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Fuzzy Based Random Impulse Noise Removal From Color Image Sequences

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Abstract

A New three-step fuzzy filter that adopts a fuzzy logic approach for the enhancement of images corrupted with impulse noise is presented where a Fuzzy filter is used for the removal of random impulse noise in color image sequences.As only one strong filtering step may inevitably remove a considerable amount of details in the images.To avoid this a successive filtering steps is presented which gives a very good tradeoff between preservation and noise removal is obtained.therefore,impulse noise is filtered step by step.In each step, noisy pixels are detected by the fuzzy rules, which are very useful for the processing of human knowledge where linguistic variables are used.Pixels that are detected as noisy is done by blockmatching based on a noise adaptive mean absolute difference. The experiment shows that the proposed method outperforms other stste-of-the-art filters both visually and in terms of objective quality measures such as the mean absolute error (MAE), the peak signal-to-noise ratio (PSNR) and the normalized color difference(NCD).

***Index Terms*— fuzzy logic and its rules , image denoising, fuzzy filter ,block matching, impulse noise, nonlinear filters.**

1.Introduction

Image sequences play an important role in today's world. They provide us a lot of information. Videos are for example used for traffic observations, surveillance systems, autonomous navigation and so on.Due to bad acquisition, transmission or recording, the sequences are however usually corrupted by noise, which hampers the functioning of many image processing techniques. A preprocessing module to denoise the images often becomes necessary. The most common noise types that can be distinguished are impule noise, additive noise and multiplicative noise . in the case of impule noise, a certain percentage of pixels grey values or colour components is replaced by noise values. Such noise values can be fixed (usually as the minimum or maximum allowed value: salt and pepper noise)or the result of a random value from a given distribution (e.g Gaussian distribution) has been added to each pixel. In the multiplicative noise type, finally, the intensity of the noise value added to a pixel depends on the intensity of the pixel grey value or colour component itself(e.g speckle noise).

2.Background

The basic concepts in fuzzy set theory and image processing. Introduces several algorithms for the denoising of image sequences. In those video filters, fuzzy logic and fuzzy set theory is used. Fuzzy set theory is a generalization of classical crisp set theory. Where crisp sets in a universal X can be modeled by X- {0, 1} mappings(membership functions).In classical set theory an element x 2 X belongs to a set or doesn't belong to it. In fuzzy set theory also membership degrees between zero and one and thus a more gradual transitions between belonging to and not belonging to is allowed. This makes fuzzy set very useful for the processing of human knowledge, where linguistic values(e.g.large, small,..)are used. For example, a difference in grey level is not necessarily large are not , but can be large to some degree. Fuzzy set theory is very effective in the domain of image processing.

Major advantage of this theory is that it allows the natural description, in linguistic terms, of problems that allows the natural description, in linguistic terms, of problem that should be solved rather than interms of relationships between precise numerical values. This advantage,dealing with the complicated systems in simple way, is the main reason why fuzzy logic theory is widely applied in technique. It is also possible to classify the remotely sensed image (as well as any other digital imagery),in such a way that certain land cover classes are clearly represented in the resulting image.

Most filters in literature, Which are developed for video, are intended for sequences corrupted by additive Gaussian noise. Only few video filters for the impulse noise can be found. However, several impulse noise filters for still images exist. The best known among them are the median based rank-order filters. Such 2-D filters could be used to filter each of the frames of a video successively. However, temporal inconsistencies will arise due to the neglecting of the temporal correlation between successive frames.Most of these methods are based on ordering the vectors in a predefined filtering window.The output for a given color pixel is then the pixel in the window around the given pixel, that has the smallest accumulated distance(Euclidean distance, angular distance, etc.)to all other vectors in the window or which is the most similar to all window pixels. To avoid blurring due to the filtering of noise –free pixels, this filtering framework has been further refined by weighted filtering techniques and switching schemes where the filter is only used for detected pixels. The drawback of vector-based methods, however, is that their performance is highly reduced for higher noise levels. Consider for example a neighborhood, in which all pixels have one noisy component, and the other components are noise-free.

