

Scratch Detection via Temporal Coherency Analysis and Removal using Edge Priority Based Interpolation

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Abstract—This paper presents an automatic scratch detection and removal approach for archive film sequences. The proposed detector mainly exploits temporal coherency of candidate scratch positions, which are obtained using an automatic scratch detection method proposed in the literature. In the restoration stage, both spatial and temporal information are employed. The proposed edge priority based scratch removal algorithm successfully removes scratch effects from archive film sequences.

I. INTRODUCTION

Restoration of archive film sequences aims to improve the subjective visual quality of archive films and also provide higher quality at identical compression rates for storage on digital media. A complete video restoration system typically comprises video segmentation [1, 2], flicker correction [3, 4], blotch removal [5, 6], scratch removal [7-14], noise reduction [15, 16] and image stabilization [17, 18].

Scratches occur in archive films mainly due to abrasion of film material with a mechanical part of the film projector. This visual degradation appears as vertical black or white lines on film. The characteristic of scratches (bright or dark) is connected with the type of film material, i.e. whether it is a negative or a positive print. Examples of black and white scratches encountered in archive films are given in Fig. 1. Scratches generally retain their spatial position over several frames and they have a width of about 1 to 5 pixels. It is a really challenging process to detect scratches automatically although they can easily be seen by viewers.

Scratch detection methods can be classified into two types: spatial and temporal methods. Spatial methods exploit intraframe properties of scratches for detection [7-10], while temporal methods mainly rely on temporal tracking of scratches [11-14].

Scratches are detected using a 1-D signal obtained from local extreme of vertically sub-sampled image frames in [7]. The resultant 1-D signal is modeled as a damped-sinusoid to decide a scratch. A generalized form of the scratch model proposed in [7] is presented in [8].

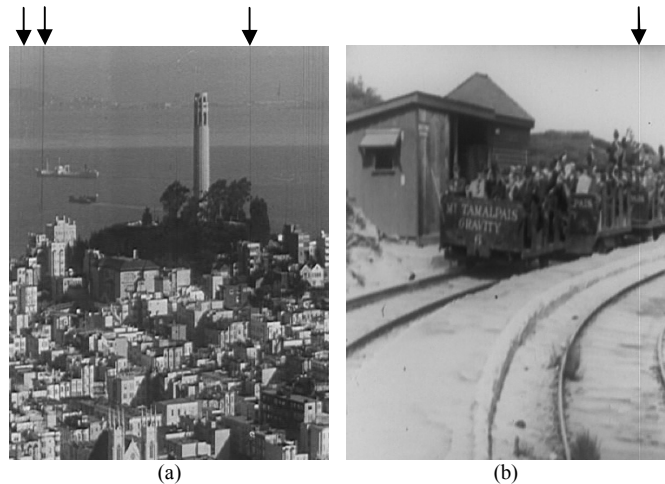


Figure 1. Black and white scratch examples. (a) “City sequence” from “Askme” archive film. (b) “Train-2” sequence from “Mount” archive film.

This method extends Kokaram’s scratch model and makes it work without any threshold adjustment. The generalized scratch detection method in [8] has better detection accuracy than [7], but still suffers from vertical edge features. Wavelet decomposition of image frames is used to detect scratches in [9]. Approximation and vertical detail coefficients are employed in the detection step, and scratch restoration is also performed in the wavelet domain. Column variances of image frames are utilized with simple statistics in [10]. Scratch removal is handled as an optimization problem and solved using genetic algorithms in this work. Temporal scratch detection is for the first time proposed in [11]. Scratch tracking is performed over vertically sub-sampled image frames employing Kalman filter in [11-13]. Recently, a Multiple Hypothesis Tracker (MHT) is utilized for scratch tracking in [14]. In the restoration stage low and high frequency components of the image frames are evaluated in different ways in [11-12]. Low frequency image parts are restored using polynomial interpolation while Fourier series are employed for high frequency components. In [14], the high frequency restoration process is performed using a MAP reconstruction approach.

Nearly all spatial scratch detection methods fail in the case of strong vertical image features. Hence, they can actually only be used as candidate scratch detectors. Thus, temporal information should be exploited for accurate scratch detection. We propose a scratch detection algorithm based on temporal coherency of candidate scratches in this paper. Scratch candidates are obtained using the spatial scratch detection method presented in [8].

