Removal of Vertical Scratches in Digitised Historical Film Sequences Using Wavelet Decomposition

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Abstract

Movie films are often damaged through ageing, chemical changes and contact with mechanical parts of the film projector. In this paper methods for the detection and removal of vertical scratches in digitised film sequences are discussed. This specific type of scratch arises by the contact of the film material running against a mechanical part of the camera or film projector. The proposed technique is based on the discrete wavelet decomposition. This transformation splits an image into approximation and detail coefficients, where the latter separate into horizontal, vertical, and diagonal representations. The algorithm reconstructs the missing data in the region of the scratch and finally the synthesis of the wavelet coefficients generates a restored version of the scratched image frame. The results show that the combination of scratch detection and removal in the wavelet domain is superior to other techniques based in the image domain which use single frames.

Keywords: *scratch detection, scratch removal, wavelet transformation, digitised film sequences*

1 Introduction

Movie films are often damaged through ageing, chemical changes and abrasion by contact with mechanical parts of the film projector. The reconstruction of already damaged material and preservation of the movie heritage is an important task, but manual restoration is expensive in time and money due to the huge data volume. Therefore unsupervised processing methods for removal of frequently occurring defects are highly desirable.

In this paper methods for the detection and removal of vertical scratches are discussed. This specific type of scratch is caused by contact of the film material with a mechanical part of the film projector. A part of the film surface, i.e. the emulsion, is lost and the result is a scratch visible over a number of frames. The bright or dark characteristic of the scratch is related to the type of film material, i.e. whether it is a positive print or a negative. The scratches start at the top of the image and run vertically over the entire image and can be found at the same horizontal location on at least several subsequent frames. The analysis of film material sampled to the European standard television broadcasting norm (PAL: 768×576 pixels) has shown that the typical scratch is approximately five pixels wide. Although the horizontal extent of the scratch is small with respect to the entire frame, the attention of the observer is attracted by the strong discontinuity and the fixed location of the scratch. Figure 1 shows single frames out of two sequences with vertical scratches due to the abrasion of the emulsion.

The problem of scratch detection and removal has been addressed in numerous papers. Standard techniques [1], [2], [3] are based on variations of the spatio-temporal mean and median filters restricted to local regions of interest. These methods are straightforwardly implemented and involve only a modest computational load. Although the result is satisfying for a still image, in a film sequence the lack of texture due to the employed reconstruction method is noticeable as a blurring. The effect is emphasised by the fact that the distorted region does not move. A method which overcomes this problem was proposed by Kokaram [4]. The introduction of a 2-dimensional autoregressive model for the image allows an interpolation of missing information that is consistent with the local neighbourhood. A major disadvantage, however, is the expense of computing the coefficients for the proposed model. Other algorithms using nonlinear operations [5], adaptive multidimensional prediction [6], and min-max functions [7] have been suggested, but none have been found to be totally satisfactory.

(a)

(b)

Figure 1: Sections of degraded film frames: (a) frame without dominant vertical features, (b) frame with dominant vertical features.

Unfortunately the majority of archived film material is relatively noisy. Thus standard interpolation techniques for the removal of the scratches fail since they do not incorporate the statistics of the noise. The incorporation of adjacent frames partly helps to overcome this difficulty by dropping the noise level. However, the need for a motion, zoom, and pan compensation almost nullifies this advantage. Therefore the following investigation is limited to single frames. A wavelet decomposition is proposed. The transformation is realised by a combination of filters so that the majority of the noise gets separated from the actual image content. Parts of the removal process can therefore be performed using standard interpolation methods [8]. Finally the synthesis from the wavelet coefficients creates a restored version of the scratched image frame while preserving the typical noisy characteristic and preventing blurred image regions. The results show that the combination of scratch detection and removal in the wavelet domain is comparable and sometimes superior to the other techniques mentioned. A significant advantage of the applied method is the possibility of an efficient implementation in hardware [9].

