Adaptive multichannel non-parametric median M-type K-nearest neighbour (AMN-MMKNN) filter to remove impulsive noise from colour images

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An adaptive multichannel non-parametric median M-type K-nearest neighbour filter to remove impulsive noise from colour images is presented. This filter uses the VMMKNN algorithm combined with an adaptive non-parametric one. Simulation results indicate that the proposed filter has better restoration performance in comparison with other known colour image filters.

Introduction: Multichannel signal processing has been the subject of extensive research during the last years, principally due to its importance in colour image processing. Numerous filtering techniques have been proposed for colour imaging [1]. In particular, nonlinear filters applied to colour images have been designed to preserve details and remove impulsive noise [2]. In this Letter, we introduce the AMN-MMKNN filter, which is based on an adaptive non-parametric approach and determines the functional form of density probability of noise from data into the sliding filtering window [3]. So, the AMN-MMKNN filter is presented by combining the adaptive multichannel non-parametric and the median M-type K-nearest neighbour (MMKNN) filter [4]. The latter has been adapted to colour imaging to provide the fine detail preservation and uses the redescending M-estimators with different influence functions [2] integrated with a median estimator to obtain sufficient impulsive noise suppression [4].

Proposed filter: We used an adaptive multichannel non-parametric (AMN) filter [3] combined with an MMKNN filter [4] to design the AMN-MMKNN filter. Such a filter is presented as:

$$\hat{x}(y)_{\text{AMN-MMKNN}} = \sum_{l=1}^{n} x_l^{\text{VMMKNN}} \left(\frac{h_l^{-M} K(y - y_l/h_l)}{\sum_{l=1}^{n} h_l^{-M} K(y - y_l/h_l)} \right) \tag{1}$$

where y is the current noisy observation to be estimated from a given set y_N, the y_l values are the noisy vector measurements, h_l is the smooth parameter that is determined as:

$$h_l = n^{-p/M} \left(\sum_{j=1}^{n} |y_j - y_l| \right) \tag{2}$$

where $y_j \neq y_l$ for $\forall y_j$, $j = 1, 2, \ldots, N$, $|y_j - y_l|$ is the absolute distance (L_1 metric) between the two vectors, p is a parameter to be determined in the range $0.5 > p > 0$, M is the dimensionality of the measurement space ($M = 3$ for colour images), and the function $K(y)$ is the kernel function that has the exponential form $K(y) = \exp(-|y|)$ for impulsive noise [3].

The x_l^{VMMKNN} values represent the proposed vector MMKNN (VMMKNN) filter to provide the reference vector [5], defined as follows:

$$x_l^{\text{VMMKNN}} = \hat{e}_{\text{VMMKNN}}^{(q)} = \text{MED}\{g^{(q)}\} \tag{3}$$

where $g^{(q)}$ denotes a set of K_c values of pixels that are weighted in accordance with the used $\tilde{\psi}(y_m)$ influence function in a filter window and are closest by value to the estimate obtained at the previous step $\hat{e}_{\text{VMMKNN}}^{(q-1)}$; y_N is a set of noisy image pixels y_m, $m = 1, \ldots, N$, in a sliding filter window; $\hat{e}_{\text{VMMKNN}}^{(0)} = y_{(N+1)/2}$ is the initial estimate that is equal to the central window pixel; q is the index of the current iteration; K_c is the number of the nearest neighbour pixels [4, 5]:

$$K_c = [K_{\min} + a \cdot D_s(y_{(N+1)/2})] \leq K_{\max} \tag{4}$$

where a controls the detail preservation; $K_{\min}$ is the minimal number of the neighbours for noise removal; $K_{\max}$ is the maximal number of the neighbours for edge restriction and detail smoothing; $D_s(y_{(N+1)/2})$ is the spike detector defined as follows [4]:

$$D_s(y_{(N+1)/2}) = \left[\frac{\text{MED}\{|y_{(N+1)/2} - y_m|\}}{\text{MAD}} \right] + \left[\frac{1}{2} \cdot \frac{\text{MAD}}{\text{MED}\{y_m\}} \right] \tag{5}$$

and MAD is the median of absolute deviations from median [2].

The algorithm finishes when $\hat{e}_{\text{VMMKNN}}^{(q)} = \hat{e}_{\text{VMMKNN}}^{(q-1)}$. We also propose for enhancement of the removal ability of filter (3) to involve the standard median filter. The numerical simulations have shown that for $K_c > 7$ the VMMKNN filter can be substituted for each channel (red, green and blue) by the 3×3 median filter and for $K_c > 350$ we use the 5×5 median filter.

Simulation results: The described AMN-MMKNN filter with the simplest influence function, and VMMKNN filter with the simplest, Hampel three-part redescending, Andrews sine, Tukey biweight, and Bernoulli influence functions have been evaluated, and their performances have been compared with different colour nonlinear filters [3, 6].

The 320×320 'Lena' colour image was corrupted by 20% of impulsive noise (the original 'Lena' image is shown in Fig. 1*a*). The criteria used to compare the performance of various filters were: the peak signal-to-noise ratio (PSNR), the mean absolute error (MAE), and the next two, applying in colour imaging, mean chromaticity error (MCRE), and normalised colour difference (NCD) [2, 3]. Table 1 shows that the mentioned criteria are often better for the proposed AMN-MMKNN filter compared with when other filters are used. Fig. 1 shows the processed images for the 'Lena' test image explaining the impulsive noise suppression. Fig. 1*b* shows the input image corrupted with noise probability occurrence of 20% for each colour channel, and Figs. 1*c* and *d* exhibit the filtering results produced by the 5×5 VMMKNN and 5×5 AMN-MMKNN filters, respectively. The restored images appear to have a good subjective quality.

Fig. 1 *Subjective visual qualities of restored 'Lena' colour image produced by VMMKNN and AMN-MMKNN filters*

a Original test image 'Lena'
b Input noisy image (with 20% of impulsive noise)
c Proposed VMMKNN filtered image (simplest)
d Proposed AMN-MMKNN filtered image

Table 1: Comparative restoration results for 20% impulsive noise for 'Lena' colour image

Algorithm	PSNR	MAE	MCRE	NCD
5×5 vector median (VM)	21.15	10.73	0.035	0.038
5×5 GVDFAD [6]	22.01	11.18	0.028	0.036
5×5 MAMNFE [3]	22.67	9.64	0.027	0.035
5×5 AMN-VM [3]	24.14	10.04	0.034	0.040
AMN-MMKNN	24.61	9.05	0.026	0.032
VMMKNN (simplest)	23.15	10.00	0.033	0.034
VMMKNN (Hampel)	23.07	10.01	0.033	0.035
VMMKNN (Andrews)	23.05	10.04	0.033	0.035
VMMKNN (Tukey)	23.04	10.05	0.034	0.035
VMMKNN (Bernoulli)	23.05	10.04	0.034	0.035

The optimal values for the parameters of the proposed AMN-MMKNN and VMMKNN filters are: $0.5 < a < 12$ and $K_{\min} = 5$. The parameters of the influence functions are: $r \leq 81$ for Andrews sine, $r \leq 255$ for Tukey biweight and Bernoulli, $\alpha = 10$, $\beta \leq 90$ and $r = 300$ for Hampel three-part redescending.

Conclusions: The designed VMMKNN and AMN-MMKNN filters are able to remove impulsive noise and preserve the edges and fine details in colour imaging. The filters, particularly the AMN-MMKNN technique, have demonstrated better quality of image processing, in both the visual and analytical sense in comparison with different known colour image processing algorithms.

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