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COLOUR VIDEO FILTERING BASED ON VECTOR ORDER-STATISTICS

The paper introduces a multichannel filtering approach for colour video denoising taking advantage of an order-statistic theory for vector-valued image signals. The proposed adaptive vector filter utilizes switching between an identity operation and a directional distance smoothing function based on the trimmed set of lowest ranked multichannel samples. Because the proposed method uses the same ordering scheme as the standard vector filters, the computational complexity of the new method is computationally attractive. Moreover, the method outperforms the standard vector filters especially in terms of signal-detail preservation. In this paper, we analyse a three-dimensional filter structure based on a cube filter window spawning 27 samples of three following frames. Thus, the proposed algorithm can be applied for the filtering of spatio-temporal or time-varying vector-valued image signals such as colour image sequences or colour video.

1. INTRODUCTION

Modern communication and multimedia applications such as videoconferencing, videophoning, digital television and Internet services incorporate the recent advances in the field of hardware, software, digital signal and image processing, telecommunications, graphics and computer vision into an integrated system and extend the possibilities of the conventional communication. In order to preserve the visual quality of the time-varying image part of multimedia signals that can be often degraded by bit errors or impulsive noise, a number of motion compensated and non-motion compensated methods [5],[6],[8],[9] for gray-scale image sequence denoising have been developed.

Because of high dimensionality of colour video [11] the filtering strategies tend to combine various image processing areas such as motion tracking [4],[6],[12], spatial filtering [2], processing of vector data [10], etc. In order to assure the restoration precision, it is necessary to overcome high spatial nonstacionarity of frames [5] and to utilise high temporal correlation in the image sequence. In addition, the correct recognition of the objects on the scene significantly depends on the preservation of the colour information so that the applied filtering techniques should utilise also the correlation that exists between colour channels. Because the motion estimation algorithms [4],[5],[6],[9] often fail in environments corrupted by non-Gaussian noise, the most effective

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filtering tool for suppression of bit errors in colour video is represented by non-motion compensated spatiotemporal vector filters outputting the lowest ranked vector [8],[10].

The proposed method is designed to outperform the widely used standard vector approaches such as vector median (VMF) [1], basic vector directional filter (BVDF) [10] and directional distance filter (DDF) [3]. After the adaptation of the filter parameters to varying signal and noise statistics, the new method achieves excellent balance between the signal-detail preservation and the noise attenuation ability.

2. STANDARD VECTOR FILTERING SCHEMES

Let $y(x): Z^l \rightarrow Z^m$ represents a multichannel image frame, where l is an image dimension and m characterises a number of colour channels. In the case of standard colour images, parameters l and m are equal to 2 and 3, respectively. Let $\mathbf{x}_1, \mathbf{x}_2, ..., \mathbf{x}_N$ be a set of input multichannel samples such that $\mathbf{x}_i \in Z^l$, for $i = 1, 2..., N$.

In general, the difference between two multichannel samples $\mathbf{x}_i = (x_{i1}, x_{i2}, ..., x_{im})$ and $\mathbf{x}_j = (x_{j1}, x_{j2}, ..., x_{jm})$ can be quantified through the commonly used Minkowski distance [10]

$$\left\| \mathbf{x}_i - \mathbf{x}_j \right\|_\gamma = \left(\sum_{k=1}^{m} \left| x_{ik} - x_{jk} \right|^\gamma \right)^{\frac{1}{\gamma}} \qquad (1)$$

where γ characterises the used norm, x_{ik} is the k-th element of the sample $\mathbf{x}_i$.

Because vector filters respect a natural inherent correlation that exists between colour channels, each image sample is processed as a vector of channel intensities. The output of vector filters based on the robust order-statistic theory is defined as the lowest ranked vector according to a specific ordering technique [1],[3],[8],[10].

