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Signal-adaptive nonlinear filtering for scratch reduction in images

Kristina Kelber and Alexander Hübler

Department of Electrical Engineering, University of Applied Sciences Dresden
Friedrich-List-Platz 1, D-01069 Dresden, Germany
Email: kelber@et.htw-dresden.de, Alex-Huebler@web.de

Abstract—In this paper, a new method for reduction of scratches and other thin, line-like artefacts in images is presented. It is based on an adaptation of size and orientation of the mask of a 1D median filter according to the shortest path across the artefact.

1. Introduction and motivation of work

For the reconstruction of substandard films, old movies, or videos, special methods for reduction of scratches and artefacts caused by dust are desired. Especially for cases where expensive equipment for a professional reconstruction is not available, a simple algorithm is required, which provides fairly good results. Furthermore, an automatic approach is preferable due to the large number of images to be processed.

This work is focussed on removal of line-like artefacts that might be caused by scratches, dust, or overlays. Line scratches are often produced by mechanical elements of the devices. Therefore, such scratches are considered as narrow vertical lines where the original signal (pixel information) is heavily corrupted or completely lost. Hair-like dust on the film surface during digitalization also causes long but thin artefacts of arbitrary shape. Furthermore, the method presented here can be used to remove (colour) line overlays from images as considered in [1]. An image containing different line-like artefacts is used to demonstrate the principle of the approach (fig. 1).

Figure 1: Image containing several line artefacts

2. State of the Art

In most cases, artefacts allocate small regions of the image. The objective of the reconstruction is to make these artefacts invisible by replacing the corresponding pixel values with suitable ones. Pixel values which are not influenced by an artefact should remain unchanged.

Different approaches for solving this problem have been discussed. In general, they are divided into two phases. The first one, called *detection phase*, is necessary to find the region of the artefacts (region of interest, ROI) in the image. The second one, called *removal phase*, is used to reconstruct corrupted or missing pixel values.

In detection phase, methods such as statistics and MAP techniques [2], rank-ordered differences [3], local gradient measures in the image [4], or its cross section [5] or morphological filters combined with tracking over several frames [6] are applied. Some modern film scanners use an extra sensor that scans the very surface of the film itself to provide the ROI of dust or scratches.

Methods used in the removal phase are interpolation or approximation [6], morphologocal filters [7], MAP techniques [8], Fourier series for reconstruction of high-frequency components [6], and image inpainting [9].

Rank-order filters (e.g. minimum, median, maximum, fig. 4)[10] are also known from classical image processing. Particularly for the removal of impulse noise, a median filter is used. It removes artefacts and details that are smaller than half of its filter mask size. At the same time, it does not blur edges, which is an important advantage of this nonlinear filter compared to linear ones.

3. Modified approach

The approach presented here has been developed to remove colour overlays from greyscale images [1] and line-like scratches from images of (substandard) film digitized by direct, single frame projection on an image sensor as depicted in fig. 2.

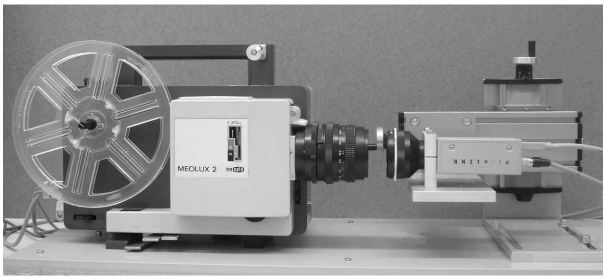

Figure 2: Hardware for direct, single frame, projection of substandard film on an image sensor

3.1. Detection phase: Find region of interest

The ROI of colour overlays has been detected by the evaluation of colour information and shape of the region in the RGB image [1]. The method presented in [5] has been used for the detection of vertical line scratches. Because line scratches are either light (white) or dark (black) vertical stripes, their ROI can be found based on the calculation of the cross section of the luminance, followed by an evaluation of width, height, and energy of the region. As the result of the detection phase, a scratch mask (binary image) has been obtained that specifies the ROI of all line-like artefacts. As an example, the corresponding scratch mask for the image in fig. 1 is depicted in fig. 3. It represents a vertical scratch as well as several other thin, line-like artefacts.

