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Denoising Piecewise Constant Images with Selective Averaging and Outlier Removal

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Abstract. Piecewise constant images, which are sampled from piecewise constant functions, are an important kind of images data. Typical examples include QR codes (Quick Response codes), logos and text images, which are widely used in both general commercial and automotive industry use. In this paper, we consider the problem of removing Gaussian noise from this kind of images. A novel method based on selective averaging and outlier removal is proposed. The selective averaging updates the intensity value at each pixel by averaging pixels in its homogeneous neighborhood. This scheme prevents the diffusion between pixels belonging to different homogeneous regions. Thus, it preserves image edges quite well. The outlier removal is adopted to detect and suppress outliers appearing in the output of selective averaging. The experiments on both gray and color image denoising show that our method is feasible and effective for piecewise constant image restoration, and achieves superior performance among all the compared methods.

AMS subject classifications: 68U10

Key words: Selective averaging, outlier removal, piecewise constant images, Gaussian noise.

1. Introduction

Piecewise constant images sampled from piecewise constant functions are an important kind of images data. Typical examples include QR codes [22] (Quick Response codes), logos and text images, which are widely used in both general commercial and automotive industry use. Each of them consists of some different homogeneous regions separated by distinct edges. A homogeneous region is a connected component with the same intensity values. Due to the limitation of imaging devices, these images are unavoidable to be degraded by different kinds of noise. Gaussian noise is the most important one compared

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to other noise in digital images generated by reflection imaging. In this paper, we focus on the problem of removing Gaussian noise from piecewise constant images.

In the past decades, image denoising is a fundamental task in image processing, which has been an active research area and attracted much attention. The aim is to eliminate noise from an image while preserving its edges and features. So far many algorithms have been proposed and studied for natural image denosing, e.g., [4–8, 10, 12–17, 20, 23, 26–28, 31, 33, 34]. These methods are very suitable to deal with images including rich details, and achieved promising denoising results. To process noisy piecewise constant images, it is possible to design specific algorithms based on these methods to obtain better performance.

Recently, some algorithms were proposed for binary image or QR codes denoising in the literature [1, 3, 9, 11, 19, 21, 24, 25, 29]. A weighted mean square error method [3] was applied to deal with noisy binary images. Based on the total variation [27], the global minimum of the variational model in [9] is restricted to the set of binary images. Similarly, another two energy functionals based on anisotropic total variation and L_1 fidelity term was proposed in [11]. To remove noise from binary images, the pulse coupled neural network and a quantum multilayer self organizing neural network methods were introduced in [1, 21]. An optimization approach using signomial programming [29] was presented to obtain good binary results. Three classical filter methods were used in [24] for mainly eliminating speckle noise in binary images. The latest two methods in [19, 25] were also presented for QR codes or binary image denoising. Although these methods achieve great success for binary image or QR codes denoising problem, they are only effective for this type of images consisting of two values.

For piecewise constant images consisting of at least two values, there is little attention to estimate noise from them. In this paper, considering the features of this kind of images, we propose a novel method based on selective averaging and outlier removal for denoising. Selective averaging is a simple but effective filtering method, in which the idea is to search for a homogeneous neighborhood to compute the updated image. It essentially uses the Neumann boundary condition [30] at the image edges. According to the thermodynamic theory, there is no diffusion in different homogeneous regions. Thus, it preserves image edges very well. Outlier removal is used to detect and suppress outliers appearing in the output of the selective averaging. Experimental results demonstrate that our method is especially effective for Gaussian noise removal from noisy piecewise constant images (such as QR codes, logos and text images), and performs best among all the compared algorithms.

The rest of this paper is organized as follows. To illustrate our idea, we first introduce our method for 1D signal denoising in Section 2. Then, we extend the proposed method for 1D case to the case of 2D image in Section 3. Section 4 shows experiments and comparisons for both gray and color image denoising. Some conclusions are summarized in Section 5.

2. Selective averaging and outlier removal for 1D signal

We now present our method for 1D signal, from which one can see the essential idea. Let $f \in \mathbb{R}^m$ be the observed signal and $g \in \mathbb{R}^m$ be the ground truth. We consider that g