Another way to express the distance between multichannel samples is based on the angle between two multichannel samples $\mathbf{x}_i = (x_{i1}, x_{i2}, ..., x_{im})$ and $\mathbf{x}_j = (x_{j1}, x_{j2}, ..., x_{jm})$

$$\mathrm{A}(\mathbf{x}_i, \mathbf{x}_j) = \cos^{-1}\left(\frac{\mathbf{x}_i . \mathbf{x}_j^T}{|\mathbf{x}_i| . |\mathbf{x}_j|} \right) \qquad (2)$$

$$= \cos^{-1}\left(\frac{x_{i1}x_{j1} + x_{i2}x_{j2} + ... + x_{im}x_{jm}}{\sqrt{x_{i1}^2 + x_{i2}^2 + ... + x_{im}^2}\sqrt{x_{j1}^2 + x_{j2}^2 + ... + x_{jm}^2}} \right) \qquad (3)$$

Let us assume the filter structure with the power parameter p so that the power $1-p$ is associated with the sum of vector distances and the power p (from interval $\langle 0,1 \rangle$) is associated with the sum of angles and let us consider that the ordering criterion is expressed through products

$$\Omega_i = \left(\sum_{j=1}^{N} \left\| \mathbf{x}_i - \mathbf{x}_j \right\|^{\gamma} \right)^{1-p} . \left(\sum_{j=1}^{N} \mathrm{A}(\mathbf{x}_i, \mathbf{x}_j) \right)^{p} \quad \textit{for} \;\; i = 1, 2, ..., N \tag{4}$$

then the ordered set is given by

$$\Omega_{(1)} \leq \Omega_{(2)} \leq ... \leq \Omega_{(r)} \leq ... \leq \Omega_{(N)} \tag{5}$$

Assuming that (5) implies the same ordering scheme to the input set, then we obtain

$$\mathbf{x}_{(1)} \leq \mathbf{x}_{(2)} \leq ... \leq \mathbf{x}_{(r)} \leq ... \leq \mathbf{x}_{(N)} \tag{6}$$

The sample $\mathbf{x}_{(1)}$ associated with $\Omega_{(1)}$ represents the DDF output. For $p = 0.5$, the sum of vector distances and the sum of vector angles have an equivalent importance. This is the case of the standard DDF filter. If $p = 0$, the DDF operates as the VMF, whereas for $p = 1$, the DDF is equivalent to the BVDF.

3. PROPOSED ADAPTIVE APPROACH

In general, the distance measure Ω_i associated with the input sample $\mathbf{x}_i$ reflects the similarity of $\mathbf{x}_i$ to the input set. In the ordered sequence (6), the set of the lowest r ranked multichannel samples, for $r \leq N$, practically includes the samples of the similar properties in the vector space. The samples of this trimmed set are characterised by very small products of the aggregated vector distance measure and the aggregated vector angular measure. Thus, the trimmed set of samples $\mathbf{x}_{(1)}, \mathbf{x}_{(2)}, ..., \mathbf{x}_{(r)}$, for $r \leq N$, has some interesting properties.

Because impulse noise affects a certain amount of samples, whereas other samples remain unchanged, the image samples can be separated into two classes. Namely, it is possible to differentiate a class of noise-free samples and a class of noisy, corrupted samples. In order to ensure the appropriate association with the sample class, it is necessary to determine the decision rule in dependence on local statistic properties of the samples inside the sliding filter window [8].

The decision rule is defined as follows

$$\begin{array}{llll} \text{IF} \;\; Val \geq Tol & \text{THEN} & \mathbf{x}_{(N+1)/2} & \text{is corrupted} \\ & \text{ELSE} & \mathbf{x}_{(N+1)/2} & \text{is noise-free} \end{array} \tag{7}$$

where Val characterises the detector operation based on the simple mathematical relationship between the central multichannel sample $\mathbf{x}_{(N+1)/2}$ and its neighbourhood samples and Tol is the threshold value. If $Val \geq Tol$, then $\mathbf{x}_{(N+1)/2}$ is most probably corrupted. If $Val < Tol$, then $\mathbf{x}_{(N+1)/2}$ is probably noise-free, because the similarity of the central sample to other samples in its nearest neighbourhood is relatively high.

Let us compute the mean value $\bar{\mathbf{x}}(r)$ of the trimmed set $\mathbf{x}_{(1)}, \mathbf{x}_{(2)}, ..., \mathbf{x}_{(r)}$

$$\bar{\mathbf{x}}(r) = \frac{1}{r}\sum_{i=1}^{r}\mathbf{x}_{(i)} \tag{8}$$

The trimmed mean $\bar{\mathbf{x}}(r)$ provides an appropriate representation of multichannel samples of similar properties in the vector space. If the trimmed mean $\bar{\mathbf{x}}(r)$ is compared with the central sample $\mathbf{x}_{(N+1)/2}$ and their difference is quantified by