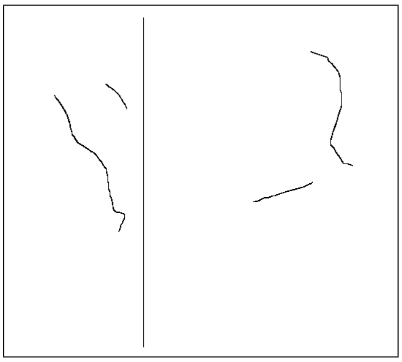

Figure 3: Binary scratch mask (inverted)

3.2. Removal phase: Reconstruct missing pixel

As mentioned above, rank-order filters are used for removal of impulse noise in images. Rank-order filtering of an image matrix is realized as follows:

1. the pixel values of a fixed filter mask size (e.g. 3×3 pixels) are rank-ordered for each pixel and
2. one or a combination of more of theses ordered values is selected as the new value for the corresponding pixel.

For the removal of the impulse noise, the *median* filter is used which selects the value situated in the middle position of the sorted sequence as depicted in fig. 4.

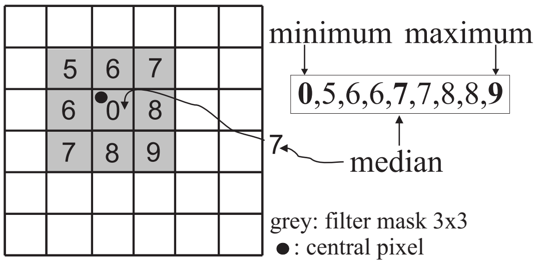

Figure 4: Minimum, median, and maximum filter

Median filters of mask size N^2 pixels remove light or dark artefacts (and details) of a size less than $N^2/2$ pixels. Impulse noise (also called salt & pepper noise) has, in general, the size of just one pixel. Artefacts considered here are line-like and thus very thin in one dimension as depicted in fig. 3.

The idea, presented here, is to *adapt size and orientation of the filter mask* of the median to the ROI of the artefacts obtained in the detection phase and described by the binary scratch mask (e.g. fig. 3) and thus to use a **signal-adaptive median filter**.

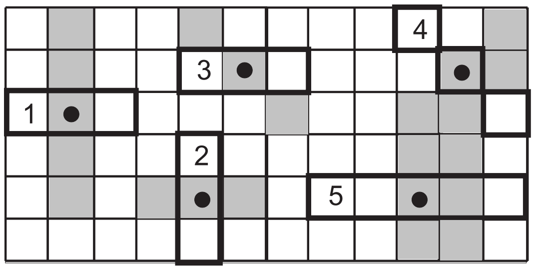

Figure 5: Examples of median filter masks adapted in size and orientation to the ROI of the artefacts. All ROI pixels are marked in grey. The adapted filter mask for selected ROI pixels (marked by black dots) is shown by black rectangles.

The principle of tailoring the filter mask to the ROI is depicted in fig. 5 for different shapes of the ROI. For straight lines (examples 1 to 3), a horizontal or vertical 1D median filter is sufficient. For more complex structures (examples 4 to 5) the mask is selected for each pixel according to the shortest path across the artefact.

4. Signal-adaptive median filter

The algorithm is based on the binary scratch mask and consists of two steps.

Step 1: All pixels of the ROI are classified according to the size and direction of the shortest path across the artefact.

To do so, for each pixel marked in the binary scratch mask, the extent of the ROI in horizontal, vertical, and diagonal ($\pm 45°$) direction is calculated. Fig. 6 [1] shows the results for all four directions for an example. For the reconstruction in step 2, the minimum

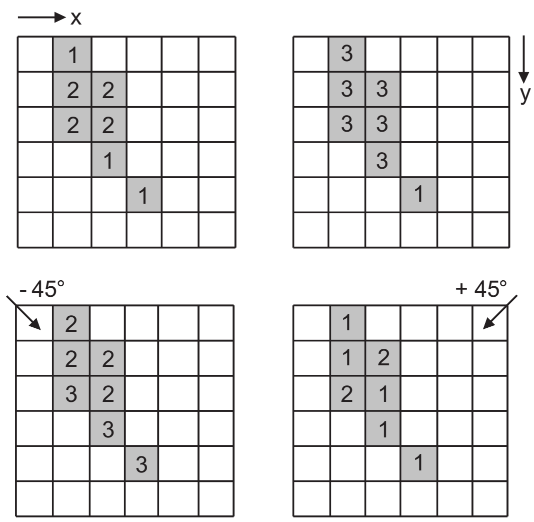

Figure 6: Extent of the ROI in horizontal, vertical and diagonal ($\pm 45°$) direction (example). ROI pixels are depicted in grey and the corresponding number specifies the size of the shortest path.