II. SCRATCH DETECTION VIA TEMPORAL COHERENCY

Spatial scratch detection methods can give various false alarms if they are adjusted to detect all scratches, while they may miss some scratches if they are tuned to less precise detection. It is clear that spatial properties of an image frame are insufficient for accurate scratch detection. Therefore, the proposed scratch detection method exploits temporal correlation. Interframe temporal correlation is employed to verify candidate scratches that are obtained from the spatial scratch detection method proposed in [8].

Steps of the proposed temporal method are listed below:

1. Obtain candidate scratches for frame t using the spatial method proposed in [8]. These candidates can be real scratches or can be false detections caused by vertical edges.
2. Compose a block size of $M \times N$ including the candidate scratch at the center of the block. Search for this block in the next image frame using minimum mean absolute error criteria. If the matching error is low enough, this means that the corresponding block of the frame t is found in frame $(t+1)$. Next, the matching error at the center of these two blocks is calculated. If this error is higher than a pre-defined threshold, this means that this candidate is a scratch. If it were not a scratch, the matching error at the center of the blocks should be low when the entire block is matched. If this error is low, scratch decision can not be given at this time. This candidate can be a real scratch or a vertical edge.
3. If a scratch decision is not yet given, the same process described in step 2 is repeated for the next image frame. If a scratch decision is given at any stage of this process, the whole route is tracked backward and all scratch candidates are marked as a real scratch.
4. If scratch decision is not given along the current shot and scratch candidate exists at the same spatial position in the next shot, this is a scratch which continues over contiguous shots.

In order to handle secondary scratches that are not visible over the entire image frame (i.e. are visible in only part of the frame), the searching procedure is modified. Blocks used in the searching are divided into three parts and the searching operation is repeated for each part. If any one of these blocks gives a scratch alarm, scratch decision is given for the related

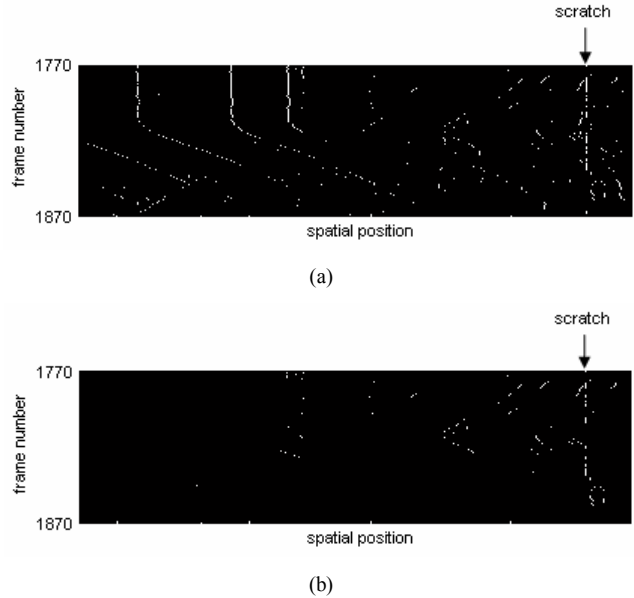


Figure 2. Scratch detection result for 100 frames of the “Train-2” sequence (a) Detection result of the method proposed in [8] (b) Detection result after temporal coherency analysis.

candidate in order to detect secondary scratches. Detection results for the “Train-2” sequence of the “Mount” archive film for the spatial method proposed in [8] and the proposed method are given in Fig. 2.

The “Train-2” sequence contains camera panning towards the left direction. As seen in Fig. 2(a), spatial positions of some scratch candidates are changing over time. These are only edges that are miss-classified by the method proposed in [8] and not real scratches. The proposed temporal coherency analysis can eliminate various false scratch detections as seen in Fig. 2(b).

Scratches are always observed to exist at the same spatial position for at least two frames. Single frame defects can be regarded as a blotch and can be detected and restored with blotch restoration methods such as the techniques proposed in [5,6]. Exploiting this information about scratches, a binary opening operation is performed over refined scratch candidates. A structure element of size 1×2 is utilized for this purpose. Detection results after binary opening are displayed in Fig. 3.



Figure 3. Scratch detection result for 100 frames of the “Train-2” sequence after binary opening operation.

