Morphological λ-Reconstruction applied to restoration of blotches in old films

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ABSTRACT

This paper presents a method useful for the detection and interpolation of blotches in old films. The main advantage of this method is that it does not require motion estimation, which is difficult to compute in noisy and degraded image sequences. Our method imposes a set of criteria which must be fulfilled for the possible blotches. These criteria are temporal-uncorrelation, and high contrast with respect to the background. We propose to make use of morphological operators in order to establish the areas in need of restoration.

We put forward the use of marker dilation and an operator called λ-reconstruction to detect areas of temporal uncorrelation. This is an intermediate method (tunable through the λ parameter) between previously reported techniques such as temporal opening and temporal reconstruction opening. Its use renders our technique more versatile in the case of motion within a scene. To detect areas of high contrast we use the residue from the h-reconstruction operator. Furthermore, we show that the λ-reconstruction output operator can be used as an interpolation method for filling the damaged areas.

KEY WORDS
Blotch, Detection, Interpolation, Morphology, Film Restoration

1 Introduction

One important problem for the current society is the preservation of its cultural heritage: paintings, music, films,... The conservation of movies has an extra difficulty: the deterioration of the photographic material which has caused the loss of 50% of movies recorded before 1950. For this reason, nowadays, digitization and restoration turn into important activities. Old films often present different degradations like blotches, scratches, flicker, warping, noise,... This paper deals with blotches, which are dark or bright spots that usually are produced either by the loss of gelatine in the photographic material (bright spots) or by the dust and other particles deposited over the film (dark spots).

The restoration process consists of two stages: detection and interpolation. The aim of the first stage is to obtain a mask for every frame, labelling the pixels as blotch or not blotch. In the second stage, the intensity of the pixels labelled as blotch is restored using the blotch surroundings (temporal and spatial areas around the blotch).

In the literature several techniques are proposed in order to detect and interpolate blotches based on different algorithms, like ordered statistics [1, 2], Markov random fields [3] or mathematical morphology [4]. In this paper, we present three detection/interpolation methods based on the properties of the blotches themselves and some morphological algorithms. We compare the results obtained using a temporal opening (closing) with those obtained using the temporal opening (closing) by reconstruction. Similar methods to these are proposed in [4]. However, both methods arises a series of problems which we will present in section 2. In order to solve the problems arising from both methods, we propose to achieve blotch detection and interpolation using the λ-reconstruction, a method based on a morphological operator never used before in restoration, and a pre-dilation (pre-erosion) of markers used in the λ-reconstruction operation.

Moreover, one of the main drawbacks of most of previous restoration approaches is the necessity of motion estimation in the detection stage and also in the interpolation stage. The methods of motion estimation, applied in the detection stage, fail because the intensity data is missing in the areas of blotches. This problem is less important in the interpolation stage because the algorithms know the locations of blotches and their intensities are not included in the motion estimation process. In contrast, our method does not estimate motion vectors, however the amount of scene motion must be considered in order to reduce the number of false positives detected. One method of calculating the amount of scene motion can be the mean difference between adjacent frames. With this measure we can control the value of λ and the size of the structuring element used in the marker pre-dilation (pre-erosion).

The detection/interpolation methods presented in the

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following sections will be based on the properties of the blotches which are usually characterized by:

- Temporal uncorrelation: different positions in consecutive frames.
- High intensity contrast.

Figure 1 shows three consecutive frames belonging to the same shot from the film *Sangre y Arena*. The central image presents several dark blotches. These blotches are darker than the background (high contrast) and do not appear in temporal adjacent frames (temporal uncorrelation).

The video sequence must be segmented into shots before beginning the restoration [5] process. This is necessary due to the fact that a blotch in the detection stage, is an image area that is present in a frame and not in adjacent ones. In a shot change, specially in a cut, this property is presented although there are no blotches in the image.

This paper is organized as follows. In section 2 we present the detection stage. Prior, the methods which detect areas with temporal uncorrelation, and below the method wich detect areas with high contrast. The methods for interpolating the missing data are shown in section 3. Finally some results and conclusions are presented in sections 4 and 5, respectively.