The example images in this paper are monochrome. While the majority of old movie films are black-and-white, it is straightforward to apply the technique to colour films. For the multispectral case the Karhunen-Loeve transformation [8] may be used to minimise the correlation between the spectral bands. Thereby each band may be individually processed using the proposed technique. The corresponding inverse transformation produces the reconstructed multispectral film sequence.

2 Scratch characteristic

Horizontal profiles through areas of a frame that are affected by a scratch exhibit a similar characteristic although a scratch is more distinctive for bright regions while dark regions appear less affected like shown in Figure 1(b). The reason is the different thickness of the original emulsion. The damage for a thin layer is less significant than for a thicker layer of the emulsion since the depth of the scratch is smaller.

A suitable model for a scratch caused by a contact with a mechanical part is a clean groove. According to the laws of optics the projected profile of the scratch can be described by the sinc function. In practice the diffraction is not observable over an infinite extent and therefore a weighted version of the sinc, e.g. by a Kaiser window, is more appropriate to approximate the profile. Figure 2(a) shows an example for both functions. Unfortunately this model is only of limited use for the detection process since thin vertical features can exhibit almost the same characteristic. These features are best modelled by two step functions with opposite orientations a small distance apart. Figure 2(b) depicts the density profile of the emulsion after the exposure for a single step function. Placing a second step function with the opposite orientation left of the first step to describe a thin feature results in a density profile similar to the groove of a real scratch and therefore in a similar diffraction pattern. Thus a distinction between a scratch and a thin vertical feature using the intensity profile of the projection along the scratch, as suggested by Kokaram [10], is almost impossible, particularly if no information about the number and type of copy and developing processes is available.

Figure 2: Characteristic of scratch and edge feature: (a) Theoretical (···) and weighted (-) diffraction profile of a scratch, (b) density profile for an edge.

Scratch detection is difficult to perform in the presence of dominant vertical features in the image. Unsupervised techniques often result in a variety of vertical features being falsely detected as scratches, although an observer can clearly distinguish between such a feature and a scratch. An example is the image shown in Figure 1(b). This difficulty might be the reason why recent publications [2], [4], [5], [6], [10], [11] assume either prior knowledge about the scratch position or illustrate methods on imagery with hardly any vertical features.

3 Method

The first step is the transformation of the intensity image *I* into the approximation *A*, and the detail coefficients *V*, *H*, and *D* of the discrete wavelet transform. The approximation *A* is a low-pass filtered version of *I*, while the detail coefficients are generated by a combination of low- and high-pass filters extracting vertical, horizontal, and diagonal details, respectively [12]. The Haar wavelet was utilised for the imagery under investigation due to its robust characteristic and efficient computation. The scratch detection is based on the *A* and *V* coefficients as described in Section 3.1. The position of detected scratches is passed together with *A* and *V* to the reconstruction phase. *A* and *V* are transformed to *A'* and *V'* in the scratch removal process (Section 3.2). A restoration of *H* and *D* is only necessary if the components are detectably affected by the scratch. The final reconstructed image *I'* is synthesised using the components (*A'*, *V'*, *H*, *D*) or (*A'*, *V'*, *H'*, *D'*), respectively. Figure 3 shows a schematic of the process.

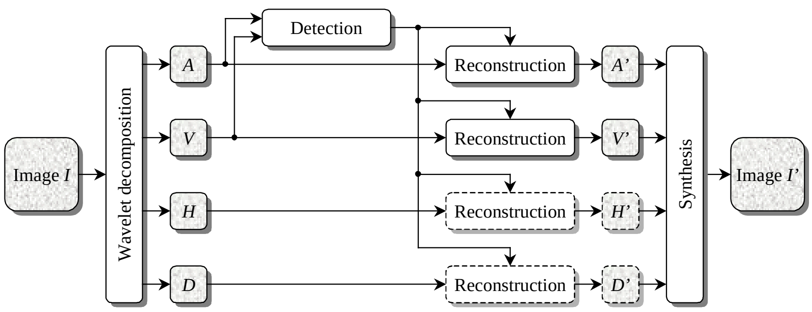


Figure 3: Schematic of the restoration process.

