REMOVAL OF BLOTCHES AND LINE SCRATCHES FROM FILM AND VIDEO SEQUENCES USING A DIGITAL RESTORATION CHAIN

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ABSTRACT

Line scratches and blotches are two of the most common and annoying artifacts of image sequences. A digital restoration chain for the removal of these artifacts was conceived and implemented. The basic elements of the chain are the digital encoder, the artifact generator, the artifact detectors, the interpolators and the quality measurer. The digital encoder has the mission to convert analogue sequences into digital ones and, if necessary, to make a format conversion. The artifact generator allows quantitative and qualitative tests of the restoration algorithms. If we have access to the original non-degraded sequence we can add, in a controlled way, artifacts with the generator, and then measure efficiently the quality of the restoration algorithms, since we have the original, the degraded and the restored sequences to compare. In a real restoration process, the degraded sequence is directly applied to the artifact detector. The artifact detector finds the degraded regions in the image and, somehow, marks them. The interpolator replaces the marked degraded pixels with others that are the result of an interpolation algorithm. Finally, the quality measurer rates the quality of the restored sequence.

1. INTRODUCTION

The continuous increase of the production of new multimedia applications, together with a new and diversified group of customers searching for contents for those applications, forces its owners to find ways of quickly making available good quality copies preserving, however, the originals. Archives (libraries, museums, televisions, film producers, etc) own most of the contents. In video archives the larger part of that material is in the analogue format, so the storage and constant reproduction of the sequences cause irreversible damages. The logical solutions for this problem are the digitalisation followed by the restoration of the digital version of the old analogue sequences. Digital restoration allows the test of several algorithms without damaging the original sequence. For each sequence the most suitable technique is applied, making possible that the restored sequence is alike the original, non-degraded, one.

When playing a degraded video sequence different kind of artifacts are present. Some more annoying than the others but all of them modify the properties of the original image. Two of the more annoying artifacts are the blotches and line scratches. These are two frequent degradations that cause severe damage in the original sequence. They are typical film artifacts, although they can also be seen on video sequences.

Blotches are characterized for being impulsive, randomly distributed, with irregular shapes of approximately constant intensity. These artifacts last for one frame. In the degraded regions there is not any correlation between the present frame and the precedent and following ones. Blotches are originated by dust, warping of the substrate or emulsion, mould, dirt or other unknown causes. Blotches in film sequences can be either bright or dark spots. If the blotch is formed on the positive print of the film then the result will be a bright spot, however if it's formed on the negative print, then in the positive copy we will see a dark spot.

Line scratches are narrow vertical, or almost vertical, bright/dark lines that affect a column or a set of columns of the frame. Usually the scratch has the dimension of the entire column although there are cases where smaller scratches exist. The scratches follow a model [1] that can be described as the multiplication for a positive constant, designated penetration depth, along the entire column. Line scratches, unlike blotches, can persist for several frames in the same position. The erosion that exists when the film material is run against a foreign object in the projection device causes the line scratches. The transference process between film material and Telecine can also produce scratches.

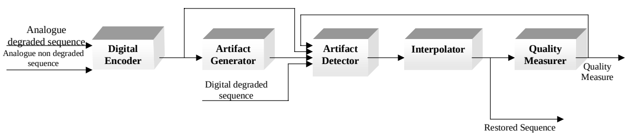

Figure 1. Digital Restoration Chain

To remove the artifacts a restoration chain was implemented as shown in Figure 1. The elements of the chain are the digital encoder, the artifact generator, the artifact detector, the interpolator and the quality measurer. The chain has two working modes: test mode and restoration mode. The test mode is used to evaluate the performance of the restoration algorithms. In this mode the input of the chain is a non-degraded image sequence. If the sequence is in analogue format, it is firstly digitally encoded. The artifact generator add chosen noise (blotches or line scratches) to the sequence and stores the binary noise mask sequence. The detector identifies the regions that contain artifacts in the degraded sequence and provides that information to the interpolator, which uses it to interpolate the defective regions. At the entrance of the quality measurer three image sequences are available: the "clean" non-degraded original sequence, the degraded sequence and, finally, the restored one. The quality measurer compares the three sequences and outputs a restoration score. Together with the automatic quality measurer a human operator evaluates, subjectively, the quality of the restored sequence and introduces feedback in the rest of the chain, if necessary. In the restoration mode, which is the normal operation mode for the chain, the non-degraded sequence is not available, so the artifact generator is not necessary.

A complete restoration chain for blotches and line scratches was implemented. For the blotches the SDI detector [2] and the ML3Dex [2] spatio-temporal median filter were used as detector and interpolator. Scratch detection is performed by a variation of the SDI detector designated by SDI_S. The scratch interpolation is done by a simple spatially weighted filter called LSSI (Line Scratches Spatial Interpolator).

2. DIGITAL ENCODER

The digital encoder is an A/D converter that converts the input analogue sequence into a digital, uncompressed, sequence. This block of the chain also decodes digital compressed sequences, like MPEG files.