Figure 1. Three consecutive frames from the film Sangre y Arena. Dark blotches appear in the central frame.

2 Blotch Detection

The purpose behind the detection of blotches is to create a damage mask for every frame in the sequence; this binary mask indicates in white the presence of a blotch and its absence is shown in black.

This section presents three methods in order to obtain the damage mask which only exploits the temporal uncorrelation property of the blotches. We study the temporal opening and the opening by reconstruction and propose as solution to problem of the detection of areas with temporal uncorrelation,the opening by λ-reconstruction. In addition, in order to improve detection, we intend to use a method that supplements previous ones employing the other property of defects: high contrast.

Figure 2 presents a block diagram of the global detection process. The mask of blotches, for every frame, is obtained calculating the logical **AND** between the mask of areas with temporal uncorrelation (M_1) and the mask of areas with high contrast (M_2).

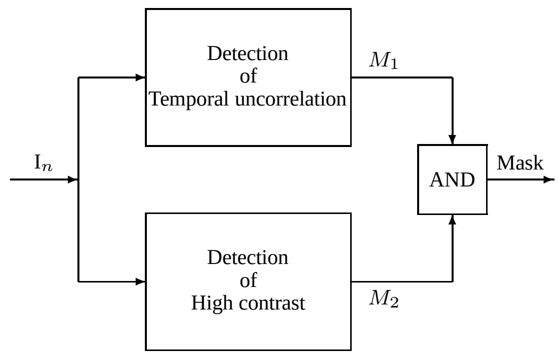


Figure 2. Block diagram of the blotch detection process.

2.1 Methods that detect temporal uncorrelation

2.1.1 Temporal Opening (Closing)

In order to detect bright (dark) blotches, a temporal opening (closing) with a flat structuring element of size 2 is applied. Using this, all those clear (dark) image areas which only appear in the current frame, but not in the following or in the previous one, will be eliminated. By taking the residue between the current photogram and the opening (closing), and applying a threshold to this result, we will obtain the binary mask (M_1) corresponding to the clear (dark) blotches. A block diagram of this method is presented in figure 3, where min (max) is the calculation of the minimum (maximum), for every pixel, between both images.

However, small objects which are brighter (darker) than the background with a displacement larger than half their size, ranging from one frame to another, will be la-

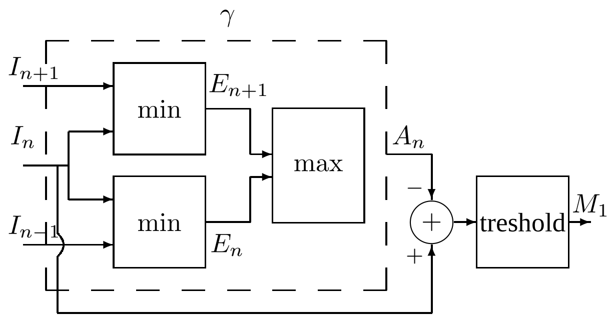


Figure 3. Block diagram of the Temporal Opening method.

belled as a blotch. Thereby generating a false alarm which will introduce an artifact into the interpolation. The number of false alarms can be reduced by dilating (eroding) adjacent frames prior to undertaking the temporal opening (closing). This is an improvement which we have introduced to the method. The size of the dilation (erosion) is related to the amount of scene motion, and increases according to the amount of motion. However, the detection probability is reduced with the size of this dilation (erosion).

2.1.2 Opening (closing) by reconstruction

The opening (closing) by reconstruction (γ^{rec}) is a morphological operator provided in [6, 7]. It only preserves intact those clear (dark) areas of the current image that are marked by a marker image. The clear (dark) areas that do not appear in the marker are eliminated. The marker is the maximum (minimum) between the previous image and the following one and, as such, only the bright (dark) objects which appear in the current image, but not in the adjacent ones, are eliminated.

