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An expeditious cum efficient algorithm for salt-and-pepper noise removal and edge-detail preservation using cardinal spline interpolation

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ABSTRACT

This work proposes a faster and an efficient way to remove salt-and-pepper impulse noise and edge-preserving regularization of the henceforth obtained image. In this paper, we propose a two phase mechanism where the noisy pixels are identified and removed in the first phase. The detected noisy pixels in the first phase are involved in cardinal spline edge regularization process in the second phase. Promising results were found even for Noise levels as high as 95% with the proposed algorithm. The results were found to be much better than the previously proposed nonlinear filters or regularization methods both in terms of noise removal as well as edge regularization.

1. Introduction

Transmission errors, camera sensors having improper pixel elements, faulty memory locations and timing errors in analog-to-digital conversion [1] are the main reasons behind pixel corruption in digital images. However, only certain pixels are corrupted in such type of noise but the rest are noise-free. Denoising the image is a fundamental task since the subsequent output is used in other image processing operations such as, edge detection and regularization, image segmentation, image zooming, and image compression object recognition. The two common types of impulse noise are the salt-and-pepper noise and the random-valued noise. In images corrupted by salt-and-pepper noise, the noisy pixels can take only the maximum and the minimum values in the dynamic range while images corrupted by random valued noise can take any value in between the minimum and maximum noise values in the same dynamic range. The goal of noise removal is to suppress the noise while preserving the other very fine details of the images.

Different technical methods have been proposed to remove impulse noise. The median (MED) filter was once the most popular nonlinear filter. Its denoising power is elaborated in [2]. The computational efficiency of this filter can be seen in [3]. However, since every pixel in the image is replaced by the median value in its neighborhood, the median filter often removes desirable details i.e., vital information is lost in the image and moreover the image becomes blurred. The weighted median filter [4] and the center-weighted median filter [5] were proposed as replacements to median filter by giving more importance to some selected pixels ("decision based") in the filtering kernel. They performed better than the median filter but they still caused a loss in information as even the uncorrupted pixels were affected. The adaptive median filter [6], the multistate median filter [7], the homogenous information based median filters [8,9], the peak-and-valley filter [10,11], the adaptive center weighted median filter [12], iterative method to remove impulse noise proposed by Luo [13], signal-dependent filter proposed by Abreu et al. [14], impulse detection by the pixel-wise MAD proposed by Crnojevic et al. [15], noise suppression using the Jarque–Bera test [16], modified Threshold Boolean filter based on the impulse detecting functions [17], impulse cancellation using a two-output nonlinear filter [18], etc. were proposed. These are "decision-based" or "switching" type filters where only the noisy pixels are replaced by a median value that takes into account the local variation. Henceforth, the edge details are lost.

For the removal of Gaussian noise, error minimizing methods [19–22] have been successfully used to preserve the fine details in images. However, these methods failed in the case of impulse

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noise. Moreover the restoration will alter basically all pixels in the image, including those that are not corrupted by the impulse noise.

Data-fidelity terms have also been used to remove impulse noise [23] (VAR). The variational approach in this work has been combined with adaptive median filters (ADPM) [6] recently [24] (VARADP). The results of this work [24] have been compared with the following methods: the standard median (MED) filter, and also the recently proposed filters like the progressive switching median (PSM) filter [25], the multistate median (MSM) filter [7], the noise adaptive soft-switching median (NASM) filter [8], the directional difference- based switching median (DDBSM) filter [26], and the improved switching median (ISM) filter [27].

In this paper, a "decision-based" cum "detail-preserving" technique is put forward that is efficient and faster than the previously proposed methods for salt-and-pepper noise removal and subsequent edge-preservation. The noisy pixels were detected in the initial stage and later replaced by interpolating the surrounding uncorrupted pixels using Cardinal splines. The indices of these noisy candidates were stored and for the pixels corresponding to these indices, the nearest neighbors were selected and they were again interpolated with cubic Cardinal splines for edge-detail preservation.

B-splines have been widely used in signal and image processing [28]. Many researchers like Unser [29,30] have applied them into various field of image processing like compression, transformation of images [28–31]. Cardinal splines are used for the interpolation since they have the property to pass through the control points. The Cardinal splines also have local propagation property that they are not affected by the change of single control point. The main reason for using Cardinal splines is that they have compact support with good continuity [32].

