# Restoration of Films Affected by Partial Color Artefacts*

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**Abstract**

In this paper we present a novel restoration algorithm for a special type of film artefacts resulting mainly from film emulsion melting and the vinegar syndrome. We have devised the algorithm based on the observation that the affected areas did not lose their contents entirely. Rather, one of the film layers still preserves some of the original image structure. This artefact behaviour is exploited for both identifying and restoring these artefacts. The algorithm is validated by showing some results on real case examples.

## 1 Introduction

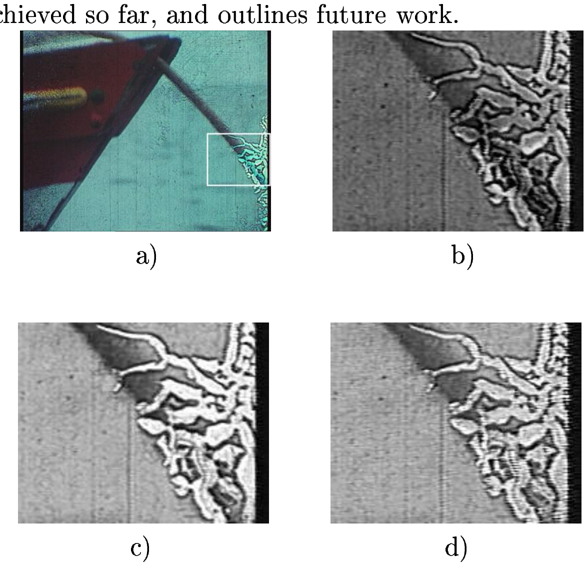
Film archives with material from the last century face deterioration at a progressive pace. Even if films are stored in protective conditions, the degradation process is not stopped, but rather slowed down. While there are several chemical and physical treatments that are able to clean, or at least slow down some types of degradations, in many cases it is impossible to do so, or the costs involved get too high.

The advent of powerful computers has permitted lately the digital processing of image sequences. Accordingly, the restoration of (digitized) films is now possible by means of intelligently devised algorithms [4, 8]. Some of these algorithms use spatial information to recover a damaged area, while others use temporal information from consecutive frames, or a combination of them. These algorithms proved to be quite successful in the restoration of digitized film and video.

Nevertheless, a problem occurs in the course of digital restoration of motion picture, when the so-called *pathological motion* ($PM$) occurs. This is a complicated motion that may take place in the image sequence, and it includes fast or highly irregular motion, occlusions, scene entrances, and/or other specific circumstances [5]. In such cases, as well as in the presence of severe artefacts, the motion estimation and the subsequent motion compensation, fail altogether. Since these two processes are essential ingredients for the temporal restoration algorithms, the restoration outcome may at times look worse than the original. A solution in this case is to detect $PM$ areas and protect them against any restoration [7]. Unfortunately, this also protects the artefacts inside the $PM$ areas against restoration. In order to avoid this side effect, algorithms have been developed that identify artefacts lying within $PM$ areas, which would allow their further restoration [6].

In this context, we have devised an algorithm that takes advantage of the available spatial/color information in order to restore the degraded color films. The algorithm we propose here is demonstrated on a real case of heavily degraded film that also exhibits pathological motion, making temporal-based restoration an impossible task.

In Section 2, we present the general film structure and the properties of the artefacts that we concentrate on. Section 3 lays out our new restoration algorithm. Section 4 presents and discusses the results we have achieved so far, and outlines future work.



a) b) c) d)

Fig. 1. Frame corrupted by partial color artefacts. a) Original image, with the main artefact indicated by the white rectangle; b-d) Zoom-in on the artefact in the red, green and blue layers, respectively.

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## 2 Film Structure and Properties of the Artefacts

The structure of a positive color film usually consists of an arrangement of layers as follows: an anti-halation layer, the safety film base (the actual film support), a blue layer, a green layer, a red layer (these three layers consist of some special, color-sensitive emulsion), some gelatin layers in between these layers and a protective gelatin layer on the surface [9]. Although the order may change in some cases, the aforementioned structure can be considered as general.

