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Two–Scale Image Analysis in the Image Smoothing Problem

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Abstract

The comparison of image smoothing algorithms based on Parzen window estimation is investigated. The closeness of sigma filter and bilateral filter is displayed. It is demonstrated that decomposition algorithm, based on two–scale analysis procedure, allows obtaining more precise image smoothing results.

Keywords: Image smoothing; Parzen estimation; sigma filter; bilateral filter; decomposition algorithm; two–scale analysis

1. Introduction

Image smoothing task is a traditional one in the area of video information processing and analysis. The main problem consists in preserving boundaries and contour steps between image areas, corresponding to observed objects. A scene to be analyzed in its distant parts might be not similar in the set of objects that is in distributions of their brightness and color. Therefore among the smoothing methods those are especially relevant, that use spatially limited analysis area (local window). Local analysis window may include one or several different image areas. The distribution of values of window elements (pixels) will be a mixture of several independent distributions, corresponding to covered areas.

It is known that in the case of a mixture of several independent distributions, the Parzen window is quite effective method for evaluating the smoothed value in a point [1,2]. The essence of using this method consists in applying the

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local analysis simultaneously both in the spatial area, and in the area of pixel values. There are several known algorithms that are developed basing of this approach. The most known are: sigma-filter Li [4], bilateral filter [7], decomposition algorithm [5,6,9]. Parzen evaluation methods continue to attract the attention as to the image smoothing as to another data processing tasks [10,11,17]. Nevertheless the comparative analysis of observed methods was not carried out yet.

2. Image fragment model

Let consider an image as a set of non-overlapping smooth connected areas, each of them distinguishing from neighbor areas by their brightness properties, and therefore separated by contour steps. These areas densely packed into bounded two-dimensional image definition space. In accordance with the research [12], the general part of a typical image is covered by spatial areas, each containing from 10^2 up to 10^4 and even more pixels. Therefore real analysis fragment as may hit into one enough large area, as may overlap or even fully cover several neighbor areas.

Typically, the brightness's of different areas and values of their elements correspond to different objects of observed scene, and hence they might be considered as independent, even if they are situated closely to each other. At the same time the elements, distanced but belonging to one and the same area, will be statistically dependent in enough large distances — at least in the limits of observation window size.

In accordance with two-scale image fragment model [5,8], inside one fragment an image values are represented as the sum of three components: smooth s_{ij}, texture t_{ij} and noisy ξ_{ij} ones. At that, the smooth components of those parts of R regions that are covered by the local fragment are described by the polynomial of power not higher then ω:

$$s_{ij}^r(W_{mn}) = \sum_{r=1}^{R} \delta_r \sum_{p=0}^{\omega} \sum_{q=0}^{p} a_{pq}^r i^{p-q} j^q \ ; \qquad (1)$$

here (i,j) is the point inside the fragment W_{mn}; δ is the indicator function of a set: $\delta_r = 1$, if $(i,j)\, \chi\, U^r$, and $\delta_r = 0$ in other cases. Introducing the texture t^r and noisy ξ components to (1) we receive:

$$x_{ij}^r = \sum_{r=1}^{R} \delta_r \left(\sum_{p=0}^{\omega} \sum_{q=0}^{p} a_{pq}^r i^{p-q} j^q + t_{ij}^r + \xi_{ij} \right) . \qquad (2)$$

As it is typical for the lengthy areas of real images, the alterations of values of smooth components in the boundaries of local analysis window are rather small [8]. Therefore these values may be considered as constant, that is ω = 0, $s_{ij}^r(W_{mn}) = s_{mn}^r$ and (2) will be:

$$x_{ij}^r = \sum_{r=1}^{R} \delta_r \left(s_{mn}^r + t_{ij}^r + \xi_{ij} \right) . \qquad (3)$$

This is the formula of piecewise image fragment model. It describes some local part of an image, covered by a fragment W_{mn}. Under displacement of the fragment, the parts of the areas will be changed, and generally speaking $s_{mn}^r \neq s_{m+\Delta m, n+\Delta n}^r$. Considering t and ξ as unbiased and normally distributed values, their sum $\tau = t + \xi$ also will be distributed as normal value: $N(0, \sigma_\tau^2)$, where $\sigma_\tau^2 = \sigma_t^2 + \sigma_\xi^2$. Then (3) will be simplified as follows:

$$x_{ij}^r = \sum_{r=1}^{R} \delta_r (s_{mn}^r + \tau_{ij}^r) . \qquad (4)$$

This model is simple, close to the properties of the majority of real images [5][8], and is convenient for constructing various filtering algorithms, including rank ones. If a fragment covers a part of only one image area, the distribution of the values x_{ij}^r will be single-mode. If a fragment covers a parts of two or more (R) areas, then the number of modes of the distribution may reach R. The locations of the modes are defined by the average values $s^1,\ldots,s^R$ of the