In this method, a false alarm occurs when an object undertakes a motion which is greater than its size. In order to allow for larger motions without causing a false alarm, we propose, prior to the reconstruction, to dilate (δ_B) (to erode,ϵ_B) the marker with a structuring element whose size depends on the amount of scene motion. In the same way as in the previous case, the mask (M_1) is obtained by taking the residue between the reconstructed image and the original one, and applying a threshold to the result. The block diagram of this method is presented in figure 4.

The problem with this method is that the detection probability decreases, because blotches that are connected to image areas with a similar intensity level will be reconstructed and thereby pass undetected. This problem can be observed in figure 6 (c). Moreover, when the size of the structuring element used in the marker dilation (erosion) increases, the detection probability also decreases.

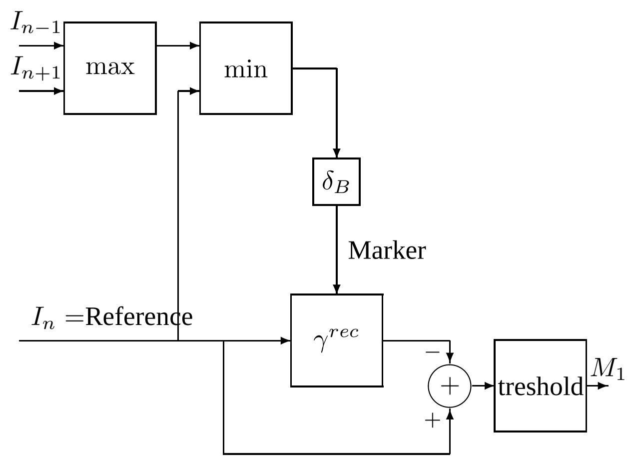


Figure 4. Block diagram of the Opening by Reconstruction method using marker dilation. γ^{rec} is the morphological reconstruction and δ_B the morphological dilation.

2.1.3 Opening (closing) by $\lambda-$reconstruction

In order to minimize the negative effects arising from both methods explained above: increment of false alarms in scene with large motions for temporal opening (closing), and decrement of detected blotches for opening (closing) by reconstruction, we propose to use the λ-reconstruction to reconstruct the actual frame using the marker constructed as in the method explained in section 2.1.2.

In the opening (closing) by λ-reconstruction, the reconstruction is calculated with a structuring element non flat. This morphological operator is presented in [8, 9]. As such, an intermediate solution between the methods 2.1.1 and 2.1.2, is obtained. A value of $\lambda = 0$ is equivalent to applying the opening (closing) by reconstruction method, and if $\lambda = \infty$ it is equal to using the temporal opening (closing). Therefore, we intend to use the opening (closing) by λ-reconstruction as a method to detect the blotches in a sequence, controlling the value of λ by calculating the amount of motion present in the scene (a global approximation, without estimating motion vectors).

2.2 High contrast detection method

To improve the three previous detection methods, we present a complementary criterion which takes into account another property of the blotch: the high contrast. The algorithm is based on a morphological operator which eliminates image areas with a contrast than a certain level h [10]. This intraframe operator consists of computing the reconstruction of an image using the same image with the brightness reduced in h as a marker and, thereby, achieving the residue between the reconstruction result and the original image. By applying a threshold of 1 and a threshold of h to the residue, and combined the two binary image obtained, as in the block diagram presented in figure 5, we obtain a mask (M_2) which can indicate the image areas with a contrast larger than h.

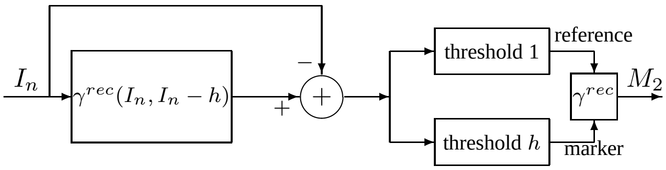


Figure 5. Block diagram of the high contrasted areas detector (γ^{rec} is the morphological reconstruction).

The mask of areas with high contrast (M_2) is combined with the mask obtained using the selected method for the detection of temporal uncorrelation (M_1), and, as such, a mask capable of indicating contrasted areas having high temporal uncorrelation, is obtained. These two masks can be combined conducting the logical operation **AND** between them (figure 2) or reconstructing the temporal uncorrelation mask (M_1) with the high contrast mask (M_2) as a marker. In the results presented in the next section, the second method has been used.