Films can be affected by dozens of types of film artefacts ([1],[2]), making artefact detection and correction a non-trivial task. Each artefact has its own properties and may show up in particular circumstances. In this paper, we try to identify and correct a special type of artefact for which the original information seemed to be completely lost at a first glance. However, an intense study of it revealed that only the *green* and *blue* film layers (i.e. the outermost ones) are totally lost, while the inner *red* layer still contains some original information. We will call this type of degradation a *partial color artefact*. Film experts have established that the partial color artefacts in the examples at hand are mainly due to emulsion melting and vinegar syndrome. In the shown images, other less noticeable artefacts are present as well, such as small dirt, hair, vertical scratches, glue traces, color fading, etc. These, however, will not be considered here.

The emulsion melting happens when the dye layers dissolve, producing irregular patterns in each frame. It is an irreversible process. The vinegar syndrome appears due to poor ambient storage conditions and it got its name from the vinegar odour it produces (in the course of their chemical breakdown, the acetate-based film bases start to release acetic-acid; a 5% acetic-acid solution in water actually represents the common vinegar as we know it). This type of degradation represents one of the biggest problems of film archives, and, like the emulsion melting, it is an irreversible process. Moreover, from a certain moment on, the vinegar syndrome is an auto-catalytic process, progressively fuelling itself in the course of time. Both emulsion melting and vinegar syndrome can have various appearances [1, 2], but it is not the purpose of this paper to describe them. Fig. 1 shows a frame from our sequence, with emulsion melting and vinegar syndrome symptoms.

## 3 Restoration scheme

The restoration flow is depicted in Fig. 2. First, the partial color artefacts are detected as regions exhibiting extreme colors only in the green and blue layers. Then, the (less affected) red layer is used in order to guide the restoration. Based on the image structure that is still present in the red layer, we find for each pixel inside the partial color artefacts, a "sibling" pixel belonging to the same object, but lying outside the artefact. The RGB value of the sibling will then be pasted into the current pixel.

### 3.1 Detection of Partial Color Artefacts

In order to detect the partial color artefacts, ideally, we should be able to set some thresholds for selecting the normal/abnormal levels of red, green and blue. However, setting fixed thresholds is not desirable, because artefact intensities differ from film to film, or from frame to frame. A conservative threshold, while less prone to errors, would miss a good deal of the artefacts. On the other hand, a relaxed threshold would result in too many false artefacts detected. To avoid these problems, the detection of the partial artefacts uses a *hysteresis thresholding* [3], that proves to work quite efficiently in our case. The general idea of the hysteresis thresholding is that the image is first thresholded with a conservative threshold. The regions resulted from this step are then dilated in a connected neighbourhood that satisfies the second, relaxed threshold. In our case, each of the three layers - red, green and blue - has its own thresholds, since the red and the blue layers are somewhat darker, in general.

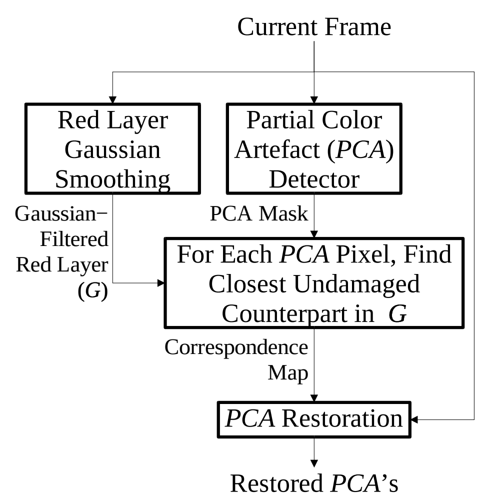
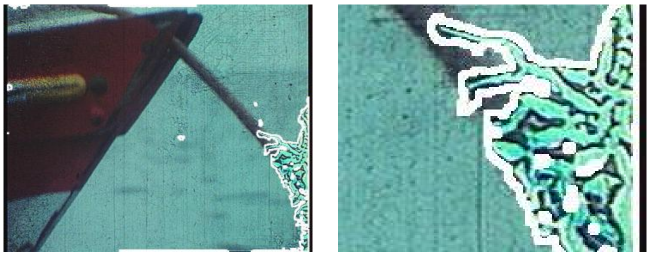