size w_{min} of the results for all four directions is selected to use the shortest path (and thus a minimum size median filter). If this minimum size is valid for different directions, filter masks based on different directions can be used for reconstruction. The result of this classification according to size and direction of the shortest path is depicted in fig. 7 (left) for the example in fig. 6. Fig. 7 (right) shows the same result for vertical and horizontal directions only.

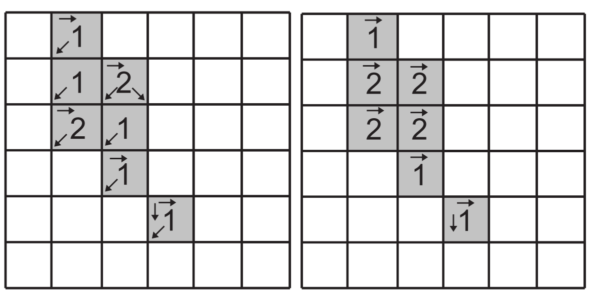

Figure 7: Result of ROI pixel classification for all four directions (left) and for horizontal and vertical directions only (right). For each pixel the minimum size w_{min} of the path is described by the number, the direction is described by the arrows.

Step 2: Based on the result of step 1, a 1D median filter in horizontal, vertical, or diagonal direction is used to replace each corrupted or missing ROI pixel. The size N of the filter mask has to be odd numbered. It has to be large enough to cover more correct pixels than (corrupted) ROI pixels in order to replace the ROI pixel by a suitable one. Therefore, N is based on the minimum path size w_{min} across the ROI and is calculated as

$$N = 2 \cdot w_{min} + 1 \qquad (1)$$

5. Results

Figure 8: Result of reconstruction using signal-adaptive median filters (mask size 1x3 or 1x5 pixel)

For simulation and test, the algorithm has been implemented in MatLab (R2007b). As one result, fig. 8 shows that the scratches in fig.1 (which have a minimum path size $w_{min} \leq 2$ for all ROI pixels) could be completely removed by applying one 1D median filter of size 1x3 or 1x5 in one of the four directions to each ROI pixel. To discuss details and to compare results to classical median filtering, the results for a section of the scratched image in fig. 1 are depicted in fig. 9 and 10. The effect of using a subset of filters only is presented for different mask sizes and orientations in fig. 9. It clearly shows that a filter mask size according to eq. (1) is necessary and sufficient to make the scratch nearly invisible. Fig. 10 shows the result of a classical median filtering (using square mask of size $N \times N$) applied to the whole image. For the images $\hat{f}(x,y)$ in fig. 9 and 10, the signal-to-noise ratio (in dB)

$$SNR = 20 \log \frac{\sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x,y)^2}{\sum_{x=0}^{M-1} \sum_{y=0}^{N-1} (f(x,y) - \hat{f}(x,y))^2} \qquad (2)$$

has been calculated. Compared to the original image $f(x,y)$ the SNR of the scratched image is $34,20dB$.

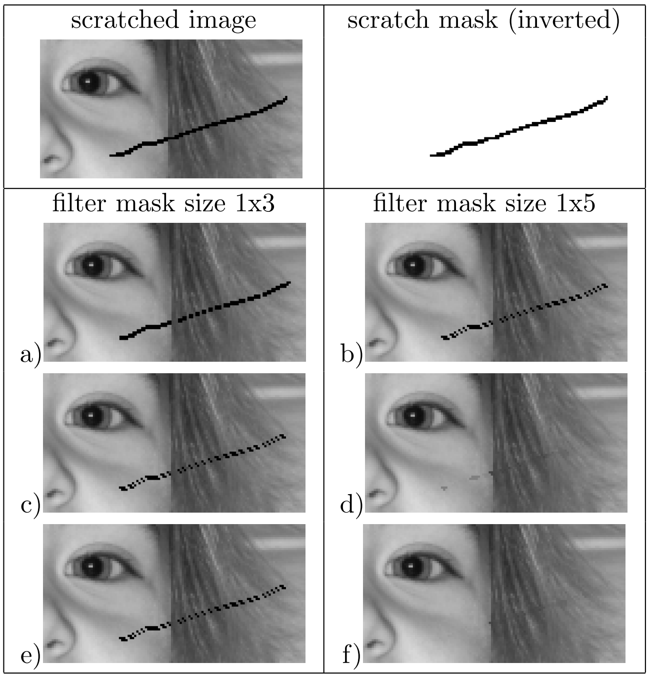

Figure 9: Reconstruction using signal-adaptive median filters a),b) horizontal and vertical direction only, c),d) diagonal directions only, e),f) all four directions

