A new method for adaptive color image filtering

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Abstract An adaptive color image filter (ACIF) is proposed in this note. Through analyzing noise corruption of color image, efficient locally adaptive filters are chosen for image enhancement. The proposed adaptive color image filter combines advantages of both nonlinear vector filters and linear filters, it attenuates noise and preserves edges and details very well. Experimental results show that the proposed filter performs better than vector median filter, directional-distance filter, directional-magnitude vector filter, adaptive nearest-neighbor filter, and α-trimmed mean filter.

Keywords: color image, noise analysis, locally adaptive filters, adaptive color image filter (ACIF).

Color image perception and processing have been becoming the subject of extensive research as it has widely been applied to multimedia, biology internet, and so on. Color image filtering techniques can be used in computer vision systems and image and video communication systems. A number of color image filtering techniques have been developed to utilize correlations among color vectors effectively. It has been shown that nonlinear filters, which are based on order statistics, remove impulse noise and preserve details of image quite well. The most typical nonlinear vector filter is the vector median filter (VMF), which was proposed by Astola et al.¹⁴. VMF employs the correlation among color vectors with distance measure. Trahanies et al. developed vector directional filter (VDF), in which the directional information among vectors is utilized rather than the distance information in VMF. Having combined VDF and VMF, Karakos et al. proposed directional-distance filter (DDF), which performs better than VDF. Furthermore, Plataniotis et al. have proposed a nonlinear ranked-order filter based on a content model of similarity, which was called directional-magnitude vector filter (DMVF). It is known that nonlinear filters based on order statistic techniques perform well in removing impulse noise and preserving details, but they fail to suppress Gaussian noise. In contrast, linear filters are powerful in attenuating Gaussian noise, while they are not strong enough to remove the impulse noise and will blur edges in image. An adaptive nearest-neighbor filter (ANNF) based on vector directional ordering is an efficient linear filter with adaptive weights. The α-trimmed mean filter (α-TMF) has showed quite good performance to filter out mixed noise. It first removes 2α worst pixels from a slide window, then outputs a linear combination of the remainder in the window. Additionally, the mask used in the filter also influences filter's performance under different degrees of noise corruption. Thus, it is important for an adaptive color filter to estimate the type and degrees of noise corruption, so as to adopt powerful filtering techniques and appropriate masks for suppressing noise.

An adaptive color image filter (ACIF) based on noise analysis is proposed in this note. With the analysis of noise in color image, locally adaptive filters are suitably chosen to enhance image. The new filter is compared with other typical color image filters, in which all test noisy images are generated by Photoshop-5.0 and PaintShopPro-5.0. The results show that the new filter, ACIF, performs better in filtering out impulse noise, Gaussian noise and mixed noise and preserves edges and details of image.
better than the other typical color image filters, VMF, DDF, DMVF, ANNF, and α-TMF.

1 Noise analysis of color image

Let \( \{V_{i,j}; 1 \leq i \leq K, 1 \leq j \leq L\} \) be a color image in RGB color space, \( V_{i,j} = (v_{i,j}^R, v_{i,j}^G, v_{i,j}^B) \), \( v_{i,j}^R \), \( v_{i,j}^G \) and \( v_{i,j}^B \) denote the components in R, G and B channels, respectively. Considering R channel of pixel \( V_{i,j} \), let set \( \{\Delta v_{x,y}^R = |v_{x,y}^R - v_{i,j}^R|; i-1 \leq x \leq i+1, j-1 \leq y \leq j+1, \text{ and } (x, y) \neq (i, j)\} \) be the distances between \( V_{i,j} \) and its eight neighbors. \( d_{i,j}^R \) is defined as average of the four minima in \( \{\Delta v_{x,y}^R\} \) in order to determine whether R channel of \( V_{i,j} \) is corrupted. Corresponding to G and B channels of \( V_{i,j} \), \( d_{i,j}^G \) and \( d_{i,j}^B \) can be defined similarly. For color pixel \( V_{i,j} \), it is regarded as a noisy pixel if any of its three channels is corrupted by noise. Thus, a binary function \( N_{i,j} \) is defined by