Fig. 2. Restoration scheme.

Furthermore, as shown in Fig. 1, the partial color artefacts may be surrounded by some dark borders. We also want to add them to the partial artefact mask. This is realized by selecting the pixels in a strip around the partial artefacts detected so far, that satisfy $\sqrt{\frac{p_R^2+p_G^2+p_B^2}{3}} < T$, where $p_R$, $p_G$, and $p_B$ represent the pixel values in the red, green and blue layers, respectively, and $T$ is a predefined threshold.

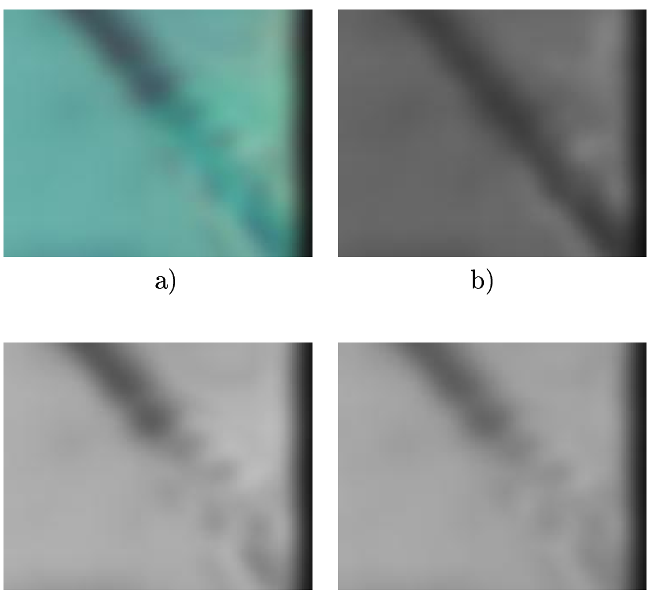
Finally, to eliminate the influence of noise, and to add the smooth edges of the artefacts, the mask is twice closed and then dilated once.



a) b)

Fig. 3. a) Original image overlayed with artefact masks (white border); b) Zoom-in on the main artefact.

Fig. 3 shows the original frame with an overlay of masks for the partial color artefacts (a), as well as a zoom-in on the artefact area (b). Visual inspection of the masks confirms that the detection algorithm performs as desired.



c) d)

Fig. 4. Zoom-in on the artefact in the gaussian-filtered image. a) RGB image; b) Red layer (the only one to be further used); c) Green layer; d) Blue layer.

### 3.2 Restoration of the Partial Color Artefacts

As previously mentioned, the red layer is still intact in some cases (or at least partly intact, as is the case with our samples). The underlying assumption of the restoration algorithm is that the general structure of the original artefact-free image, is still present in the red layer from our input image, and can be recovered by smoothing it. The isophotes of the smoothed red layer are then (almost) similar to the isophotes of the original artefact-free image. Although we do not draw samples from the smoothed red layer itself in the restoration process, it is used to indicate the areas where we may draw samples from. Further in this subsection we elaborate on these aspects. The restoration method will be outlined for one *partial color artefact* ($PCA$), but in practice it is repeated separately for each $PCA$ of the current frame.