$$\Omega' = \left\|\bar{\mathbf{x}}(r) - \mathbf{x}_{(N+1)/2}\right\|_{\gamma} \cdot \mathrm{A}(\bar{\mathbf{x}}(r), \mathbf{x}_{(N+1)/2}) \tag{9}$$

the achieved value Ω' represents a good measure of impulse distortion so that the general decision rule (7) can be modified as follows

$$\begin{aligned} &\text{IF } \ \Omega' \geq Tol \quad \text{THEN} \quad \mathbf{y} = \mathbf{x}_{(1)} \\ &\qquad\qquad\qquad\quad \text{ELSE} \quad \mathbf{y} = \mathbf{x}_{(N+1)/2} \end{aligned} \tag{10}$$

where $\mathbf{y}$ is the output of the adaptive order-statistic technique (AOST).

If the difference Ω' (9) between the trimmed mean $\bar{\mathbf{x}}(r)$ and the central sample $\mathbf{x}_{(N+1)/2}$ is larger than or equal to the threshold Tol, the central sample will be replaced with $\mathbf{x}_{(1)}$ that represents the DDF output. Otherwise the central sample $\mathbf{x}_{(N+1)/2}$ is noise-free and it will be unchanged, i.e. the proposed AOST will perform the identity operation.

4. EXPERIMENTAL RESULTS

For the evaluation of the efficiency of the new method we used the test colour sequences “Grandmom” and “Osu-1” which consist of 99 frames of the size 300×240. The test sequences were distorted by impulsive noise (Fig.1a), defined by

$$\mathbf{x}_i = \begin{cases} \mathbf{v}_i & \text{with probability } \ p_{\mathrm{v}} \\ \mathbf{o}_i & \text{with probability } \ 1 - p_{\mathrm{v}} \end{cases} \tag{11}$$

where i denotes the pixel position, $\mathbf{x}_i$ denotes the original image pixel, p_{v} is the intensity of the noise process and $\mathbf{v}_i = (v_R, v_G, v_B)$ is the noise vector-valued sample of random integers from the interval $[0, 255]$ updated for each corrupted pixel.

We evaluated the objective results (Tab. 1 and Tab. 2) using the mean absolute error (MAE), mean square error (MSE), normalised colour difference (NCD) [10] and the cross correlation measure (ΔR) [7]. In general, MAE reflects the signal-detail preservation, MSE evaluates the noise suppression capability, NCD is the measure of the colour chromaticity preservation and ΔR expresses the preservation of the motion trajectory.

Fig.1 shows the noisy frame and the output of the proposed method in comparison with the vector median filtersome chosen filter outputs. In order to compare the performance of the relevant filtering methods, Fig.2 shows the estimation error related to the filtering of 10% impulsive noise in the test sequence Osu-1. Note that the parameter r is optimally set as $r = 7$. The appropriate threshold Tol depends on the power parameter p. We provide sub-optimal thresholds 60, 35 and 0.12 for the power parameter p equal to 0, 0.5 and 1, respectively.

Fig. 1 Achieved results related to the test sequence Osu-1: (a) image distorted by 10% impulsive noise, (b) VMF output, (c) output of the proposed ATVF method (p=0, r=7, Tol=50).

