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Adaptive PM Model for Image De-noising Enhanced with Adaptive Linear Filtering

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Abstract— In this paper, adaptive Perona-Malik (PM) diffusion method is introduced which combines both the PM equation as well as the heat equation. The advantages of the PM equation are image segmentation, image enhancement, noise removal, edge detection, etc. The edge indicator is used as a variable exponent as a result of which, the diffusion mode can be controlled adaptively. The enhancement method is done by using adaptive linear filtering technique for image restoration. This method is adopted for enhancing the resolution, restoration of image pixels and for improving the quality of ultrasound images and magnetic resonant images.

Keywords— Adaptive linear filtering, edge indicator, diffusion mode, Perona – Malik (PM) equation, variable exponent.

I. Introduction

Among the noise removal techniques based on anisotropic diffusion equations, the Perona–Malik (PM) equation [1], which was proposed in 1990, has stimulated a great deal of interest in the image processing community in the last decade. It is commonly believed that the PM equation provides a potential algorithm for image segmentation, noise removal, edge detection, and image enhancement. Here, the diffusion coefficient *c(s)* is a nonnegative function on the magnitude of local image gradient and has such properties as $c(0)=1$, $c(s)>=1$,and c(s) $\longrightarrow$0, as $s \rightarrow 0$. Two commonly used diffusion coefficients are

$$c(s) = \exp\{-(s/K)^2\}$$
$$c(s) = \frac{1}{1+(s/K)^2}.$$

In order to make full use of the total variation (TV) model and the heat equation filter since it is able to avoid the staircase effect, the combined models of both filters were proposed by Blomgren *et al*. [23] and Chen *et al*. [24]. Based on a functional with the variable exponent, the diffusion resulting from the proposed model is a combination of TV regularization and Gaussian smoothing.

This paper proposes an adaptive PM method based on the variable exponent. Using the edge indicator, we roughly segment the image into two sub-regions, i.e., the inside regions and the region's nearby boundaries. In addition, by the edge indicator, the diffusion mode is adaptively controlled: in the inside regions, the new method acts as the heat equation to remove noise; in the region's nearby boundaries, the new method acts as the PM equation to preserve the edge. Because of the controllability of the diffusion mode, the new method can overcome the difficulty of the original PM equation and sufficiently preserve small features.

The paper is organized as follows: Section 2 discusses the brief overview of background work. Section 3 describes the proposed work. Section 4 shows experimental results. Enhancement with Adaptive Linear Filtering Technique is discussed in Section 4.Finally in Section 5 the conclusion and future scope is described.

II. Background Work

A. Behavioural Analysis of Anisotropic Diffusion in Image Processing

Here, we analyze the behavior of the anisotropic diffusion model of Perona and Malik. The main idea is to express the anisotropic diffusion equation as coming from a certain optimization problem, so its behavior can be analyzed based on the shape of the corresponding energy surface. We show that anisotropic diffusion is the steepest descent method for solving an energy minimization problem. It is demonstrated that an anisotropic diffusion is well posed when there exists a unique global minimum for the energy functional and that the ill -posedness of a certain anisotropic diffusion is caused by the fact that its energy functional has an infinite number of global minima that are dense in the image space. We give a sufficient condition for an anisotropic diffusion to be well posed and a sufficient and necessary condition for it to be ill posed due to the dense global minima. The mechanism of smoothing and edge enhancement of anisotropic diffusion is illustrated through a particular orthogonal decomposition of the diffusion operator into two parts: one that diffuses tangentially to the edges and therefore acts as an anisotropic smoothing operator, and the other that flows normally to the edges and thus acts as an enhancement operator.

B. Stabilized Anisotropic Diffusions

Anisotropic diffusion is an iterative process which provides efficient signal smoothing with feature preserving capabilities. However, the traditional anisotropic diffusion algorithms are highly sensitive to the number of iterations. In this paper, we introduce a novel method in the diffusion formulations to stabilize the diffusion results. It is generally applicable to most of the anisotropic diffusion algorithms, and the experimental results show that the stabilized algorithms provide improved results.