So, although a lot of the components are still noise-free, no noise-free vector will be found for the output of the vector will be found for the output of the vector-based methods. It would be better to filter the color bands separately, but by using information from the other color bands. However, not much alternatives for the vector-based approach can be found in literature. In this paper, we present a filter for the removal of random impulse noise in color image sequences, in which each of the color components is filtered separately based on fuzzy rules , in which information from the other color bands integrated.

To preserve the details as much as possible, the noise is removed by three successive filtering steps.Only pixels that have been detected to be noisy are filtered . this filtering is done by block matching, at echnique used for video compression that has already been adopted in video filters for the removal of Gaussian noise, but that has not really found its way to impulse noise filters yet . The correspondence between blocks is usually calculated by a mean absolute difference (MAD). That is heavily subject to noisy impulses.

Therefore, we introduces a MAD measure that is adaptive to detected noisy pixels components . To benefit as much as possible from the spatial and temporal information available in the sequence, the search region for corresponding blocks contains pixel blocks both from the previous and current frame.

The Experiment shows that the proposed method outperforms other state-of –the-art filters both visually and in terms of objective quality measures such as the MAE,PSNR and NCD.

3.Implementing Method

The proposed filtering framework consists of three successive filtering steps as depicted in below

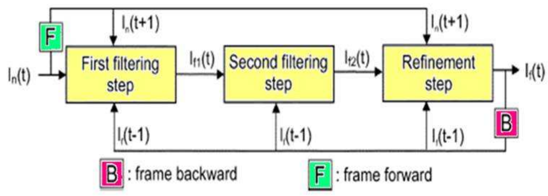


Fig.Block diagram of proposed method.

If we respectively denote the original (noise free) sequence by the I_o then the T th frame of that sequence by $I_o(t)$ and the red, green and blue component of the color $I_o(x, y, t)$ of the pixel at the Xth row and Yth colomn in that frame by $I_o^R(x, y, t), I_o^G(x, y, t) I_o^B(x, y, t)$.

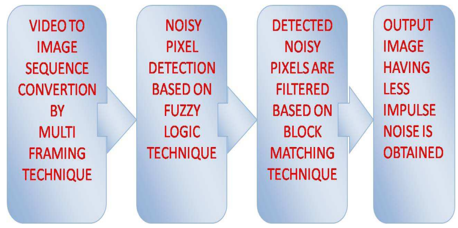
The noisy sequence is determined by that a pixel component is corrupted and it has to replaced by a identically distributed independent random noise value coming from a uniform distribution on the interval of possible color component values.

$$I_n^c(x,y,t) = \begin{cases} I_o^c(x,y,t), & \text{with probability } 1-p, \\ \eta^c(x,y,t), & \text{with probability } p, \end{cases}$$

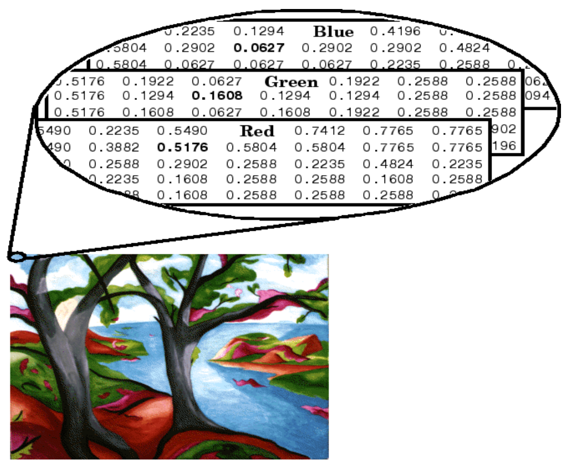
The videos used here are of 8 bits for the storage of the color component values and that storage values is of uniform distributed in the interval [0,255].Thereafter,the probability that a given color component value is corrupted is independent on whether the neighboring values or the values in the other color components are corrupted or not.