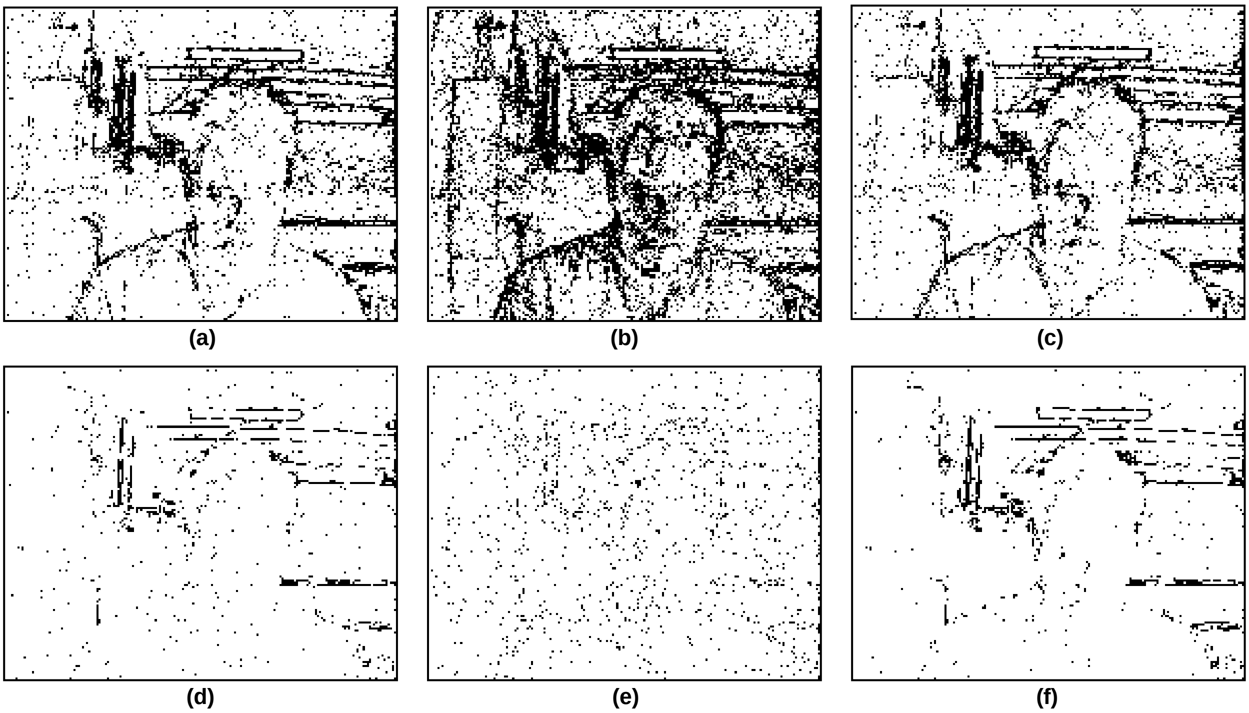

Fig.2. Estimation errors of relevant filtering schemes: (a) VMF, (b) BVDF, (c) DDF, (d) proposed ATVF (p=0, r=7, Tol=60), (e) proposed ATVF method (p=0.5, r=7, Tol=35), (f) proposed AOST (p=1, r=7, Tol=0.12).

5. CONCLUSION

In this paper, we presented a non-motion compensated 3-D adaptive vector filter for outliers detection and impulsive noise removal in colour video. The proposed method is fast and computationally attractive. In addition, the achieved results show that the new filter has excellent preservation capabilities and provides significant improvement of the standard vector filtering schemes.

Tab.1. Achieved results using the test image sequence “Grandmom”.

Noise	5% impulsive noise				10% impulsive noise			
Method	MAE	MSE	NCD	ΔR	MAE	MSE	NCD	ΔR
Noisy	4.167	534.5	0.0443	0.283	8.408	1031.8	0.0854	0.438
VMF	3.163	24.6	0.0647	0.006	3.251	26.2	0.0659	0.006
BVDF	4.261	59.4	0.0642	0.008	4.397	70.1	0.0651	0.012
DDF	3.267	26.4	0.0642	0.006	3.355	28.3	0.0651	0.005
$AOST_1$	0.252	5.0	0.0044	0.001	0.445	7.3	0.0082	0.001
$AOST_2$	0.888	33.9	0.0200	0.011	1.241	53.5	0.0232	0.022
$AOST_3$	0.315	6.4	0.0051	0.001	0.499	8.4	0.0087	0.001

Tab.2. Achieved results using the test image sequence “Osu-1”.

Noise	5% impulsive noise				10% impulsive noise			
Method	MAE	MSE	NCD	ΔR	MAE	MSE	NCD	ΔR
Noisy	3.813	447.4	0.0430	0.160	7.352	855.8	0.0830	0.266
VMF	5.700	191.5	0.0373	0.075	5.818	196.1	0.0378	0.074
BVDF	8.787	449.6	0.0362	0.050	8.853	457.4	0.0365	0.050
DDF	5.793	200.1	0.0364	0.068	5.782	202.4	0.0368	0.050
$AOST_1$	2.389	159.9	0.0059	0.056	2.645	166.2	0.0082	0.057
$AOST_2$	0.902	75.8	0.0031	0.018	1.561	126.8	0.0053	0.030
$AOST_3$	2.783	169.6	0.0067	0.061	3.012	175.0	0.0086	0.061

$AOST_1$ ($p = 0,\ r = 7,\ Tol = 50$), $AOST_2$ ($p = 1,\ r = 7,\ Tol = 0.12$), $AOST_3$ ($p = 0.5,\ r = 7,\ Tol = 35$).

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