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Neuro fuzzy and punctual kriging based filter for image restoration

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ABSTRACT

In this paper, we present a hybrid, image restoration approach. The proposed approach combines the geostatistical interpolation of punctual kriging, artificial neural networks (ANNs), and fuzzy logic based approaches. Images degraded with Gaussian white noise are restored by first utilizing fuzzy logic for selecting pixels that needs kriging. Three fuzzy systems are employed. Both type-I and type-II fuzzy sets in addition with neuro fuzzy classifier (NFC) have been used for the detection of noisy pixels. To avoid edge pixels, a post processing technique is used to check the edge pixel connectivity up to lag 5. If the pixel under consideration is an edge pixel, it is excluded from the fuzzy map and thus not estimated. The concept of punctual kriging is then used to estimate the intensity of a noisy pixel. ANN is employed to minimize the cost function of the kriging based pixel intensity estimation procedure. ANN, in contrast to analytical methodologies, avoids both matrix inversion failure and negative weights problems. Image restoration performance based comparison has been made against adaptive Weiner filter and existing fuzzy kriging approaches. Experimental results using 450 images are used to validate the effectiveness of the proposed approach. Different image quality measures are used to compare the efficacy of the proposed NFC and fuzzy type-II approaches for detecting noisy pixels in conjunction with ANN and kriging based estimation.

1. Introduction

Image restoration has become a widely investigated field of image processing. In spite of the advances made by recent methods, it is still a challenging task as these methods have yet to achieve a desirable level of applicability in many realistic scenarios. Moreover, with the ever increasing production of digital contents such as images and videos acquired with low resolution cameras and in poor conditions. In such cases, the importance of image restoration has significantly increased. One of the primary tasks in developing image restoration techniques is noise removal without destroying edge information. Noise smoothing and edge enhancement are generally considered as conflicting tasks. Since smoothing a region might destroy an edge while sharpening edges might lead to amplification of unnecessary noise [1]. Therefore, we present a new spatial filtering technique; a neural approach based on punctual kriging and fuzzy logic control. This new approach takes into account this conflict and tries to remove noise, while efficiently preserving the image details and edges information.

Punctual kriging, named after its developer, Krige [2] is heavily used in mining and geostatistics based applications. It is an interpolation technique that gives an optimal linear estimate of an unknown parameter at a sampling point in terms of its known values at the surrounding sampling points [3]. The estimation involves calculation of the semi-variances and modeling of semi-variograms from the sampled data. Besides this, kriging has been applied in many other fields as well.

Fuzzy filters have been extensively applied in image processing over the last decade. Young Sik and Krishnapuram [4] devised fuzzy rule based multiple filters, derived from the method of weighted least squares, for noise removal. Some researchers have also investigated the use of fuzzy clustering for the removal of impulsive noise [5–7]. In [8], Farbiz and Menhaj have introduced an approach of image filtering based on fuzzy logic control. They have shown how to remove impulsive noise and smooth out Gaussian noise while, simultaneously, preserving image details and edges efficiently. Liang and Looney [9] have proposed a competition fuzzy edge detector to distinguish the noisy pixels from the edge

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pixels. Further, Khriji and Gabbouj [10] have recently proposed a fuzzy transformation based approach for multichannel image processing. Fuzzy spatial filters have been widely explored for restoration of images. However, with the increase of local information, the number of fuzzy rules in these filters also increases accordingly. To reduce the requirement of such complicated rules, fuzzy control is used as a complementary tool along with the existing techniques to develop better and accurate methods. This is one of the major aims of the investigations presented in this paper.

In the most basic image restoration approach using neural networks, noise is removed from the image by simple filtering. Cellular neural networks by Chua and Yang [11,12] have been proposed for noise suppression. Improvements have been done for training cellular neural networks that make use of genetic algorithms by Zamparelli [13]. Generalized adaptive neural filter [14,15] is another interesting neural architecture for noise filtering. It consists of a set of neural operators based on stack filters [14] that make use of binary decomposition of gray valued data.

Combination of order statistic filters and Hopfield neural network have also been developed and used by Qian et al. [16] for noise removal and image de-blurring. Suetake and Uchino [17] have proposed a radial basis function network and Wiener hybrid filter to exploit merits of both for removing noise with an arbitrary distribution. Multilevel sigmoidal activation functions [18] are used by Sivakumar et al. to model a blurred and noisy image with many gray levels without any knowledge of the statistics of the additive noise and blurring function. In [19], Widyanto et al. have proposed a method to improve recognition as well as generalization capability of back-propagation neural network as a hidden layer self-organization inspired by immune algorithm. Recently, Palmer et al. [20] have introduced a spatially regularized neural approach that makes use of local image statistics to apply varying regularization to different areas of the image by using a parallel implementation of the Hopfield neural network. Gwanggil et al. [21], have proposed deinterlacing technique based on a type-II fuzzy logic filter and have introduced application of type-II fuzzy sets for interpolation of interlaced fields. Similarly in [1] an image filtering with hybrid impulse detector is proposed.