Here we follow three fitering steps in order to preserve the details or in formation in that image sequences.as by removing noise step by step, the details can be preserved as much as possible.indeed, if a considerable part of the noise has already been removed in the previous step, and more noise-free neighboors to compare to are available, it will be easier to distinguish noise from small details.In the first step we calculate for each pixel component a degree to which it is considered noisy.if the noisy degree is larger than the noise-free degree,the pixel component is filtered,otherwise it remains the same unchanged.the determination of both the degrees is mainly on temporal information i.e,comparision to the corresponding pixel component in the previous frame.Note ,however, that only in non-moving areas can large temporal differences be assigned to noise.in areas where there is motion,such differences might also be caused by that motion.As a consequence, impulses in moving areas will not be detected always in this step.they can , however,be detected in the second step output this step is analogous as to the first step,again a noise-free degree and a noisy degree are calculated.however, the detection is now mainly based on color information.A pixel component can be seen as noisy if there is similarity to its (spatio-temporal)neighbours in the given color, while there is in the other color bands.The third step output, finally, removes the remaining noise and refines the result by using as well temporal as spacial and color information. For example, homogeneous areas can be refined by removing small impulses that are relateively large in that region, but are not large enough to be detected in detailed regions and that thus have not been detected yet by the previous general detected steps.The results of the different successive filtering steps are illustrated in the 20th frame of the salesman sequence.

A.FIRST FILTERING STEP



Scenerio 1) **DETECTION:** In this phase, each pixel is assigned a degree to which it is considered noisy or noise-free randomly.if the noisy degree is larger then the noise-free degree then that particular detected pixel component will be filtered other remain the same.Detection is made based on fuzzy rules. We consider a pixel to be noise-free if it is similar to the corresponding component of the pixel at the same spatial location in the previous or in the next frame. In the case of motion, the pixels I the previous frames can not be used to determine whether a pixel component in the current frame is noise-free. Therefore, more conformation in needed ie.,more similar neighbours or also similar in the other color components . in case of nose-free degree of the red component (and analogously for other components also) this is achieved by the following fuzzy rule.



Fuzzy Rule 1: IF(($|I_n^R(x,y,t) - I_f^R(x,y,t-1)|$ is NOT LARGE POSITIVE OR $|I_n^R(x,y,t) - I_n^R(x,y,t+1)|$ is NOT LARGE POSITIVE) AND there are two neighbors $(x+k, y+l, t)$ $(-2 \le k, l \le 2$ and $(k,l) \ne (0,0))$ for which $|I_n^R(x,y,t) - I_n^R(x+k,y+l,t)|$ is NOT LARGE POSITIVE)

OR (there are four neighbors $(x+k, y+l, t)$ $(-2 \le k, l \le 2$ and $(k,l) \ne (0,0))$ for which $|I_n^R(x,y,t) - I_n^R(x+k,y+l,t)|$ is NOT LARGE POSITIVE OR (there are two neighbors

$(x+k, y+l, t)$ $(-2 \le k, l \le 2$ and $(k,l) \ne (0,0))$ for which $|I_n^R(x,y,t) - I_n^R(x+k,y+l,t)|$ is NOT LARGE POSITIVE AND ($|I_n^G(x,y,t) - I_n^G(x+k,y+l,t)|$ OR $|I_n^B(x,y,t) - I_n^B(x+k,y+l,t)|$ are NOT LARGE POSITIVE)))

Anologously, a degree to which the component of a pixel is considered noisy is calculated.here we consider a pixel to be noisy if the pixel component is large positive compared to the pixel at the same spacial location in the previous frame and if not for five of its neighbours .futher we also want conformation either by the fact that in this color band, there is a direction in which the difference between the considered pixel and the two respetive neighbours in this direction are both large positive or large negetive and if the absolute difference between those two neighbours is not large positive i.e,there is an impulse between two pixels that are expectedto belong to the same object) or by the fact that there is no large differnce between the considered pixel and the pixel at the same spacial location in the previous frame in one of the other two color bands this leads to the following fuzzy rule.

Fuzzy Rule 2: IF($|I_n^R(x,y,t) - I_f^R(x,y,t-1)|$ is LARGE POSITIVE AND NOT (for five neighbors $(x+k, y+l, t)$ $(-2 \le k, l \le 2$ and $(k,l) \ne (0,0))$ $|I_n^R(x+k,y+l,t) - I_f^R(x+k,y+l,t-1)|$ is LARGE POSITIVE AND ($|I_n^G(x+k,y+l,t) - I_f^G(x+k,y+l,t-1)|$ OR $|I_n^B(x+k,y+l,t) - I_f^B(x+k,y+l,t-1)|$ is LARGE POSITIVE)))