C. Image Selective Smoothing and Edge Detection by Nonlinear Diffusion

A new version of the Perona and Malik theory for edge detection and image restoration is proposed. This new version keeps all the improvements of the original model and avoids its drawbacks: it is proved to be stable in presence of noise, with existence and uniqueness results. Numerical experiments on natural images are presented.

D. Robust Anisotropic Diffusion

Relations between anisotropic diffusion and robust statistics are described in this paper. Specifically, we show that anisotropic diffusion can be seen as a robust estimation procedure that estimates a piecewise smooth image from a noisy input image. The "edge-stopping" function in the anisotropic diffusion equation is closely related to the error norm and influence function in the robust estimation framework. This connection leads to a new "edge-stopping" function based on Tukey's bi-weight robust estimator that preserves sharper boundaries than previous formulations and improves the automatic stopping of the diffusion.

The robust statistical interpretation also provides a means for detecting the boundaries (edges) between the piecewise smooth regions in an image that has been smoothed with anisotropic diffusion. Additionally, we derive a relationship between anisotropic diffusion and regularization with line processes. Adding constraints on the spatial organization of the line processes allows us to develop new anisotropic diffusion equations that result in a qualitative improvement in the continuity of edges.

E. Nonlinear total variation based noise removal algorithms

A constrained optimization type of numerical algorithm for removing noise from images is presented. The total variation of the image is minimized subject to constraints involving the statistics of the noise. The constraints are imposed using Lagrange multipliers. The solution is obtained using the gradient-projection method. This amounts to solving a time dependent partial differential equation on a manifold determined by the constraints. As t tends to infinity the solution converges to a steady state which is the denoised image.

The numerical algorithm is simple and relatively fast. The results appear to be state-of-the-art for very noisy images. The method is non-invasive, yielding sharp edges in the image. The technique could be interpreted as a first step of moving each level set of the image normal to itself with velocity equal to the curvature of the level set divided by the magnitude of the gradient of the image, and a second step which projects the image back onto the constraint set.

F. Texture Preserving Variational De-noising Using an Adaptive Fidelity Term

De-noising algorithms based on gradient dependent energy functional, such as Perona-Malik and total variation de-noising, modify images towards piecewise constant functions. Although edge sharpness and location is well preserved, important information, encoded in image features like textures or certain details, is often compromised in the process of de-noising. We propose a mechanism that better preserves fine scale features in such de-noising processes.

This is accomplished by adding a spatially varying fidelity term that locally controls the extent of de-noising over image regions according to their content. Local variance measures of the oscillatory part of the signal are used to compute the adaptive fidelity term. The results show improvement in the signal-to-noise ratio over scalar fidelity term processes, and they are more appealing visually. This type of processing is relatively simple, can be used for a variety of tasks in PDE-based image processing and computer vision, and is stable and meaningful from a mathematical viewpoint.

III. PROPOSED METHOD

The proposed model reconstructs sharpen edges as effectively as PM-based diffusion and meanwhile recovers smooth regions as effectively as pure isotropic diffusion (in particular, without stair casing). We have used the edge indicator as the variable exponent to control the diffusion mode. The edge indicator segments one image into two sub-regions. In spite of the degeneration of the image, the edges are still clear compared with other regions. Sub-region almost contains all edges of this image, and sub-region is the inside region in the image. Because of the convolution, this segmentation is not sensitive to the influence of noise.

The selected input image is subjected to Gaussian noise. The noise level consists of 0.01, 0.02, 0.03, 0.1 or 0.5. The noisy image of any one of the above level is generated. The parameters such as MSE- Mean Square Error and PSNR-Peak Signal to Noise Ratio are estimated. The aim of the edge indicator is to distinguish the features of the image by different values. For instance, Perona and Malik introduced the following edge indicator function: Unfortunately, the previous edge indicators only roughly detect the features, and basing only on the values of the edge indicators, we cannot judge the feature on each pixel one by one. In the new model, the edge indicator $\alpha(x)$ may be chosen as, the edge indicator segments one image into two sub-regions. In spite of the degeneration of the image, the edges are still clear compared with other regions. Sub-region almost contains all edges of this image, and sub- region is the inside region in the image. Because of the convolution, this segmentation is not sensitive to the influence of noise. The parameters such as MSE- Mean Square Error, MAE- Mean Absolute Error and PSNR- Peak Signal to Noise Ratio are estimated.