3. ARTIFACT GENERATOR

The artifact generator adds defects to the original image. The blotches last only for one frame and have an irregular shape, and almost uniform intensity. As it is impossible to reproduce all the shapes of the blotches, the generator assumes that the blotches can have two possible shapes: ellipses and line segments. For each shape the number of artifacts per frame follow a Poisson model with N_{max} and λ as the maximum and average number of blotches per frame respectively. In the ellipses the aspect ratio as well as the ellipse intensity follow Normal distributions. As for the line segments the coordinates of the start point $(x_0,, y_0)$ are defined using two uniform distributions. The coordinate x_0 is uniformly distributed between 0 and $XSIZE$ while y_0 is uniformly distributed between 0 and $YSIZE$, where $XSIZE$ and $YSIZE$ are the number of columns and lines of the image. From the start point distances d_x and d_y are sampled from a Normal distribution, in order to obtain the end coordinates of the segment $(x_0+ d_x, y_0+ d_y)$.

The line scratches can be modeled as a single column or set of adjacent columns multiplied by a real constant a ($0<a<1$) along the entire column. This constant is called penetration depth [2]. Unlike blotches, scratches can last for several frames. The number of frames that a scratch lasts follows a Poisson model with F_{max} and λ_f as the maximum and average number of frames per scratch. The number of scratches per frame follows a Poisson distribution similar to the blotches. The localization of the scratch (c) and its width (w) and penetration depth (d) follow uniform distributions.

4. ARTIFACT DETECTOR

Blotches are detected from the degraded sequences using the SDI [2] detector. The SDI detector is a simple heuristic that compares each pixel of the present frame with the same pixels of the previous and next frames after motion compensation, and generates a number $0<SDI<1$. If the value of SDI is larger than the local average SDI by some threshold (t_3) then the processed pixel is marked as a blotch. A trade off must be made, when choosing the thresholds, between the number of correct detected pixels and the number of false alarms. Figure 2 represents the variation of the number of false alarms (pixels incorrectly detected as degraded pixels) and correct detections (pixels correctly detected as degraded pixels) with the variation of the threshold (t_1). It clearly exhibits the necessity to choose carefully the value of the threshold t_1. Figure 3 shows an example of the performance of the SDI_S detector.

The motion compensation is achieved using block matching phase correlation. For each correlation surface (motion block) two candidate vectors are computed. The first candidate is the vector V_1 with the highest amplitude in the correlation surface. To select the second vector only the vectors that are at least P pixels far away from V_1 are considered. From this subset of vectors the one that has the greatest amplitude is chosen providing that its amplitude is not lower than $k\%$ of V_1.

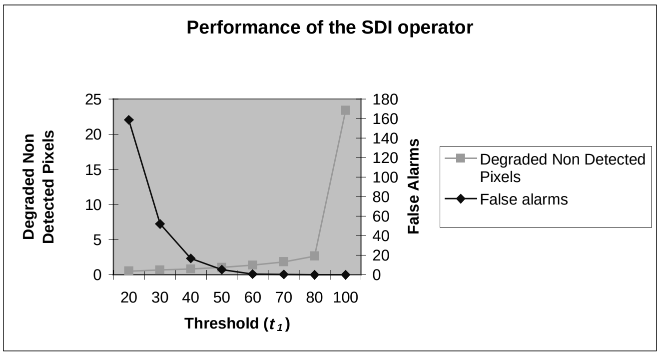

Figure 2. Performance variation of the SDI with respect to t_1

In the line scratches case a new variation of the SDI, designated SDI_S, is used as detector. The SDI_S is described by the equation 1, where $Y_n(x)$ represents the intensity of the pixel x of the n^{th} frame and v is the motion compensation vector, which is found in the same way as in the blotches detector. It is also necessary, like in blotches, to apply a threshold (t_3) to the local average. However, unlike blotches, scratches can stay in the same position for several frames, so the interpolation must be made immediately after the detection to avoid the non-detection of some of the line scratches. The SDI_S generates a binary noisy mask of the line scratches clearly defined. The noisy mask is applied to a morphological filter that localizes vertical lines. It separates the random noise from the line scratches. Like in blotch detection, it is necessary to make a trade-off between correct detection and false alarms when choosing the thresholds for the SDI_S.

$$b = Y_n(x) - Y_{n-1}(x + v_{n,n-1}(x))$$

$$p = Y_n(x)$$

$$d_1 = |p|$$

$$d_2 = |p - b|$$

$$SDI_S = \begin{cases} 1 - \left|\frac{d_1 - d_2}{d_1 + d_2}\right| & if\ d_1 > t_1\ and\ d_2 > t_2 \\ 0 & other\ cases \end{cases} \qquad (1)$$