AND ((in one of the four directions (the differences $I_n^R(x,y,t) - I_n^R(x+k,y+l,t)$ AND $I_n^R(x,y,t) - I_n^R(x-k,y-l,t)$ $((k,l) \in \{(-1,-1),(-1,0),(-1,1),(0,1)\})$ are both LARGE POSITIVE OR both LARGE NEGATIVE) AND the absolute difference $|I_n^R(x+k,y+l,t) - I_n^R(x-k,y-l,t)|$ is NOT LARGE POSITIVE) OR ($|I_n^G(x,y,t) - I_f^G(x,y,t-1)|$ is NOT LARGE POSITIVE OR $|I_n^B(x,y,t) - I_f^B(x,y,t-1)|$ is NOT LARGE POSITIVE))

Analogously to the linguistic term large positive,also large negative is represent by a fuzzy set, characterised by a membership function as shown belowin fig 4

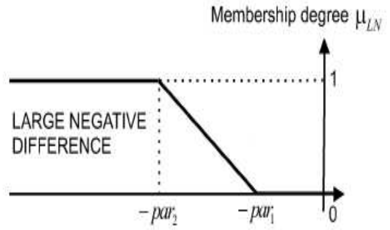


Fig. 4. The membership function μ_{LN} of the fuzzy set *large negative*.

The membership functions of the fuzzy set large negative. frame is large positive and five of its neighbours do not show motion, is then given by

$$\beta(x,y,t) = \min(\mu_{LP}(|I_n^R(x,y,t) - I_f^R(x,y,t-1)|), 1 - t_{pos}(x,y,t)).$$

Further, the degree to which there is no large difference between the considered pixel and the pixel at the same spacial location in the previous frame in one of the other two color bands is given by

$$\delta(x,y,t) = \max(1 - \mu_{LP}(|I_n^G(x,y,t) - I_f^G(x,y,t-1)|), 1 - \mu_{LP}(|I_n^B(x,y,t) - I_f^B(x,y,t-1)|)).$$

Finally, the degree to which there is a direction in which the pixel at position is an impulse, denoted by, is determined as the maximum value in the set

$$\{\min(\max(\epsilon^1_{(k,l)}(x,y,t), \epsilon^2_{(k,l)}(x,y,t)), \epsilon^3_{(k,l)}(x,y,t)) \,||(k,l) \in \{(-1,-1),(-1,0),(-1,1),(0,1)\}\}$$

Where

$$\epsilon^{1}_{(k,l)}(x,y,t) = \min(\mu_{\mathrm{LP}}(I^{R}_{n}(x,y,t) I^{R}_{n}(x+k,y+l,t)), \mu_{\mathrm{LP}}(I^{R}_{n}(x,y,t) - I^{R}_{n}(x+k,y+l,t))),$$

$$\epsilon^{2}_{(k,l)}(x,y,t) = \mu_{\mathrm{LN}}(I^{R}_{n}(x,y,t) - I^{R}_{n}(x,y,t) + k, y \quad \mu_{\mathrm{LP}}(I^{R}_{n}(x,y,t) - I^{R}_{n}(x,y,t) + k, y$$

$$\epsilon^{3}_{(k,l)}(x,y,t) =_{1} \mu_{\mathrm{LP}}(|I^{R}_{n}(x+k,y+l,t)$$

By Combining the above

$$\mu^{R}_{\mathrm{noisy}}(x,y,t) = \min(\beta(x,y,t), \delta(x,y,t), \gamma(x,y,t)).$$

Scenerio 2). **Filtering:** In this subsection, we discuss the filtering for the red color band. The filtering of the other color bands is analogous. We decide to filter all red pixel components that are considered more likely to be noisy than noise-free, i.e. for which. The red components of the other pixels remain unchanged to avoid the filtering of noise-free pixels (that might have been incorrectly assigned a low noisy degree, but for which the high noise-free degree assures us that it is noise-free) and thus detail loss. On the other hand, noisy pixel components might remain unfiltered due (I_{f_1}) to an uncorrected high noise-free degree, but those pixels can still be detected in the next filtering step.

$$\mu^{R}_{\mathrm{unch}}(x,y,t) = \begin{cases} 0, & \text{if } \mu^{R}_{\mathrm{noisy}}(x,y,t) > \mu^{R}_{\mathrm{noisefree}}(x,y,t) \\ 1, & \text{else.} \end{cases}$$