We have already mentioned that the artefact influence is partly present in the red layer as well. In order to clean it, together with the noise, we smoothed the red layer with a large gaussian filter (a standard deviation $\sigma = 7$ was used in our experiments). We shall note the gaussian-filtered red layer of the image with $G$. Fig. 4 shows a zoom-in on the smoothed RGB image, as well as each smoothed layer, separately.

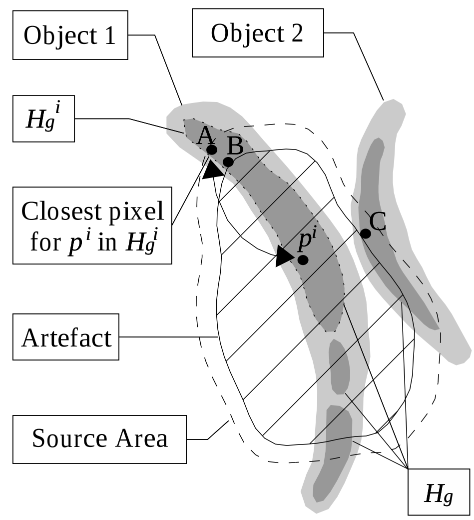



Fig. 5. Scheme of the smoothed red layer appearance, with artefact overlay.

For each $PCA$, a *source area* ($SA$) was defined as a strip of pixels around the artefact (5 pixels, in our experiments). $SA$ is depicted with a dashed border in Fig. 5 . The source area will be used to draw samples from, in the final steps of the restoration. Of course, care was taken to eliminate from $SA$ those pixels that already belonged to other artefacts. We have iterated through each grey level $g$ in $G \cap PCA$, and computed a hysteresis thresholding, resulting in a mask of pixels having a value of $g \pm \Delta$ (e.g. $\Delta \cong 4\%$ from the overall greyvalue range). We shall name this the *hysteresis mask* ($H_g$). Normally, $H_g$ follows the structure of the object(s). However, different objects with the same grey level $g$ may exist within the same $PCA$ (see Fig. 5), so $H_g$ will consist of several disjoint areas. For this reason, each pixel $p_g^i$ in $G \cap PCA$, having a grey level of $g$ will possess its own hysteresis mask, $H_g^i$. $H_g^i$ is given by that part of $H_g$ which is connected with $p_g^i$. Further, pixel $p_g^i$ will draw its restored value from that part of $H_g^i$ that lies outside the artefact, $Q_g^i = H_g^i \cap SA$. Namely, the values of $p_g^i$ will be replaced by the RGB tuple (from the initial, unprocessed image) of $p^k_{Q_g^i}$, with:

$$k = \arg\min_j \sqrt{d_r\left(G\left(p_g^i\right), G\left(p^j_{Q_g^i}\right)\right) + \left(\frac{d_p\left(p_g^i, p^j_{Q_g^i}\right)}{d_p\left(p_g^i, p^j_{Q_g^i}\right) + 1}\right)^2}$$