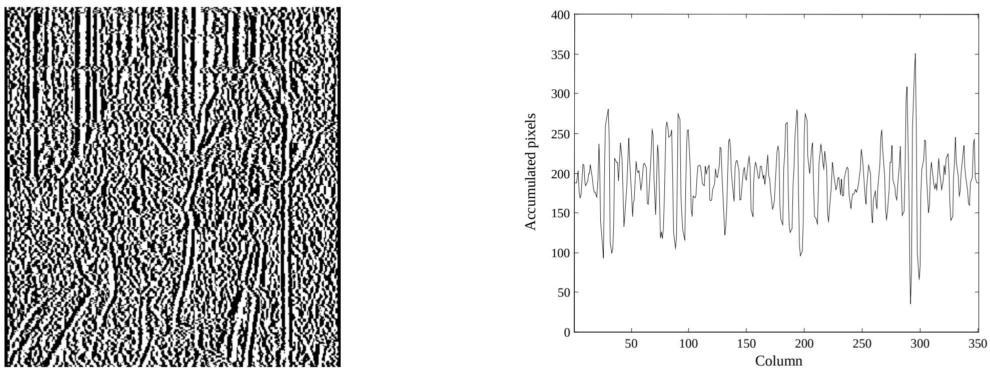
Note that both the detection and reconstruction operate in the wavelet domain. The advantage is that much of the noise is separated together with the detail information from the approximation of the image. Therefore standard reconstruction methods can be applied to the approximation *A*. Moreover, vertical structures (features and scratches) are emphasised in the *V* component and are hence easier to detect. The whole process is now described in more detail.

3.1 Scratch detection

This paper suggests a simple multistage process limited to single frames with the immense volume of data to be processed in mind, e.g. approximately 180,000 frames for a two-hour movie. To decrease the number of false detections the method considers the special characteristic of a scratch which differs in contrast, thickness, and often vertical extent from a vertically aligned feature.

The first step in the detection algorithm extracts possible scratch positions using the vertical detail coefficients in *V* by computing the means down the columns. A preselection is obtained by selecting the local maxima of the 1-dimensional plot. The threshold can be chosen in a conservative way since both features and scratches exhibit a strong characteristic in *V*. Although they are not easily distinguished in the *V* component, the purpose of this step is to decrease the computational load for the second step by excluding large areas of the frame or the complete frame (very often) if there are no dominant vertical components.

The second step of the scratch detection algorithm uses unsharp masking [8] and thresholds the unsharp masked version A_u of the approximation *A*, i.e. it generates a binary image *B* with $B(x,y)=1$ if $A_u(x,y)$ is positive. The thresholding is with respect to dark scratches and has to be inverted for bright scratches. It is sufficient to restrict the filter for the unsharp masking process to one dimension since the scratch is aligned with the y-axis. Note that the length of the filter window has to exceed the extent of a scratch by at least one pixel. As an example Figure 4(a) shows the binary image *B* corresponding to Figure 1(b). The advantage of using unsharp masking is the higher sensitivity achieved with respect to the intensity of the pixel neighbourhood. Thus even dark regions like those in Figure 1(b) between the upper image border and the doctor's head contribute towards the detection. Finally the projection of the binary image *B* along the y-axis is thresholded. Figure 4(b) depicts the projection of the binary image *B* in Figure 4(a) and exhibits a global maximum at the x-position of the scratch. The extent of the scratch is determined by the minima to the left and right of the scratch centre.



(a) (b)

Figure 4: Unsharp masking for scratch detection: (a) binary image *B* of Figure 1(b), (b) projection of B with a maximum at the x-position of the scratch.

3.2 Scratch removal

The removal of the detected scratches is done separately for *A* and *V*. Three different methods for the reconstruction of *A* have been tried and are presented here. (1) A median filter restores a distorted pixel, i.e. a pixel which is part of the detected scratch, by replacing it with the median intensity value of the nearest pixels outside the scratch. (2) A cubic spline interpolation is employed to restore the region of the scratch. (3) Polynomials of the third degree are fitted in a least squares sense along the rows over the neighbourhood of the scratch to generate an estimate for the missing pixels. For the reconstruction of the vertical coefficients *V* the implemented version uses the first method, i.e. the median filter, since it has been found that this restoration method gives the best results. The different characteristic of the *V* coefficients is due to the vertical high pass filter which emphasises all vertical structures. The median filter preserves this emphasis better than the others.