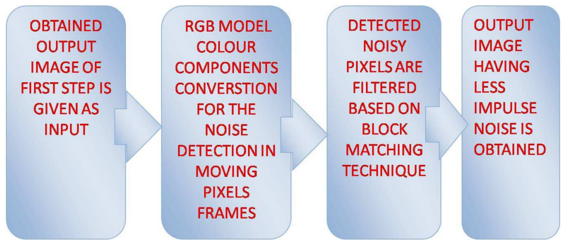
$$\mu_{\mathrm{unch}}(x,y,t) = (\mu^{R}_{\mathrm{unch}}(x,y,t), \mu^{G}_{\mathrm{unch}}(x,y,t), \mu^{B}_{\mathrm{unch}}(x,y,t))$$

a vector that gives information on whether (I_{f_1}) the respective color component of the color pixel should be filtered. Analogously as denotes the frame of denotes the 2-D array of vectors that gives information about the pixel components of the frame of the sequence. To exploit the spatial and temporal information in the sequence as much as possible, the filtering is performed by block matching. To do this, a noise-adaptive mean absolute difference (MAD) is used to calculate the correspondence between the color components of two blocks of image pixels (where is a general parameter that determines the block size): with and In the above equations, and are the two frames (2-D color images), to which the blocks belong, and indicate the spatial coordinates of the central pixel of the considered block and respectively stand for the vertical and horizontal coordinates of the displacement vector, i.e., the block that is considered in has as the central pixel. The binary functions and indicate whether the pixel components and are reliable and should be used (respectively) or not (respectively).

$${}^{R}\mathrm{MAD}^{I,\mu}_{\tilde{I},\tilde{\mu}}(x,y,r,s,W) = \frac{\sum_{k=-W}^{+W}\sum_{l=-W}^{+W} \nu(x,y,k,l,r,s)\phi(x,y,k,l,r,s)}{\sum_{k=-W}^{+W}\sum_{l=-W}^{+W} \nu(x,y,k,l,r,s)}$$

Using only noise-free pixel components allows us to calculate a more reliable measure to estimate whether two blocks would correspond in the red component if they were both noise-free. If the noise adaptive MAD is assigned the value. Further, the noise adaptive MAD is not considered reliable if not for at least half of the positions in the blocks, both compared values are reliable (and) or not for half of the reliable positions the absolute difference is not large positive (i.e.,). It is also not considered reliable if both the green and blue component of the central pixels are reliable and their absolute difference is large positive .

B.Second filtering step:



Here our aim to preserve the details as much as possible, the noise is removed in successive steps. In this step, the noise is detected based on the output of the previous step and in this second filtering step, a degree to which a pixel component is expected to be noise-free and a degree to which a pixel component is expected to be noisy, is calculated. In the calculation of those degrees, we now take into account information from the other color bands.

A color component of a pixel is considered noise-free if the difference between that pixel and the corresponding pixel in the previous frame is not large in the given component and also not large in one of the other two color components. It is also con- sidered noise-free if there are two neighbours for which the dif ference in the given component and one of the other two components are not large. So, the other color bands are used here as a confirmation for the observations in the considered color band to make those more reliable.For the red component (and analogously the other color components), this gives the following fuzzy rule

Fuzzy Rule 3: IF($|I^{R}_{f_1}(x,y,t) - I^{R}_{f}(x,y,t-1)|$ is NOT LARGE POSITIVE AND($|I^{G}_{f_1}(x,y,t) - I^{G}_{f}(x,y,t-1)|$ is NOT LARGE POSITIVE OR $|I^{B}_{f_1}(x,y,t) - I^{B}_{f}(x,y,t-1)|$ is NOT LARGE POSITIVE)

OR(for two neighbors $(x+k, y+l, t)$ $(-1 \leq k, l \leq 1$ and $(k,l) \neq (0,0))$ $|I^R_{f_1}(x,y,t) - I^R_f(x+k, y+l, t)|$ is NOT LARGE POSITIVE AND($|I^G_{f_1}(x,y,t) - I^G_f(x+k, y+l, t)|$ is NOT LARGE POSITIVE OR $|I^B_{f_1}(x,y,t) - I^B_f(x+k, y+l, t)|$ is NOT LARGE POSITIVE))