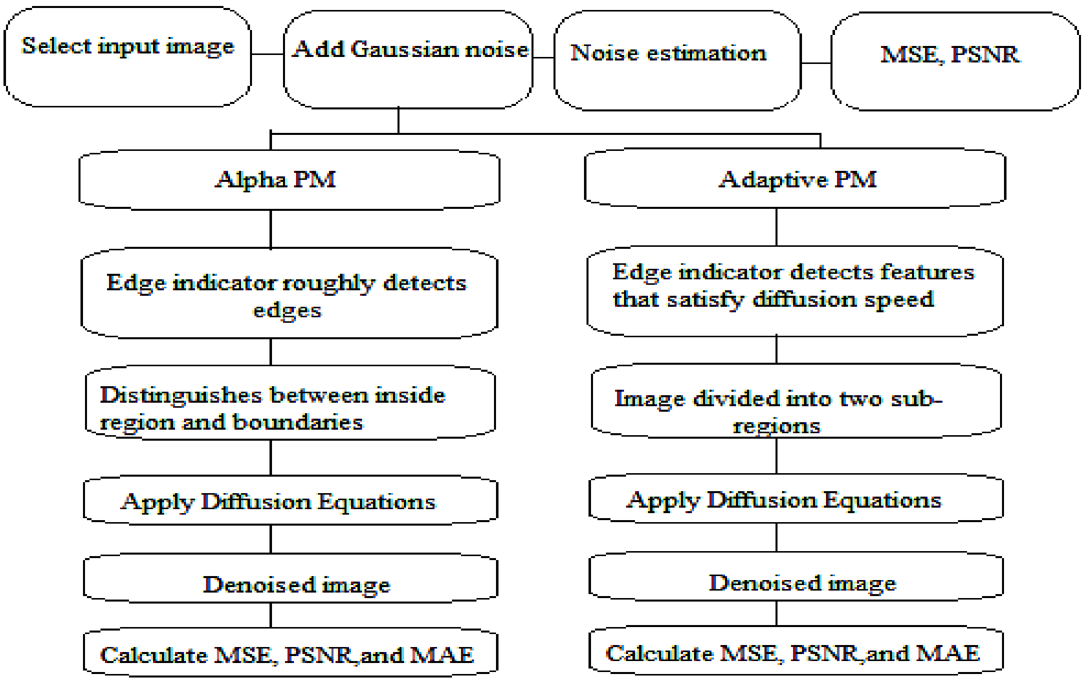

Figure 1: Block diagram of the proposed method

IV. Experimental Setup and Results

The image was first made noisy or corrupt first by adding a certain level of noises, say from 0.1 to 1. Then the de-noising techniques were applied, first the alpha- PM method and then the adaptive PM method.