4 Results

Different measures for the qualitative validation of the proposed methods using images with simulated scratches were employed. The root mean squared (RMS) error between an unscratched image and the reconstructed image was calculated. However, this measure fails in a noisy environment and therefore the two ratio-based measures μ_u/μ_r and σ_u/σ_r were introduced. The parameters μ and σ describe the mean and the standard deviation, respectively, while the subscripts *u* and *r* represent the unscratched and the restored version of the image under investigation. A ratio close to unity denotes that the new image has a similar statistical characteristic to the original image. This does not necessarily indicate that the reconstruction is perceptibly similar, however together with the RMS it gives a good indication of the restoration quality achieved. Table 1 lists the results for the different reconstruction approaches for two levels of added Gaussian noise. The noise level is given as a signal-to-noise ratio (SNR). Note that visual inspections indicate that 20dB is a reasonable value with respect to the sampled frames of the movie.

	40dB			20dB		
	RMS	μ_u/μ_r	σ_u/σ_r	RMS	μ_u/μ_r	σ_u/σ_r
Median filter	12.045	1.0008	1.6066	16.158	1.0023	1.4212
Cubic spline Interpolation	12.575	1.0001	1.3248	15.003	1.0032	1.3781
Polynomial least squares fit	12.846	1.0013	1.6182	14.703	1.0018	1.3262

Table 1: Results for an artificial scratch in an image with different noise levels

The cubic spline interpolation performs better than the least squares fit for a high SNR due to its more accurate approximation of the sinc interpolator. But the result degrades performance-wise for an increasing noise level. This indicates that the approximation *A* is still affected by some noise. This influence is decreased using a polynomial least squares fit of the third degree. Although the median filter achieves good results with respect to the RMS and the mean ratio for a SNR of 40dB, the final images exhibit a significant blurring in the scratch region. In case of a realistic noise level the quality decreases further. However, comparisons with other reconstruction methods (nearest neighbour, bilinear, and cubic spline interpolation) have indicated that for the vertical component *V* the usage of the median filter gives the best results.

Finally Figure 5(a) and (b) give examples for the reconstruction of real imagery using the polynomial least squares approach to interpolate the missing values for the approximation and the median filter for the vertical details.

(a)

(b)

Figure 5: Scratch removal in real imagery: (a) reconstruction result for Figure 1(a), (b) enlarged section of Figure 5(a).

5 Conclusions

In this paper a wavelet-based unsupervised technique for detection and removal of scratches in movies sampled to standard television broadcasting resolution was presented. After obtaining the wavelet coefficients the detection phase starts with using the vertical detail components to preselect possible scratch positions. In a succeeding step real scratches and thin features are distinguished using unsharp masking and vertical projection. The advantage of the wavelet transformation is the emphasis of vertical image structures for the detection while the two-phase approach reduces the computational load by excluding most of the frames of a movie from further examination. Moreover only those parts of an image which exhibit a characteristic similar to a scratch are passed to the second stage. The proposed detection process shows a good performance in the presence of thin vertical features.

The reconstruction of the image content in areas of detected scratches is carried out separately for the image approximation and the vertical details using interpolation and median filtering, respectively. The benefit of using the wavelet transformed version of the frame is the preservation of horizontal and diagonal features and a separation of the image noise from the image content. Thus simple reconstruction techniques can be applied.

The proposed process of scratch detection and removal is fast since it operates on single frames and is implemented as a multistage process. Moreover recent publications have demonstrated that the used transform can be efficiently implemented in hardware. Future work includes extensions of the method incorporating the noise model for the interpolation process and the reduction of falsely detected scratches. A study to investigate the success of scratch detection over different scenes is also suggested.

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