\[
N_{i,j} = \begin{cases} 
1, & \text{if } |d_{i,j}^R| > d_m^R + d_\delta^R \text{ or } |d_{i,j}^G| > d_m^G + d_\delta^G \text{ or } |d_{i,j}^B| > d_m^B + d_\delta^B, \\
0, & \text{otherwise}
\end{cases}
\]

where the two terms of threshold corresponding to each channel are defined as

\[
d_m^C = \frac{1}{K \times L} \sum_{i=1}^{K} \sum_{j=1}^{L} d_{i,j}^C, \quad d_\delta^C = \frac{1}{K \times L} \sum_{i=1}^{K} \sum_{j=1}^{L} |d_{i,j}^C - d_m^C|, \quad C = R, G \text{ or } B.
\]

The set \( \{N_{i,j}\} \) corresponds to the detected noisy image with respect to the image \( \{V_{i,j}\} \). When \( N_{i,j} \) equals 1, it implies that the pixel \( V_{i,j} \) is probably corrupted by noise; otherwise, \( V_{i,j} \) is noise-free. The noise detector is quite sensitive to noise, however, it also mistakes some edge pixels in color image for noisy pixels. Therefore, an edge detector using four Prewitt masks with different directions is also utilized to estimate noise corruption. For R channel of \( V_{i,j} \), four distance functions, \( f_1^R(i, j), f_2^R(i, j), f_3^R(i, j) \) and \( f_4^R(i, j) \), corresponding to the four Prewitt masks, are defined as follows:

\[
\begin{align*}
&f_1^R(i, j) = \min \{|v_{i-1,j-1}^R - v_{i,j-1}^R|, |v_{i,j-1}^R - v_{i,j+1}^R|, |v_{i+1,j-1}^R - v_{i+1,j+1}^R|\}, \\
&f_2^R(i, j) = \min \{|v_{i,j-1}^R - v_{i-1,j}^R|, |v_{i,j-1}^R - v_{i,j+1}^R|, |v_{i+1,j}^R - v_{i,j+1}^R|\}, \\
&f_3^R(i, j) = \min \{|v_{i+1,j-1}^R - v_{i,j-1}^R|, |v_{i+1,j}^R - v_{i,j+1}^R|, |v_{i+1,j+1}^R - v_{i,j+1}^R|\}, \\
&f_4^R(i, j) = \min \{|v_{i,j+1}^R - v_{i,j-1}^R|, |v_{i,j+1}^R - v_{i,j+1}^R|, |v_{i,j+1}^R - v_{i,j+1}^R|\}.
\end{align*}
\]

then, an edge intensity function of R channel, \( F_{i,j}^R \), is represented as \( F_{i,j}^R = \max \{f_m^R(i, j); m = 1, 2, 3, 4\} \). In the same way, edge intensity functions, \( F_{i,j}^G \) and \( F_{i,j}^B \), corresponding to G and B channel are similarly defined. For \( \{F_{i,j}^R, F_{i,j}^G, F_{i,j}^B\} \), a binary function, \( E_{i,j} \), can be represented similar to eq.(1). Here, when \( E_{i,j} \) equals 1, it indicates that the color pixel \( V_{i,j} \) is an edge pixel. The set \( \{E_{i,j}\} \) represents the detected edge image.

To describe the noise corruption in color image, two parameters \( N_D \) and \( N_T \) are defined as:

\[
N_D = \frac{1}{K \times L} \sum_{i=1}^{K} \sum_{j=1}^{L} N_{i,j} \bar{E}_{i,j}, \quad N_T = \sum_{i=1}^{K} \sum_{j=1}^{L} E_{i,j} / \sum_{i=1}^{K} \sum_{j=1}^{L} N_{i,j}.
\]