III. SCRATCH RESTORATION

It is proposed in this paper to utilize a new pixel based correction method that determines scratched pixels new values using spatio-temporal correlation. Our method uses a contour based correction strategy similar to [19] and uses luminance transformation based matching criteria as given in [20]. In [19], all unfilled pixels that have filled pixels as their neighbors are randomly permuted and then sorted by decreasing number of filled neighbor pixels. In the proposed method a priority is assigned to each pixel surrounding the scratched area. The priorities are determined according to local image variances. High local variance means that this part of the image has details. Thus, this image part should have restoration priority. Steps of the proposed temporal method are listed below:

1. Take a square window around the pixel which has the highest priority (local window).
2. Find the best matching luminance transformed remote window from large search windows of preceding and succeeding image frames for the local window skipping all scratched regions. Note that the centre pixel of the remote window should be non-scratched.
3. Put the centre pixel of the best matched luminance transformed remote window to the corrected image.

In this work, MSE is used as the matching criterion as given in (1).

$$MSE = \frac{1}{p_u} \sum_{i=1}^M \sum_{j=1}^N [1 - m^r(i, j)] \times [1 - m^l(i, j)] \times [l(i, j) - v(r(i, j))] \quad (1)$$

$$p_u = \sum_{i=1}^M \sum_{j=1}^N [1 - m^r(i, j)] \times [1 - m^l(i, j)]$$

where p_u is the total number of used pixels, M , N represent the window size, $m^r(i, j)$ is the remote window scratch mask, $m^l(i, j)$ is the local window scratch mask, $l(i, j)$ is the local window pixel, $r(i, j)$ is the remote window pixel, and $v(\cdot)$ is the luminance transform. To match the remote window to the local window using the MSE criterion, similar to [20] a first-order polynomial function is used as the luminance transform as shown in (2).

$$\begin{aligned} v(r(i, j)) &= \alpha_0 + \alpha_1 \times r(i, j) \\ \partial MSE / \partial \alpha_0 &= 0 \\ \partial MSE / \partial \alpha_1 &= 0 \end{aligned} \quad (2)$$

$$\alpha_1 = \frac{p_u \sum_{i=1}^M \sum_{j=1}^M (1 - m^r(i, j)) \times (1 - m^l(i, j)) \times r(i, j) \times l(i, j) - \left[\sum_{i=1}^M \sum_{j=1}^M (1 - m^r(i, j)) \times (1 - m^l(i, j)) \times r(i, j) \right] \times \left[\sum_{i=1}^M \sum_{j=1}^M (1 - m^r(i, j)) \times (1 - m^l(i, j)) \times l(i, j) \right]}{p_u \sum_{i=1}^M \sum_{j=1}^M (1 - m^r(i, j)) \times (1 - m^l(i, j)) \times r^2(i, j) - \left[\sum_{i=1}^M \sum_{j=1}^M (1 - m^r(i, j)) \times (1 - m^l(i, j)) \times r(i, j) \right]^2} \quad (3)$$

$$\alpha_0 = \frac{1}{p_u} \left[\sum_{i=1}^M \sum_{j=1}^M (1 - m^r(i, j)) \times (1 - m^l(i, j)) \times l(i, j) - \alpha_1 \times \sum_{i=1}^M \sum_{j=1}^M (1 - m^r(i, j)) \times (1 - m^l(i, j)) \times r(i, j) \right]$$

In this equation α_0 and α_1 can be denoted as additive and multiplicative luminance transform coefficients respectively and these coefficients are computed as given in (3). The new value of a scratched pixel is computed as

$$y'(i, j) = v(r_{bm}((M+1)/2, (M+1)/2)) \quad (4)$$

where $y'(i, j)$ is the corrected pixel value, and r_{bm} is the best matched remote window.

Correction results for two frames of the ‘‘Mount’’ and ‘‘Askme’’ archive films are shown in Fig. 4 to give an idea about the visual performance of the proposed correction method. Full-frame correction results are given in Fig. 5 for three sample frames of the ‘‘Mount’’ and ‘‘Askme’’ archive films.