Several techniques [22–25] have also been proposed using the wavelet transform for image denoising. These methods perform a combination of statistical modeling and thresholding on wavelet coefficients at different decomposition levels to suppress noise. More recently, curvelets [26] and ridgelets [27] have been employed for line structure preservation while denoising images. Similarly, Portilla at al. [28] have proposed a method based on using scale mixtures of Gaussians in the wavelet domain for removing noise. Their idea is based on modeling the coefficients at adjacent positions and scales as a product of two independent random variables which allows it to account for empirically observed correlation between the coefficient amplitudes. Moreover, a kernel based method has also been proposed recently by Laparra et al. [29] using support vector regression in the wavelet domain. It tries to non-explicitly model the relationship between wavelet coefficients by encoding specific coefficient relations in an anisotropic kernel. Whereby, the kernel is obtained from mutual information measure computed on a database of images. The non-parametric nature of their method allows it to cope with different types of noise sources without any reformulation. Although, wavelet based methods have performed well in denoising images but they use fixed basis, which is often not suitable for images having rich amount of locally varying structural patterns specially, the natural scenes. Thus these methods introduce several visual artifacts in the reconstructed images [30].

To overcome some of the disadvantages of wavelet transform, Lei et al. [30] have recently proposed a two stage principal component analysis (PCA) based denoising method, which uses the local pixel grouping and data selection. The primary idea behind this approach follows from earlier works on image denoising which make use of PCA transformation for filtering out noise by selecting and preserving the most significant principal components [31]. The first stage in their method yields an initial estimate of the image by removing most of the noise and the second stage further refines the output. However PCA based methods often result in reconstruction with missing fine details thus significantly effecting local structural similarity in complex pictures with several edges.

Table 1
The abbreviations used in the text.

FIS	Fuzzy inference system
MSE	Mean squared error
PSNR	Peak signal-to-noise ratio
wPSNR	Weighted peak signal-to-noise ratio
SSIM	Structural similarity index measure
VMSE	Variogram based mean squared error
VPSNR	Variogram based peak signal-to-noise ratio
BPN	Backpropagation neural network
AWF	Adaptive Wiener filter
PWFK	Pham and Wagner fuzzy kriging
SAFK	Spatially adaptive fuzzy kriging
NFC	Neuro fuzzy classifier

Besides Pham and Wagner [32,33] have used punctual kriging along with fuzzy sets to enhance images corrupted by Gaussian white noise. They model soft-thresholding by fuzzy sets. In their approach, the pixel intensity in the processed image is a weighted sum of the original (noisy) and the estimated value through kriging. They have evaluated their results qualitatively in comparison with adaptive Wiener filter [34]. However, their study does not provide any quantitative performance analysis of their proposed technique [35,36]. In addition, they apply kriging to all pixels in the degraded image. Considering 3×3 neighborhood, inverse of a kriging matrix of size 9×9 is required, that can make the filtering process computationally expensive. In addition, due to a zero diagonal, inverse of the kriging matrix may not always be possible. The filter weights also suffer from the problem of negative values, which leads to an overall poor performance of the filter. It is also reported that separating noise and original signal from a single input image is under constrained, in theory it is very difficult to recover the original signal [37].

In this paper, we thus propose a hybrid technique based on fuzzy inference system, neural net and punctual kriging for image restoration. This paper makes the following contributions: we introduce an effective hybrid neuro-fuzzy based kriging methodology for image denoising. Both type-I and type-II fuzzy sets and NFC have been employed for decision making about the noisy and noise free pixels. We solve both the problems of matrix inversion failure and the negative weights in punctual kriging by exploiting learning capabilities of artificial neural network (ANN). A post processing phase is also employed to improve the noise decision map by reducing the wrong selected edge pixels.

For clarity and understanding, in Table 1, first we present the abbreviations that have been used in the text.

Rest of the paper is structured as follows: Section 2 introduces punctual kriging and variograms, fuzzy inference system, type-I and type-II fuzzy sets. It also presents some review of ANNs used for image restoration and few of the most commonly used image quality measures along with the proposed variogram based quality measure. Section 3 explains the proposed hybrid technique based on punctual kriging and the neuro-fuzzy approach of adaptive learning. Experimental results and discussion is presented in Section 4. Conclusions are made in Section 5.