The outline of this paper is as follows: An introduction to the mathematical framework of Cardinal Splines is discussed in Section 2. The proposed denoising algorithm and edge preserving algorithm is elaborated in section 3, the significant measures in Section 4, the results in Section 5 and conclusions are discussed in Section 6.

2. Mathematical framework for Cardinal Splines

The mathematical framework for compact support and continuity has been taken from Ref. [32]. The main reason for using Cardinal Spline basis is that the interpolation is more proper, since the continuity condition is maintained throughout. Also, we found that the reconstruction is smoother and continuous in the case of cubic cardinal splines of 4th order. We have developed our method based on cubic cardinal splines of 4th order only so that the above properties augur well for us. Also from (Ref. [29] in Fig. 4), Unser et al. has proved that the cardinal cubic spline function (solid line) closely approximates the ideal sinc interpolation kernel (dashed line). They also conjecture from their results that the cardinal Spline of order 4 (cubic) guarantees the continuity of the function up to its second order derivative which seems to be sufficient for

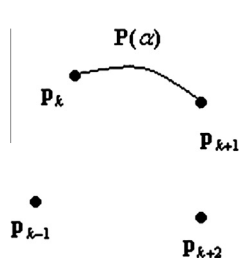

Fig. 1. Parametric point function $\boldsymbol{P}(\alpha)$ for a cardinal-spline section between control points $\boldsymbol{p}_k$ and $\boldsymbol{p}_{k+1}$.

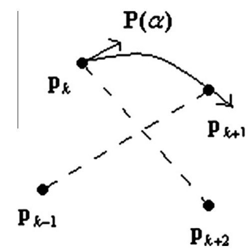

Fig. 2. Tangent vectors at the end points of a cardinal-spline section are parallel to the chords formed with neighboring control points (dashed lines).

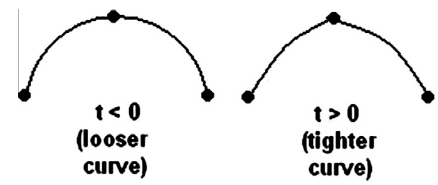

Fig. 3. Effect of the tension parameter on the cardinal-spline section.

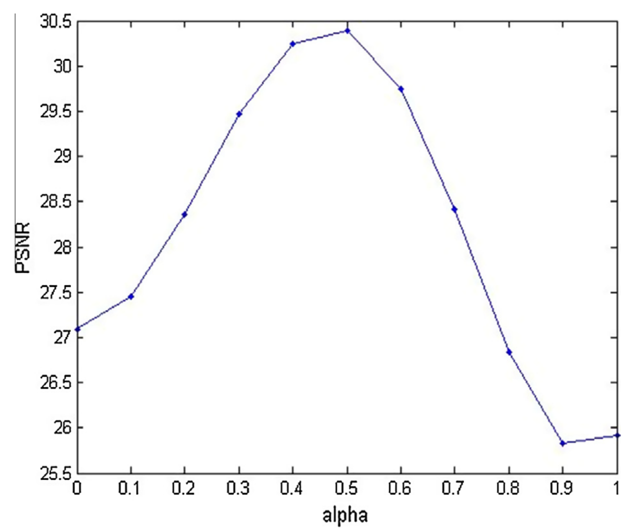

Fig. 4. Graph of PSNR vs. α at constant $\beta = -1.2$; maximum $\alpha = 0.5$.

most practical applications. Also it is proved [29] that the image resolution quality is increased by increasing the order of the cardinal Spline since the interpolation approximates more closely the ideal.

Hence, by using the above 4th order cardinal Splines, we could achieve very good interpolation and resolution.

The Cardinal Splines [33] are interpolating piecewise cubic polynomials with specified end point tangents at the boundary of each cross section. The slope at the control point is calculated from the co-ordinates of the two adjacent control points.

A cardinal spline section is completely specified with four consecutive control–point positions. The middle two control points are the section end points, and the other two points are used in the calculation of the endpoint slopes. If we take $\boldsymbol{P}(\alpha)$ as the representation for the parametric cubic point function for the curve section between control points $\boldsymbol{p}_k$ and $\boldsymbol{p}_{k+1}$, as in Fig. 1, then the four control points from $\boldsymbol{p}_{k-1}$ to $\boldsymbol{p}_{k+1}$ are used to set the boundary conditions for the cardinal-spline section as

$$\boldsymbol{P}(0) = \boldsymbol{p}_k \quad (2.1)$$

$$\boldsymbol{P}(1) = \boldsymbol{p}_{k+1} \quad (2.2)$$