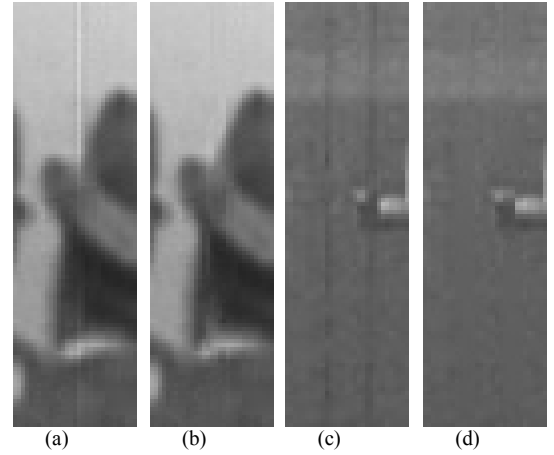


Figure 4. (a) and (c) Original scratched image frames (b) and (d) De-scratched image frames using proposed restoration method.

IV. CONCLUSIONS

An automatic scratch detection and removal approach for archive film sequences is proposed in this paper. The proposed scratch detection exploits both spatial and temporal information. Spatial information is used to obtain candidate scratches while temporal information is employed to verifying the coherency of the candidates. Candidate scratches are obtained using an automatic scratch detection method. Experimental results show that the proposed temporal coherency based scratch detection method is able to discard various false alarms that are signaled by the spatial scratch detector. Both spatial and temporal information are also employed in the restoration stage. The proposed edge priority based scratch removal algorithm clearly removes scratch effects from archive film sequences.

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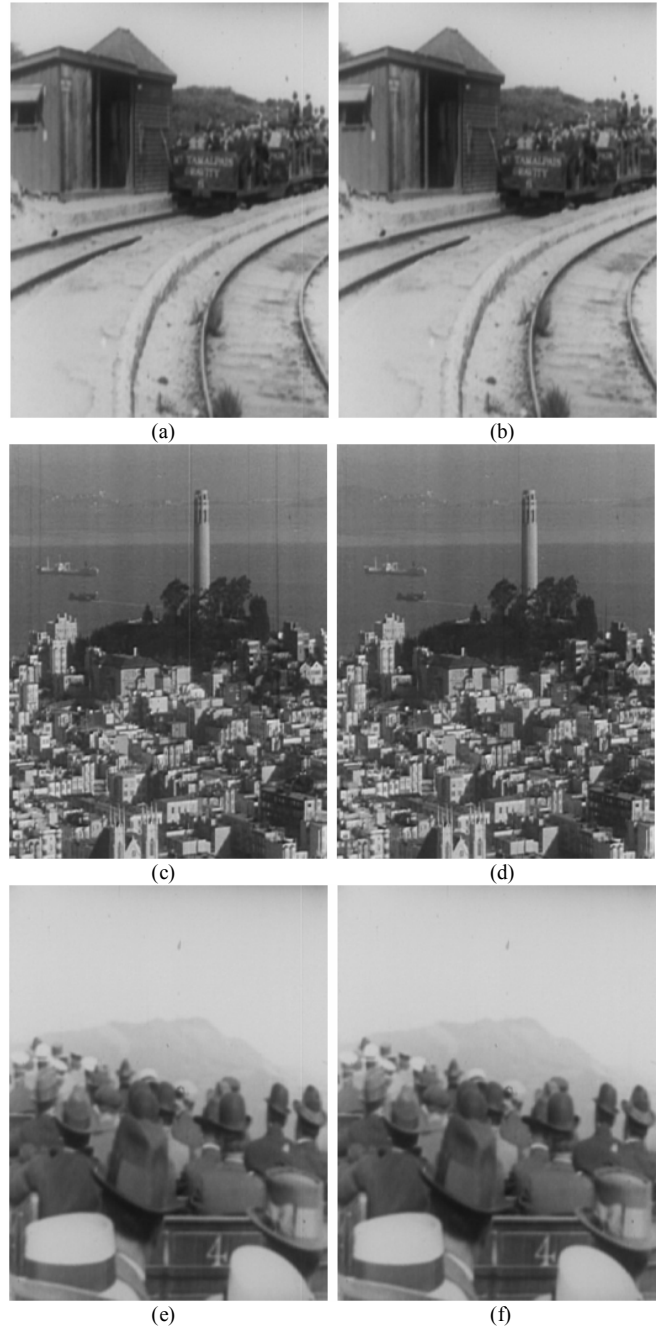


Figure 5. (a,c,e) Original scratched image frames (b,d,f) De-scratched image frames using the proposed restoration method.