Fast Removal of Line Scratches in Old Movies

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Abstract

In this paper a fast algorithm for removing line scratches in old movies is presented. It is strongly based on exploiting the defect visibility in the image. To this aim the Weber's law can be applied to coefficients of an over-complete wavelet representation of the degraded image. The intensity of the defect, which is represented as a light diffraction effect, is then attenuated in the vertical and approximation sub-bands till the minimum threshold of visibility is reached. The experimental results are very satisfying: the image is completely recovered without local artefacts or annoying smoothing effects.

Figure 1. 33th frame ($256 \times 256 \times 8b$) of Knight sequence affected by a white scratch.

1. Introduction

Recent years have seen the increase of research related to the automated restoration of archived motion picture film. The basic requirement for a successful restoration tool is independence from large parameter lists along with a very low computing time. This is due to the fact that a large amount of data has to be processed. Effective, fast and automatic algorithms are required in a competitive and useful restoration framework. In this paper we will deal with the removal of line scratches. The removal of this defect also implies an *a priori* detection step. What makes line scratches difficult to treat is that they are easily confused with actual line features in the image, and furthermore, they persist over many frames. It is trivial to say that the more precise the detection the more effective the restoration. In this paper we will not deal with detection using results presented in [5, 4].

Line scratches are almost vertical lines of the image of dark or bright intensity, having width from three to ten pixels at standard definition television resolution (see Figs 1, 2 and 3). They can occur in the same location of subsequent frames. Moreover they can vertically occupy all the image (*principal scratches*) or only a part of it (*secondary*

scratches) [5]. Having delineated a region of the image for treatment, it is then necessary to reconstruct the image data corrupted by the line artefact.

The key mechanism to reconstruct the corrupted image data is to propose a model for the degradation process as well as a model for the underlying image data. The variety of approaches [1, 2, 3, 7, 8, 10, 12] proposed in literature can be split into two main classes based on the hypothesis that

- scratch is a region of *missing data* of the image. Hence, there is not significant information of the original image in the region occupied by the scratch [2, 8, 10].
- the scratch does not obliterate all the underlying image information and the degradation model is a mixture process. A complete removal of the artefact involves recovering this residual information [3, 7, 12].

Nevertheless, almost all previous approaches usually follow the common idea to extend the image information around the scratch into the region occupied by the defect. Different and quite sophisticated interpolation schemes are employed, but they often depend on a well balanced and adap-

Figure 2. 7th frame ($512 \times 512 \times 8b$) of Sit-down sequence corrupted by several dark scratches.

tive choice of both the region to recover and the extent of the image neighbourhood. Although delineating the region to recover is mainly tied to the precision of the detection algorithm, the selection of the image neighbourhood is related to the method chosen for recovery and to the local image appearance. In fact, this region has to be neither too small, since it can still contain degraded pixel, nor too large since local component or textures of the image could be destroyed. This is particularly true when left and right neighbourhoods of the defect are completely different for example close to or through edges (see the shoulder in Fig. 1 or the sea in Fig. 2).

As proved in a previous work [3], some of the above mentioned difficulties can be overcome by introducing a visibility measure of the defect along with a better modelling of the scratch, taking advantage from its optical features. As regards the latter point, in [3] it has been shown that the scratch is the result of a light diffraction phenomenon, therefore it can be horizontally well modelled by some deterministic function. This is a crucial point in any restoration algorithm because it implies a more precise knowledge of the investigated defect. Visibility has already been the keystone of the detection algorithms proposed in [5, 4].