The degree to which the red component of the pixel at position is considered noise-free, is then

$$\mu^R_{2,\text{noisefree}}(x,y,t) = \max(\zeta(x,y,t), \eta(x,y,t))$$

$$\begin{aligned} \zeta(x,y,t) &= \min(1 - \mu_{LP}(|I^R_{f_1}(x,y,t) - I^R_f(x,y,t-1)|), \\ &\quad \max(1 - \mu_{LP}(|I^G_{f_1}(x,y,t) - I^G_f(x,y,t-1)|), \\ &\quad 1 - \mu_{LP}(|I^B_{f_1}(x,y,t) - I^B_f(x,y,t-1)|))) \end{aligned}$$

where the second largest element in the set A pixel component is considered noisy if there are three neighbors that differ largely in that component, but are similar (not a large difference) in the other two components.

and $\eta(x,y,t)$ is the second largest element in the set

$$\begin{aligned} &\{\min(1 - \mu_{LP}(|I^R_{f_1}(x,y,t) - I^R_f(x+k,y+l,t)|), \\ &\quad \max(1 - \mu_{LP}(|I^G_{f_1}(x,y,t) - I^G_f(x+k,y+l,t)|), \\ &\quad 1 - \mu_{LP}(|I^B_{f_1}(x,y,t) - I^B_f(x+k,y+l,t)|))) \\ &\quad \| -1 \leq k,l \leq 1 \text{ and } (k,l) \neq (0,0)\}. \end{aligned}$$

It is also considered noisy if in the considered color band, its value is larger or smaller than the component values of all its neighbors, and this is not the case in both of the other color bands. For the red component of a pixel (and analogously for the other components), this corresponds to the following fuzzy rule.

Fuzzy Rule 4: IF (for three neighbors $(x+k, y+l, t)$ $(-1 \leq k, l \leq 1$ and $(k,l) \neq (0,0))$ $|I^R_{f_1}(x,y,t) - I^R_f(x+k, y+l, t)|$ is LARGE POSITIVE AND $|I^G_{f_1}(x,y,t) - I^G_f(x+k, y+l, t)|$ is NOT LARGE POSITIVE AND $|I^B_{f_1}(x,y,t) - I^B_f(x+k, y+l, t)|$ is NOT LARGE POSITIVE)

Then the red component is considered NOISY. The noisy degree for the red component of the pixel at position is then calculated as follows:

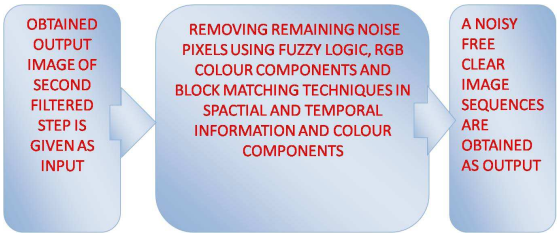
$$\mu^R_{2,\text{noisy}}(x,y,t) = \max(\theta(x,y,t), \kappa(x,y,t))$$

where,

$$\begin{aligned} &\{\min(\mu_{LP}(|I^R_{f_1}(x,y,t) - I^R_f(x+k,y+l,t)|), \\ &\quad \min(1 - \mu_{LP}(|I^G_{f_1}(x,y,t) - I^G_f(x+k,y+l,t)|), \\ &\quad 1 - \mu_{LP}(|I^B_{f_1}(x,y,t) - I^B_f(x+k,y+l,t)|))) \\ &\quad \| -1 \leq k,l \leq 1 \text{ and } (k,l) \neq (0,0)\} \end{aligned}$$

It is the third largest element in the set and where with All red (and analogously green and blue) components for which are filtered , the other red components remain unchanged : Analogously to the first step, for the filtering of the red components (and analogously the green and blue components) for which , we search for the noise-free center of the best corresponding bloc in the search region in the current and previous frame. The minimum value itself is denoted by The minimum value itself is denoted by If , the is filtered as Red pixel components that are considered noise-free remain unchanged:

C. Third Filtering Step



The result from the previous steps is further refined based on temporal, spatial and color information. Namely, the red component (and analogously the green and blue component) of a pixel is refined in the following cases:

$$\Delta(x,y,t) = |I^c_{f_2}(x,y,t) - I^c_f(x,y,t-1)|)$$

$$\frac{\sum_{k=-1}^{1}\sum_{l=-1}^{1}\sum_{c\in\{R,G,B\}}\Delta(x+k,y+l,t)}{24} - \frac{\sum_{c\in\{R,G,B\}}\Delta(x,y,t)}{24} < \text{par}_1$$

and if $|I^R_{f_2}(x,y,t) - I^R_f(x,y,t-1)| > \text{par}_2$ and $|I^R_f(x,y,t-1) - I^R_n(x,y,t+1)| < \text{par}_1$, then the red component $I^R_{f_2}(x,y,t)$ is considered to be noisy $(\mu^R_{3,\text{unch}}(x,y,t) = 0)$. The last check is to prevent noise

In non-moving areas, pixels will correspond to the pixels in the previous frame, which allows us to detect remaining isolated noisy pixels. If lies in a non-moving 3 3 neighborhood, i.e., (with) and if and, then the red component is considered to be noisy. The last check is to prevent noise propagation in the case that the pixel in the previous frame would not have been filtered correctly. • Very small impulses might not have been detected by the algorithm. In homogeneous areas however, such impulses might be relatively large and can be detected more easily. Let and respectively denote the second largest and second smallest red component value among the eight neighbors in a 3*3 neighborhood around. If (homogeneous neighborhood) and further also or (the red component is clearly larger or smaller than the neighborhood), then the red component is considered to be noisy

Based on color information, the red component is considered to be noisy if in a 3 3 neighborhood two neighbors can be found for which In all other cases the red component value is considered to be noise-free and should not be adapted anymore .Analogously as in the previous steps, for the filtering of the red components for which we search for the noise-free center of the best corresponding block in the search region in the current and previous frame. The minimum value itself is denoted by the minimum value it is denoted by a red component for which is filtered as Otherwise, it remains unchanged i.e, remain the same.

EXPERIMENTAL RESULTS

To be able to judge the performance of the proposed method, we will use the mean absolute error (MAE),

$$\mathrm{MAE}(I_o(t), I_f(t)) = \frac{\sum_{c\in\{R,G,B\}} \sum_{x=1}^{m} \sum_{y=1}^{n} |I_o^c(x,y,t) - I_f^c(x,y,t)|}{3 \cdot n \cdot m}.$$

The peak-signal-to noise ratio (PSNR)

$$\mathrm{MSE}(I_o(t), I_f(t)) = \frac{\sum_{c\in\{R,G,B\}} \sum_{x=1}^{m} \sum_{y=1}^{n} (I_o^c(x,y,t) - I_f^c(x,y,t))^2}{3 \cdot n \cdot m},$$

$$\mathrm{PSNR}(I_o(t), I_f(t)) = 10 \cdot \log_{10} \frac{S^2}{\mathrm{MSE}(I_o(t), I_f(t))},$$

And the normalized color difference (NCD) as objective measures of similarity and dissimilarity between a filtered frame and the original one , each containing rows and columns of pixels. The MAE is given by The lower the MAE, the more similar (less dissimilar) the images. The PSNR value is defined as where denotes the maximum possible value of a pixel component (here). The higher the PSNR value, the more similar (less dissimilar) the images. Finally, the NCD,

$$\mathrm{NCD}(I_o(t), I_f(t)) = \frac{\sum_{x=1}^{m} \sum_{y=1}^{n} \left\| I_o^{\mathrm{LAB}}(x,y,t) - I_f^{\mathrm{LAB}}(x,y,t) \right\|}{\sum_{x=1}^{m} \sum_{y=1}^{n} \left\| I_o^{\mathrm{LAB}}(x,y,t) \right\|}$$

Between an original and a filtered frame, is calculated as where is the Euclidean norm and and respectively denote the -transform [42] of the original and the filtered frame. The lower the NCD value, the more similar (less dissimilar) the images. The remainder of this section is structured as follows. The parameter values for the membership functions and the window sizes are determined. The proposed filtering framework is compared to other state-of-the-art noise reduction methods.

FIG . 20th frame of the “Deadline” sequence (top-left to bottom-right): orig-

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