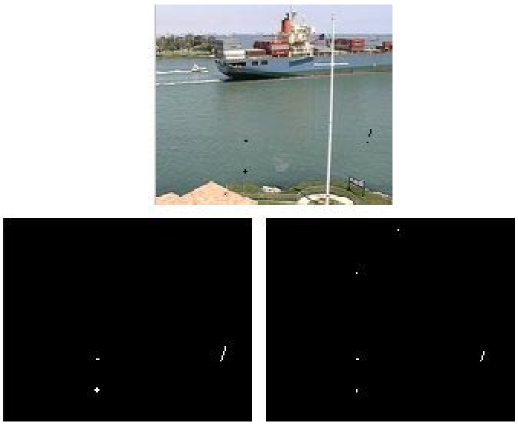

Figure 3. Blotch detection using the SDI detector: Top- Degraded sequence; Bottom left: Blotches location mask; Bottom right: Detected blotches mask using the SDI detector

5. INTERPOLATOR

For the blotches the ML3Dex [2] is used as the interpolator. ML3Dex is a multilevel median spatio-temporal motion compensated filter. Five windows are used to compute five different median values. Each of these windows is divided in three spatial windows that are applied to the previous present and future frame respectively. The output of the filter is the median value of the five previous median values. The operation of the ML3D interpolator is exhibited in figure 3.

For the line scratches it is necessary to find the penetration depth value in order to interpolate the degraded regions. A spatial weighted filter designated LSSI (Line Scratches Spatial Interpolator), is used as interpolator. The LSSI tries to find the penetration depth for each degraded pixel so that the restored pixel is obtained dividing the degraded pixel by the calculated penetration depth. To estimate the penetration depth its local average value for the nearest non-degraded left and right columns is computed and weighted according to the distance between the central and the side columns and the pixel variance of each column. The variance of the penetration depth is important since columns with a large penetration depth variance indicate, for sure, that a vertical edge is deteriorating the results. The algorithm is as follows:

For each defective column *c*:

- Find the two nearest non-degraded left and right columns closer to *c*: *l* and *r*
- Calculate the distance from *l* and *r* to *c*: d_l and d_r.
- For each pixel *c(i, j)* define a neighborhood of size *N* of *c(i, j)*: *l(j, k)*, *r(j, k)* for $i - \frac{N}{2} \le k \le i + \frac{N}{2}$
- Calculate $\frac{l(j,k)}{c(j,k)}$ and $\frac{r(j,k)}{c(j,k)}$ for each *k* and store it in two vectors v_l and v_r.
- Calculate the variances of v_l and v_r: σ_l^2 and σ_r^2.
- Calculate the mean value of v_l and v_r: $\bar{x}_l$ and $\bar{x}_r$.
- After normalizing the mean values, variances and distances:
  $c(i, j) = w_{dist}(d_l \bar{x}_l + d_r \bar{x}_r) + w_{var}(\sigma_l^2 \bar{x}_l + \sigma_r^2 \bar{x}_r)$

Figures 5 shows the performance of the LSSI interpolator.

Figure 4. Performance of the ML3Dex interpolator: Top Left- Original non-degraded image; Top Right- Blotch degraded image; Bottom left- Restored image using the correct mask of defects. Bottom right- Restored image using the mask of defects produced by the SDI_S.

Figure 5. Performance of the LSSI interpolator: Left- Line Scratch degraded image; Right- Restored image

6. QUALITY MEASURER

The quality measurer implementation was based in [3]. It is a perceptual quality measurer which divides the image in four segments (improved fidelity/high spatial activity, degraded fidelity/high spatial activity, improved fidelity/low spatial activity and degraded fidelity/low spatial activity) and weights them according to their importance. The output measure is a number $-1<n<1$ where -1 indicates maximum deterioration, 1 indicates maximum improvement and 0 indicates nor improvement nor deterioration. The automatic quality measurer only works in test mode. In restoration mode the access to the "clean" sequence is impossible, so it is necessary that a human operator perform the quality measurement, evaluating the performance of the algorithms. If the performance is not acceptable, the operator can change the parameters of the applied algorithm or switch to a more efficient one. The use of more than one operator, together with the utilization of the automatic quality measurer improves the results.

7. CONCLUSIONS

The algorithms implemented, in spite of their simplicity, proved to be very robust and efficient. With the exception of the quality measurer, the implementation of the algorithms is fast, so they do not need a very powerful platform to operate satisfactorily. This restoration chain has been implemented in separate modules, allowing the easy integration of new algorithms without modifying the others modules of the chain. It also allows the removal of several artifacts using a sequence of different modules for each artifact. In figure 6 a blotch and line scratch degraded frame is restored using the full restoration chain. The restoration score for this frame is 0.743. Implementation of new elements for the chain (detectors and interpolators), to deal with a different set of artifacts and improvement of the existing ones are planned.

Figure 6. Performance of the complete restoration chain: Left: Blotch and line scratch degraded frame; Right: Restored image

8. REFERENCES

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