In fact scratch is what human eye is able to perceive. Thus the idea for restoration is very simple: reduce the defect intensity till it is no longer visible. The degree of visibility of a scratch can be measured by exploiting the *Weber's law* [6] which gives a lower bound for intensity perception along with a way for computing it. Some encouraging and satisfying results have already been achieved in [3] where the defect was represented by its *cross-section*. The

Figure 3. 1st frame ($150 \times 300 \times 8b$) of Star sequence corrupted by several dark scratches.

latter is a zero-mean Radon transform of the degraded image mainly containing its high frequency components. Nevertheless, in order to achieve a good restoration, a further processing of low pass components (i.e. degraded image local mean) of the defect was required. Moreover, in some cases, results could depend on the width of the window used for the computation of the *cross-section*. Therefore in the present paper the algorithm for restoration presented in [3] is improved employing an over-complete wavelet representation [11] which gives a natural decomposition in high pass and low pass components of the degraded image, along with shift invariance. Moreover a reduction of its computing time along with a more precise computation of the visibility parameter of the defect are achieved. In particular, the algorithm takes advantage from the sparsity of the representation, the side effect of enhancement of the line defect, and the perfect reconstruction properties of the transform.

The paper is organized as follows. The next Section presents the proposed model while some experimental results are shown in Section 3. Some concluding remarks are then given in the final section.

2. Scratch removal and its optical features

As mentioned above, human perception of the defect is the basis of any restoration tool. Thus a reliable estimation of scratch visibility and a proper attenuation of its intensity are the main steps of the proposed approach.

The intensity profile of the defect L , as proved in [3], is well modelled by a sinc^2 function due to the light diffraction effect. The model used for representing the degraded image I is the one already used for the detection step [5, 4] and can be simply represented as follows

$$I = (1 - \gamma)G + \gamma L \quad (1)$$

where G is the original image and γ is a normalized parameter which takes into account the point-wise visibility of the scratch. In particular γ approaches 1 if scratch information

Figure 4. Recovered frame depicted in Fig. 1 using the proposed algorithm.

is greater than the original image, while it is almost zero when the scratch becomes slighter. γ is computed by means of the Weber's law [6] which suggests how to measure the visibility of an object in a given surround. Roughly speaking, it measures how much scratch intensity differs from its local image surround. Therefore, since the wavelet transform provides a measure of the local variations of a given function f , it is suitable both for the computation of γ and the whole restoration process.

An undecimated wavelet representation of the degraded image is performed for exploiting the output of the detection phase (i.e. scratches locations). Equation (1) is still valid because of the linearity of the transform and it can be used for independently modelling each sub-band S of the n scale levels decomposition. More precisely, for each sub-band and at each scale level $j = 1, \dots, n$, eq. (1) can be rewritten as follows

$$\mathbf{I}_S^{(j)} = (1 - \gamma_S^{(j)}) \mathbf{G}_S^{(j)} + \gamma_S^{(j)} \mathbf{L}_S^{(j)}. \quad (2)$$

Nevertheless, under the assumption of a quite perfect vertical extension of the defect, only approximation ($S = A_{2^n}$) and vertical ($S = V_{2^j}$, $j = 1, \dots, n$) sub-bands are processed. Hence, the recovered band $\hat{I}_S^{(j)}$ is achieved using the attenuation scheme $\hat{I}_S^{(j)} = w_S^{(j)} I_S^{(j)}$, where $w_S^{(j)} = \frac{G_S^{(j)2}}{G_S^{(j)2} + \gamma_S^{(j)} L_S^{(j)2}}$ and $G_S^{(j)} = \frac{I_S^{(j)} - \gamma_S^{(j)} L_S^{(j)}}{(1 - \gamma_S^{(j)})}$ is simply computed by inverting eq. (2). The scratch $L_S^{(j)}$ is treated as noise and it is estimated from the band in which it is predominant, i.e. in the vertical detail sub-band. Its estimation is simple since its profile is known (the wavelet transform of a sinc^2). Its amplitude $b_S^{(j)}$ is obtained in the least square sense from the coefficients belonging to the region $D_S^{(j)}$ occupied by the scratch. Briefly speaking,

$$b_S^{(j)} = \min_{\alpha \in R} \sum_{i \in D_S^{(j)}} [I_S^{(j)}(i) - \alpha F_S^{(j)}(i)]^2$$

Figure 5. Recovered frame depicted in Fig. 2 using the proposed algorithm.

where $F_S^{(j)}(i) = \sum_{k \in \Omega_S^{(j)}} g_{2k-1} \text{sinc}^2(\pi k/m)$ are the wavelet coefficients of a sinc^2 function, $\Omega_S^{(j)}$ is the wavelet support, g_k are its filter coefficients while m is the scratch width. The latter takes also into account a likely asymmetry of the true profile of the defect.

