pixels, and on bases of these definition defined the speed function and fidelity term addressing the limitations of impulse noise removal, that existing approaches treated corrupted and un corrupted pixels in same way, in case of high noise densities and less iterations left the corrupted pixels. Zuo [159] proposed generalized accelerated approximation gradient (GAPG) algorithm concerned with TV based image restoration problems

4.3 Complex diffusion processes

Gilboa [160] proposed regularized shock filter and ramp preserving denoising process by complex diffusion process by using the free Schrödinger equation. Some other examples of complex diffusion can be seen in [161-162]

5. Fuzzy Logic based Image Denoising

Since their inception neural networks and fuzzy systems are capable of learning from examples and to deal with the uncertainty respectively. Image denoising is surly a filtering system with visible fuzziness as the existence of fuzziness in the image signal and contaminated signal. Hence fuzzy systems have achieved great focus of research efforts recently. Russo [163] has reviewed the applications, filters and advancement of fuzzy systems covering classical methods [164], fuzzy weight filters [165] and fuzzified FIRE filters [166]. Zhang [167] proposed fuzzy based impulse noise detection and removal by using long-range correlation among different image portions. Examples of growing fuzzy systems applications are presented in [168-170]. Neurofuzzy systems developed by combining the neural network and fuzzy systems have also been used for image denoising [172]. Lee [171] proposed a fuzzy filter using genetic learning process, Yuksel [172] combined median filter, edge detector and neurofuzzy network to develop hybrid filter in which internal parameters adaptive optimization process is done with training. Schulte and others in [173-176] proposed fuzzy derivative estimation and fuzzy smoothing for noise detection and removal respectively. These methods perform better but with more memory and computation cost. Liang [177] proposed two stage neurofuzzy techniques for impulse noise removal. Toh and Isa [178-179] dealt with uncertainties present in local information with fuzzy reasoning and proposed Cluster-based Adaptive Fuzzy Switching Median (CAFSM) to remove all kinds of noise and salt and pepper respectively. Type-2 fuzzy logic systems (FLSs) have been getting great interest in applications in recent years [180-183]. Membership functions of type-1 FLSs are scalar whereas of type-2 FLSs these functions are fuzzy. This double degree of fuzziness makes type-2 FLSs more efficient. Fuzzy logic based systems have shown promising results due to the uncertainty in image data and fuzzy nature of image filtering.

6. Mathematical Morphology Based Image Denoising

Mathematical morphology is about shapes and structures in image processing, it is a geometrical approach with strong mathematical analysis. Mathematical morphology based image denoising has been attracting researchers recently. The research efforts are being given to design a nonlinear operator to extract geometric and topological information from images.

Mathematical morphology is application related to lattice theory to spatial structures. Adaptive mathematical morphology [184-186] is the morphological techniques having the capability of adapting the local context of the signal. Some kinds of morphological filters present are multi structure elements based morphological filter [187-188], soft morphological filters [189-191] and hybrid operator based morphological filters [192]. These approaches improved the performance of image denoising. Morphological dual operators [193-194] are key techniques to construct morphological hybrid filters.

7. Conclusion

We have focused on several methods of image denoising in nonlinear domain, although the linear methods are simple, effective and easy to implement but they are limited with high noise densities and complex noise models. Nonlinear methods have been the state of art denoising methods. The methods differ from each other on the type of noise used. All types of noise for example impulse, Gaussian white noise and speckle have been kept under considerations with their associated denoising methods. Every method has its own performance measures in its problem domain which may not work and fulfill the requirements in other problem domain. However, overall methods associated with wavelet domain have achieved great performance due to their noise adaptive and sparseness. Median based methods have been outstanding for image restoration because of nonlinearity but comparatively spatial domain computations are complex and time consuming. Fuzzy logic based methods have shown promising results.

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