3 Blotch Interpolation

The objective of the interpolation stage is to obtain the missing data in the areas indicated by the damage mask. These intensities can be extracted from the surroundings of the blotch in the same frame (spatial interpolation methods) and from consecutive frames (temporal interpolation).

- Spatial interpolation: the spatial interpolation method presented in [11] is a satisfactory option when the sequence has a substantial amount of motion, because in this case, in order to fill a blotch inside an object in motion, the temporal interpolation introduces artifacts. However, the satisfactory performance of this method demands that the blotch has no edges or rectilinear edges.

- Temporal interpolation: in the case of a static scene, or when a blotch inside a static object has to be interpolated, the results obtained using this kind of methods are better than those obtained when using spatial methods. The results of the temporal opening used in the detection can also be used for filling the areas marked by the damage mask, but only in the pixels labelled as blotches. If the interpolation is achieved using the temporal opening (closing) the texture information can be erased. On the other hand, if the opening (closing) by reconstruction result is used, the blotch is filled with the maximum (minimum) value that is provided by the marker in that area. If this area is connected to a clear (dark) image area at some point, the blotch becomes a flat area which can be very visible. If we use the λ-reconstruction, this flat area will blur with the background as the pixel to be filled moves away of the connection point, the blotch no longer being so visible.

  In order to improve the temporal interpolation in motion scenes, a method that segments the mask and estimates the motion vectors in each blotch, is being developed. The motion vectors are estimated by ignoring the blotch intensities and using its surrounding area.

4 Results

We have tested the methods with approximately 50.000 frames (2.000 seconds of video) from five different films. We have previously obtained the mean difference between the consecutive frames of each shot. For each range of differences (which have been set using different thresholds) a value of λ and a size of the structuring element for the marker pre-dilation (pre-erosion) have been selected. These values, empirically selected using our set of test sequences, maximize the quantity of detected blotches without introducing too many artifacts as a result of false alarms.

4.1 Results of blotch detection

4.1.1 Temporal uncorrelation detection

Figure 6 shows an original image from the movie *Sangre y Arena* and the obtained masks (superimposed, in white, on the original frame) using the different closings: temporal closing (b), closing by reconstruction (c) and closing by λ-reconstruction (with $\lambda = 10$) (d). The temporal closing is the method which detects more blotches, but it also produces more false alarms. This fact can be witnessed in the example: the character who is on the right hand side moves his arm (the three consecutive frames shown in figure 1 show this motion) and a false alarm is detected because the arm is a dark motion object (with a motion larger than half its size). Closing by reconstruction has the lowest detection probability. It does not detect the blotches connected to dark image areas with a similar intensity level to the blotch (for example the blotch connected to the headboard), although it produces less false alarms (it does not detect the arm). Finally, the λ-reconstruction method is a controllable intermediate solution using the λ value.

As such, the performance of these different detection methods will depend on the quantity of existing motion within the sequence, as outlined below:

- If there is no motion or if the motion is small (objects that move less than half their size), the temporal opening (closing) method works better, because it has greater detection probability, and only fails in the case of objects which undertake a motion which is more than half their size. This method allows for faster motions by achieving a previous dilation of adjacent frames.

- If very large motions exist within the scene, the operators by λ-reconstruction can be used by increasing the value of λ if the motion is smaller and decreasing this value if the motion increases.