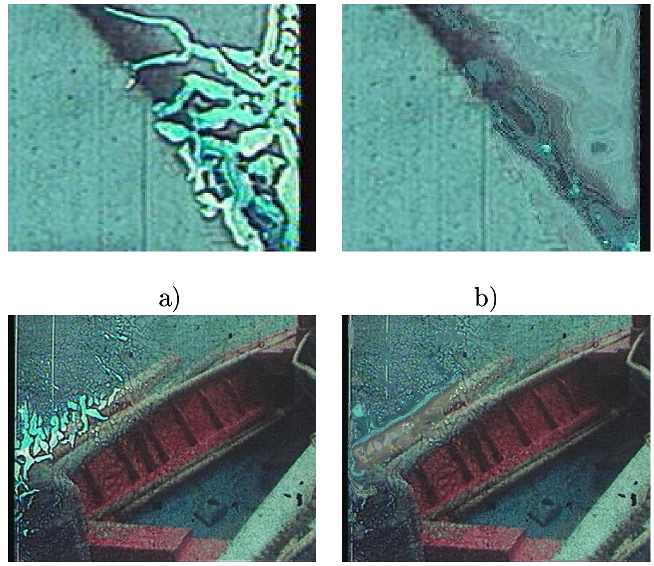
where $d_r\left(G\left(p_g^i\right), G\left(p^j_{Q_g^i}\right)\right)$ is the red value difference between the two pixels, $d_p\left(p_g^i, p^j_{Q_g^i}\right)$ is the physical (euclidean) distance, and $G(p)$ is the value of pixel $p$ in the smoothed red layer $G$. The physical distance can take values in $[0 \ldots MAX]$, with $MAX$ an unknown value. In order to both eliminate this ambiguity and enable us to combine it with the color distance having values in $[0 \ldots 1]$, the physical distance was normalized to fit in the same range. The resulting distance tries to combine the two measurements with different, orthogonal natures in an euclidean manner. For pixels whose $Q_g^i = H_g^i \cap SA = \emptyset$, we use $Q_g^i = SA$ instead. To ensure the color consistency of the interpolation, the RGB values from $p^k_{Q_g^i}$ are pasted altogether into $p^i$.

## 4 Results and Conclusions

Fig. 6 shows results of the method presented in the previous section. The general structure of the image has been recovered out of heavily degraded images. Although the restored images are not perfect (they still bear some artefact traces), we should stress again that they were recovered out of almost nothing. From this point of view, the results are promising.

One could also use general restoration algorithms here. However, those ones would not take advantage of the image structure that persists in the red layer. In our case, we do not have to “reinvent” that image structure - rather, we rely on it, since it already exists there, and enhance it. From this point of this view, we use artefact’s properties to both detect it and eliminate it.

We conclude that the restoration technique presented here successfully revived portions of the sequence affected by partial color artefacts, which were presumed to have been lost. The method can be used (with some alterations) for artefacts caused by processes other than emulsion melting or vinegar syndrome, if they exhibit similar color properties. Moreover, the present algorithm can be used as an intermediate step for a temporal restoration. The motion estimation in this case (a basic ingredient for temporal restoration) would no longer fail because of the severe artefacts. This, together with an investigation of other types of artefacts, are subject to further research.



a) b) c) d)

Fig. 6. Restoration results.[1] a,c) Original frames (zoomed in); b,d) Restored frames (zoomed in).

## References


[1] http://www.ina.fr/Recherche/Brava/Brava_public_impairments_list_3.light.html

[2] http://diamant.joanneum.ac.at/defects/index.html

[3] J. Canny, “A computational approach to edge detection”, IEEE Transactions on Pattern Analysis and Machine Intelligence, 8(6):679-698, 1986.

[4] A.C. Kokaram, "Motion Picture Restoration: Digital Algorithms for Artifact Suppression in Degraded Motion Picture Film and Video", Springer Verlag, ISBN 3-540-76040-7, 1998.

[5] A. Rares, M.J.T. Reinders, J. Biemond, "Statistical Analysis of Pathological Motion Areas", The 2001 IEE Seminar on Digital Restoration of Film and Video Archives, London, January 16, 2001.

[6] A. Rares, M.J.T. Reinders, J. Biemond, "Complex event classification in degraded image sequences", Proceedings of ICIP 2001 (IEEE), Thessaloniki, October 8-10, 2001, ISBN 0-7803-6727-8.

[7] P.M.B. van Roosmalen, "High-Level Analysis of Image Sequences", Technical Report for INA - Paris (Institut National de l’Audiovisuel), The EU "Aurora" Project, July 1999.

[8] P.M.B. van Roosmalen, "Restoration of Archived Film and Video", PhD Thesis, Delft University of Technology, 1999.

[9] R.J. Ross, “Color Film for Color Television”, Focal Press Limited, 1970, ISBN 0 240 50714 2.


[1] Sequence courtesy of RTP (Radiotelevisao Portuguesa).