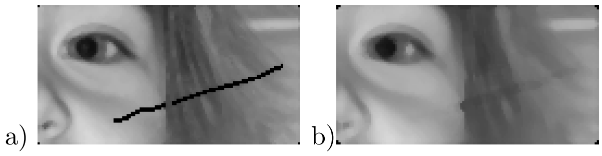

Figure 10: Application of a median filter of size a) 3x3 and b) 5x5 to the whole image (using MatLab R2007b)

Results for all other images are summarized in table 1. Detailed results for removal of colour line overlays can be found in [1].

6. Summary and future work

In this paper, a new method for reduction of scratches and other thin, line-like artefacts in images has been presented based on an adaptation of the size and orientation of the mask of a 1D median filter according to the shortest path across the ROI of the artefact. Compared to classical median filtering of a complete image, three advantages have been shown:

- Filter mask size can be reduced from $N \times N$ to $1 \times N$.
- Applying the adapted filter to the ROI pixel only avoids vanishing details in the remaining part of the image (see the hair in fig. 10 for example).
- The signal-to-noise ratio is increased.

image	size 3	size 5
9a,b)	$SNR = 34,96dB$	$SNR = 38,46dB$
9c,d)	$SNR = 38,46dB$	$SNR = 47,08dB$
9e,f)	$SNR = 38,54dB$	$SNR = 51,02dB$
10a,b)	$SNR = 25,47dB$	$SNR = 21,83dB$

Table 1: SNR (in dB) of the images in fig. 9 and 10

In the future, the results of this approach have to be compaired to other methods presented in the literature.

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References

[1] A. Hübler, *"Automatisches Retuschieren von farbigen Overlays aus Bildern*, Master thesis, University of Applied Sciences Dresden, Germany, 2007.

[2] D. Tegolo, F. Isgro: Scratch detection and removal from static images using simple statistics and genetic algorithms, *Proc. ICIP 2001*, p.265-268.

[3] M.J. Nadenau and S.K. Mitra: Blotch and Scratch Detection in Image Sequences based on Rank Ordered Differences, *5th Int. Workshop on Time-Varying Image Processing and Moving Object Recognition*, 1996, Florence, Italy.

[4] A. Machi, F. Collura, F. Nicotra: Detection of irregular linear scratches in aged motion picture frames and restoration using adaptive masks, *Proc. of IASTED Int. Conf. on Image Processing*, 2002, pp. 254259.

[5] V. Bruni and D. Vitulano: A Generalized Model for Scratch Detection, *IEEE Trans. IP*, vol. 13, no. 1, 2004, 44-50.

[6] L. Joyeux, S. Boukir, 0. Buisson, B. Besserer: Reconstruction of degrades image sequences. Application to film restoration, *Image and Computer Vision*, 2001, 503-516.

[7] T. Saito, T. Komatsu, T. Ohuchi, T. Seto, Image processing for restoration of heavily-corrupted old film sequences, *Proc. of Int. Conf. on Pattern Recognition*, Barcellona, IEEE Computer Society, 2000, pp. 1720.

[8] L. Joyeux, S. Boukir, B. Besserer: Tracking and MAP reconstruction of line scratches in degraded motion pictures, *Machine Vision and Applications*, vol.13, 2002, 119128.

[9] C.A. Zorzo Barcelos, M. Aurelio Batista: Image restoration using digital inpainting and noise removal, *Image and Vision Computing*, vol. 25, 2007, 6169.

[10] R. Klette, P. Zamperoni: *Handbook of Image Processing Operators*, John Wiley & Sons, 1996.

[11] C. Kotropoulos, G. Pitas (ed.), *Nonlinear Model-based Image/Video Processing and Analysis*, Wiley, 2001.