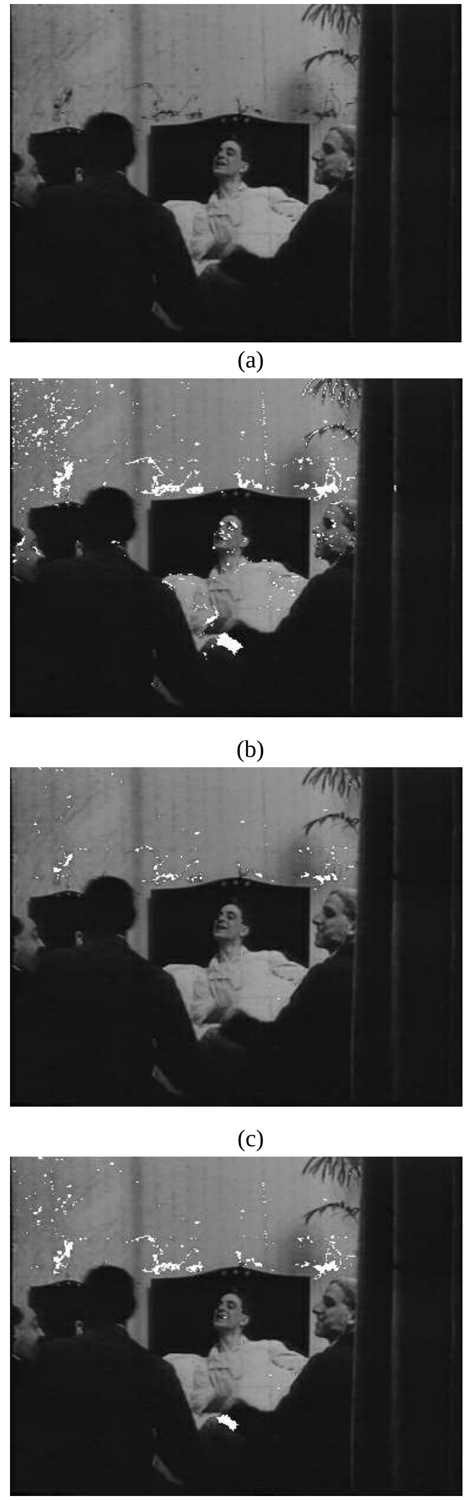
An approximate estimation of the amount of motion is sufficient to control the λ value and the size of previous dilations (erosions). This measure can be reached by obtaining the mean difference between consecutive frames.

4.1.2 Marker pre-erosion effect

Figure 7 shows the effect of the size of marker pre-erosion on the detection result for a sequence with motion objects. The detection method used has been the λ-reconstruction with $\lambda = 10$ and $h = 50$. Image (a) shows the original image. The detected blotches in cases free from marker pre-erosion, and cases with a pre-erosion of 5×5 and a pre-erosion of 9×9, respectively, can be observed in (b), (c) and (d). These are superimposed in white on the original image. As the size of the structuring element increases, the number of false alarms decreases, like the palm leaf or the head of the man sitting on the left, which are motion objects in the scene. These false alarms are marked in image (b), figure 7 with a circle, and we can observe how they disappear when the pre-erosion size increases (images (c) and (d) in figure 7). However, as the size of this pre-erosion increases, the number of detected blotches (those that are near dark regions) also decreases. Consequently, the structuring element size is selected as a trade-off between the number of false alarms and the number of detected blotches.

4.2 Interpolation stage results

Figure 8 shows an original frame from a sequence from *Sangre y Arena*, the central image in figure 1, and the restoration result. In the detection phase, the λ-reconstruction method has been used with λ=10 and a 5×5 marker pre-erosion. The contrasted demanded of the blotches has been $h = 50$. For the interpolation, the result of the λ-reconstruction has also been used.

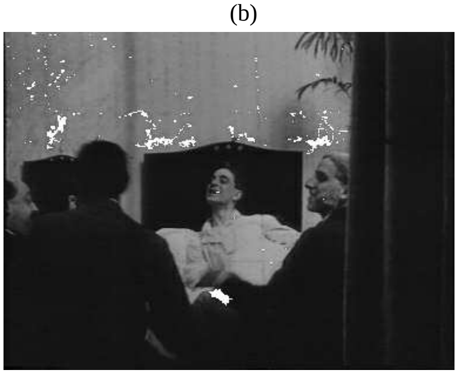


(a) (b) (c) (d)