The local estimation of $\gamma_S^{(j)}$ is achieved from the vertical sub-band by applying the Weber's law to modulus maxima since the most representative coefficients of the corresponding image information [11]. The domain of the estimation is chosen taking into account the scratch width at the analysed scale level, i.e. $2^{j-1}m$, and the wavelet support size $|\Omega_S|$.

In order to better recover the approximation band, we exploit the fact that, from a multiresolution scheme each column of the vertical detail and the corresponding one in the approximation band are respectively the high pass and low pass components of 1D wavelet decomposition of the same signal. The latter is the horizontal smoothed version of the image I . Then $w_A^{(n-1)}$ is computed from A_{2^n} and V_{2^n} suitably balanced with the energy of the wavelet. It results that the reconstruction process for the recovered image have to start from the scale level $n - 1$.

3. Some experimental results

The proposed model has been tested on several frames of different image sequences. Some results achieved on the more frequently used test images (Knight, Sitdown and Star) are shown in Figures 4, 5 and 6. As it can be observed, the algorithm works well on various types of images successfully recovering different kinds of scratches: principal or secondary, alone or not (i.e. without or with close

slighter scratches), slight or dark. It is important to notice that image features are never destroyed. On the contrary the scratch is removed without changing its surround, including noise and other kinds of defect like blotches. More precisely, in Fig. 4 there are not annoying artefacts on the shoulder of the knight while the sea is completely restored in Figs 5 and 6 — there is not smoothing of the texture. These results are achieved thanks to the adaptive and thorough measure of the visibility of the defect along with a quite faithful modelling of it (light diffraction). Moreover the use of the wavelet decomposition strongly contributed to enhance these properties. LeGall wavelets (5/3 taps) [9] are employed because of their symmetry and their support length which is well adapted to the range of the width of the defect ([3, 10]). Four scale levels of decomposition are used because it reaches a good compromise between the wavelet support, the width of the defect and the features of the various processed images. The goal in using the Weber's law is testified by looking at the secondary scratch in Fig. 2, which is indicated by the arrow. Although it occupies only a part of the image, the algorithm had worked over all the vertical extension of it without producing artefacts in the region in which scratch completely missed, as depicted in Fig. 5. On the contrary, in Fig. 3 the scratch extending over the hat of the sailor (indicated by the arrow) has been removed in Fig. 6 without blurring or whitening the black hat. We have to outline that not all detected scratches are removed from Figs 5 and 6 in order to emphasize the recovered ones. In particular, notice how slighter scratches becomes visible after removing dark scratches.

Finally, it is worth to outline that the proposed algorithm is completely automatic and requires a low computing time. In fact, the wavelet decomposition complexity is $O(N \log_2 N)$, where N is the size of the frame while the restoration process requires $O(nPB)$, where P is the number of scratches occurring in a single frame and B the number of processed blocks for $\gamma_s^{(j)}$ estimation at each scale level ($B = N/(m|\Omega_s^{(j)}|)$). In terms of CPU time, a scratch is removed in 5 seconds in a Matlab implementation.

4. Conclusions

A fast and effective algorithm for line scratches removal in old films has been presented. It is based on an additive/multiplicative modelling of the degraded image. It takes into account the human eye perception of the defect along with its modelling as a slit generating light diffraction in the digitalization process. The removal consists of a suitable attenuation of defect intensity according to the lower bound of visibility computed exploiting the *Weber's law*. The use of an over-complete wavelet representation contributes to enhance the visibility properties of the defect and then allows us to better compute it. Moreover low

Figure 6. Recovered frame depicted in Fig. 3 using the proposed algorithm.

and high frequency components can be simultaneously processed assuring a perfect reconstruction.

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