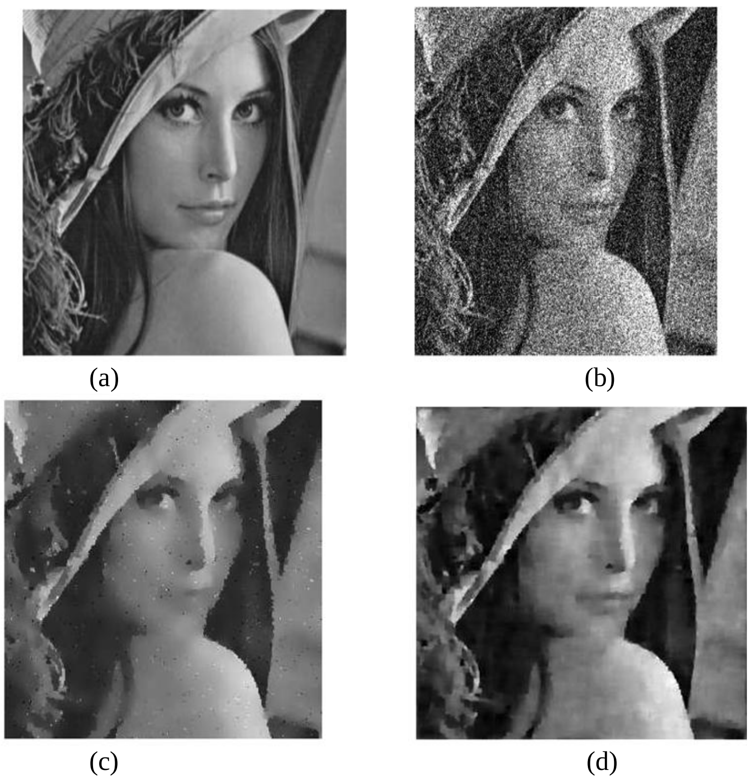

Figure 2: Lena image (a) Original image (b)Corrupted image by a noise level of 0.01(MSE=0.0195, PSNR= 65.2281) (c) de-noised image by alpha-PM method (MSE =0.0110, PSNR=67.6926, MAE=0.10013) (d) de-noised image by adaptive-PM method (MSE =0.0108, PSNR=67.7579, MAE=0.09959)

V. Enhancement with Adaptive Linear Filtering Technique

The adaptive linear filtering technique which is meant to be the enhanced method of my proposed method is also effective in the removal of drop lines, strip lines, white bands, black bands, and blotches along with impulse noise varying up to 70%. The advantage of the proposed algorithm is that a single algorithm with improved performance can replace several independent algorithms required for removal of different artefacts. This algorithm removes all these degradations more effectively with reduced blurring and edge preservation. The algorithm consists of two operations: first is the detection of degraded pixels, and the second operation is the replacement of faulty pixels with the estimated values. Here the local mean and variance of all neighbouring pixels are calculated. Then the average of all the mean values of all these neighbouring pixels is calculated. System linearity is often assumed in many adaptive signal processing applications. Nonlinearities in real applications limit the system performance.

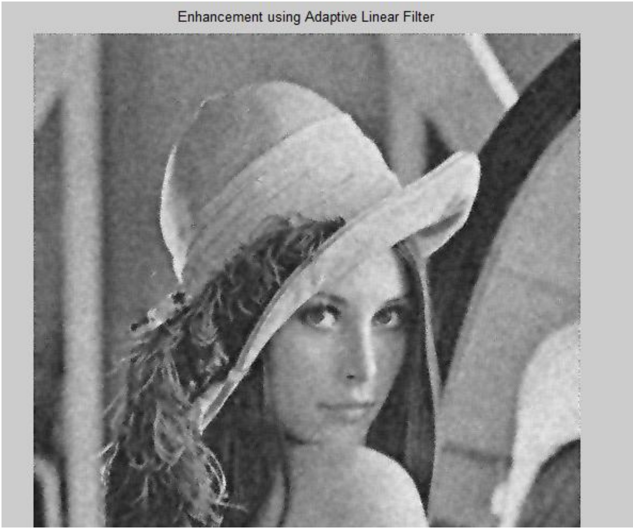

Figure 3: Enhancement using adaptive linear filtering

For various sets of images, the MSE, PSNR, MAE values obtained using alpha PM, adaptive PM and adaptive linear filtering methods are shown below.