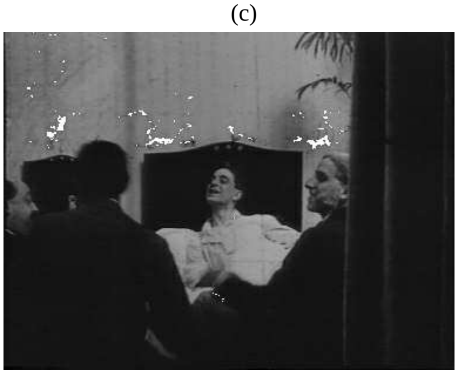
Figure 6. Comparison of the detection methods : (a) An original frame from the movie *Sangre y Arena* (the central image in figure 1). (b) The mask obtained (superimposed in white on the original frame) using the temporal closing method. (c) Obtained mask using the closing by reconstruction method. (d) The mask obtained using the closing by λ-reconstruction method where $\lambda = 10$.

(a)

(b)



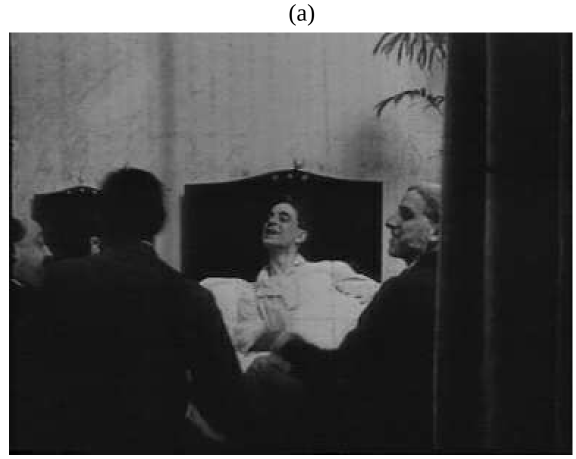
(c)



(d)

Figure 7. Detection of dark blotches using different size of marker pre-erosion in the λ-reconstruction method ($\lambda = 10$) : (a) An original frame from the movie *Sangre y Arena*. (b) Blotches detected without pre-erosion. (c) Blotches detected whit a 5×5 pre-erosion. (d) Blotches detected with a 9×9 pre-erosion.

(a)



(b)

Figure 8. Restoration result: (a) An original frame (central image in figure 1). (b) Restored image.

5 Conclusions

In this paper, some methods for eliminating defects in temporal uncorrelation have been presented. The restoration has been divided into two stages: detection and interpolation. In the detection stage, a binary mask (the damage mask) is produced. This mask indicates the location of the blotches. In the interpolation stage, only the intensity of the pixels labelled as blotch in the previous step, has been changed. The restoration process is conducted in two steps in order to preserve the correct movie information in its original undamaged state and to avoid the introduction of artifacts in areas without defects.

We have carried out an study of three detection methods based on several mathematical morphology operators, which do not require the estimation of motion vectors with any high accuracy, in order to obtain the mask of defects. The conclusion to be drawn from this study is that the temporal opening (closing) method detects more blotches. However, when there are objects in a scene which are involved in a motion more than half their size, false alarms (artifacts in interpolation) are produced. The number of false alarms can be reduced by using dilation (erosion) prior to the temporal opening (closing). The opening (closing) by reconstruction method allows for an object motions larger than object size without producing false alarms, and, thereby, it not only reduces the number of false alarms but also the number of detections. Dilation (erosion) prior to reconstruction further reduces the number of false alarms produced by motion, but it also reduces the number of detected blotches. The aforementioned problems lead us to propose an intermediate solution: the opening (closing) by λ-reconstruction, controlling the value of λ with the calculated amount of motion present in the scene.

To further reduce the number of false alarms (artifacts in interpolation) we have presented a complete detection method which stipulates that only high contrasted, uncorrelated areas will be regarded as a blotch.

In order to fill the areas indicated by the damage mask, a temporal interpolation method has been used: this is the result of temporal opening (closing), opening (closing) by reconstruction or opening (closing) by λ- reconstruction calculated in the detection stage. This kind of methods works better when the blotch is inside a static area. If it is inside a motion object (on the object edge) some artifacts can be introduced. In this case, before filling the blotch, motion compensation can be achieved. To estimate the motion vectors, one for each blotch, the algorithm ignores the blotch intensities and uses the surroundings of the bloch.

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