TABLE 1: Performance analysis of MSE for proposed method

Figure	Alpha-PM	Adaptive -PM	Adaptive linear filtering
1	0.1793	0.1780	0.1773
2	0.1834	0.1822	0.1816
3	0.1866	0.1862	0.1859
4	0.2117	0.2082	0.2079

TABLE II: Performance analysis of PSNR for proposed method

Figure	Alpha-PM	Adaptive -PM	Adaptive linear filtering
1	54.4746	54.4890	54.4998
2	54.5054	54.5509	54.5767
3	54.6532	54.6794	54.6940
4	54.7439	54.7476	54.7498

TABLE III: Performance analysis of MAE for proposed method

Figure	Alpha-PM	Adaptive -PM	Adaptive linear filtering
1	0.4107	0.4106	0.4097
2	0.4131	0.4131	0.4119
3	0.4196	0.4196	0.4191
4	0.4342	0.4322	0.4315

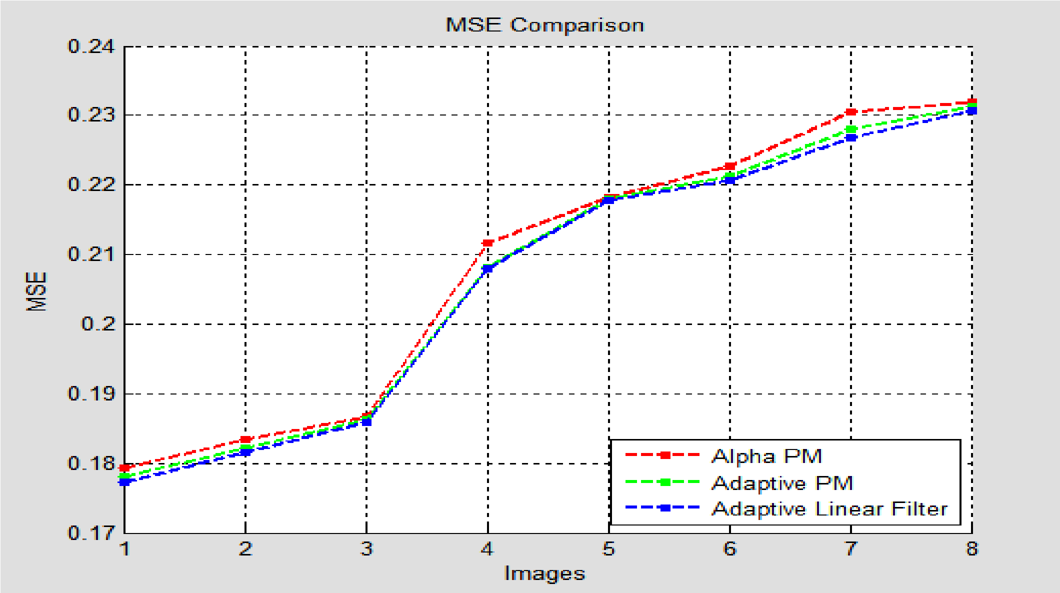

Figure 4(a) MSE Comparison

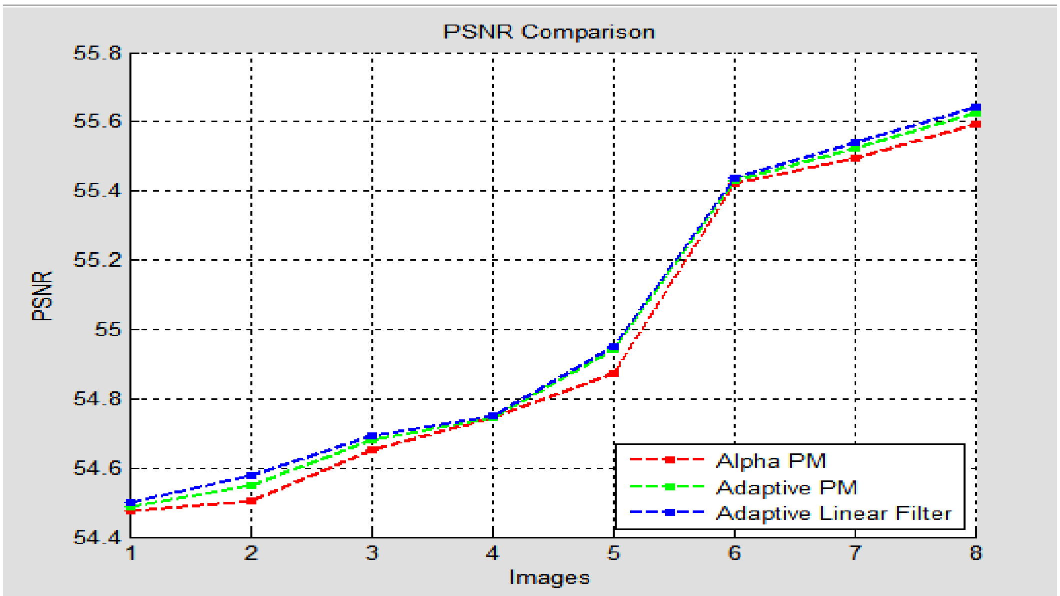

Figure 4(b) PSNR Comparison

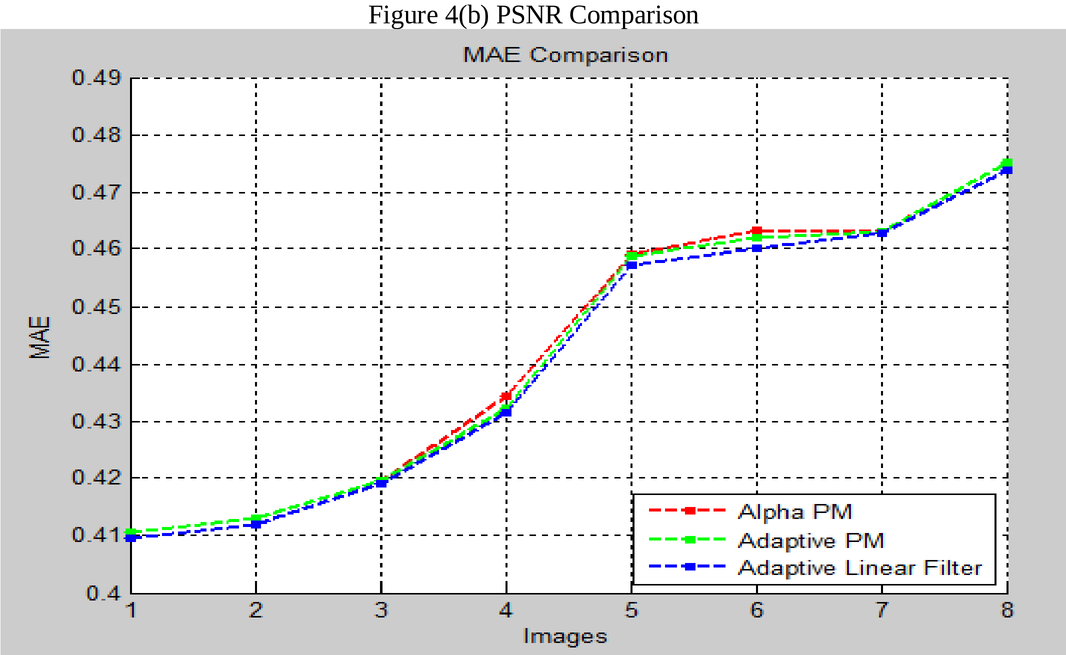

Figure 4(c) MAE Comparison

VI. CONCLUSIONS AND FUTURE SCOPE

High contrast image is still a challenging task in many fields such as medical imaging fields; defence oriented fields, and many scientific research fields including spacing exploring navigational imaging fields etc. This proposed technique lights on for enhancing contrast in all type of emerging and existing engineering and medical imaging fields. We can adopt this method on enhancing the resolution, restoration of image pixels and also use for improving the quality of images. Many research works are possible in medical imaging field with this proposed method like enhancing the quality of ultra sound images, magnetic resonant images etc. in the field of defence, this proposed method can improve the quality of image which was taken in bad weather conditions, low light conditions and also possible to enhance poor pixel images. Since this proposed method could handle a greater role in all types of image oriented application fields and helps to open a new way for research works in digital image processing.

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