RESTORATION OF VARIABLE AREA SOUNDTRACKS

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ABSTRACT

Film restoration using digital image processing has been an active research field in recent years. However, the restoration of the soundtrack has been mainly performed in the sound domain, using signal processing methods, in spite of the fact that it is recorded as a continuous image between the film images and the perforations.

In this paper, we present a complete system for variable area optical soundtrack restoration at the image level. The scanned soundtrack is treated using morphological operators, including a novel quasi-distance function. Working with the image representation of the soundtrack allows to take advantage of its redundancy. Moreover, with this approach only those defects that have been caused by ageing are corrected. The first results, concerning variable area soundtracks, are reported.

Index Terms— Variable area soundtrack restoration, quasi-distance, watershed, image processing, mathematical morphology.

1. INTRODUCTION

The majority of the films shot since the Thirties use an optical soundtrack to record the sound. The standard Academy Optical Mono track was introduced by the Academy of Motion Picture Arts and Sciences. Following this standard, the optical soundtrack is located in a space of 3mm between the images and the perforations. Thus, the duplication of a film automatically allows to copy its soundtrack. In its classical version of area variation, the aural signal amplitude implies more or less important width of the modulated band of the optical soundtrack, around a central axis of symmetry.

Unfortunately, the optical soundtrack undergoes the same type of degradations as the image of the film (*e.g.* scratches, dust), but as the track is close to the film edge and perforations, it is sometimes degraded by abrasion or impaired over a large surface due to moisture.

Typically, sound processing and restoration are performed only after the transformation of the optical information into acoustic electric signal, and several defects introduce distortions that are delicate to correct after the transformation : As powerful as they are, digital audio processing systems cannot make the difference between some audio artifacts caused by the degradation of the optical soundtrack, and some sounds present in the original soundtrack.

In this paper, a complete algorithmic workflow for variable area optical soundtrack restoration, at the image level, is presented. The nature of the images to be treated and their defects are presented in the following section. The third section sums up the state of the art. Finally, in the fourth and fifth sections the proposed method and the obtained results are presented.

2. OPTICAL PICKUP AND IMAGE ACQUISITION

2.1. Principles

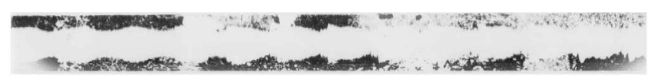

Fig. 1. Damaged variable area / fixed density soundtrack.

The optical soundtrack is read by projecting light from a lamp through a narrow slit, then through the film. A photodetector detects the transmitted intensity and converts the changes of brightness to an electrical modulation, further processed and amplified to generate the sound. The old standard was based on variable density : varying shades of grey induced the variations of light intensity. This process produced an important noise and caused later problems for color stocks. Therefore, the fixed density process (also called variable area) took over the former one, and is still in use today. In this process, the varying proportion of black versus white modulates the intensity while the dust spots scattered on the black area obviously do not generate noise. Research activities reported in this paper only concern these variable area soundtracks (fig. 1).

2.2. Digital input and output images

The so-called Academic ”A” chain components includes the optical pickup and the preamplifier [1]. The defined band-width for these components is roughly 40Hz-10KHz (according to the Academic curve, used from 1930 until the fifties, and the introduction of the Dolby noise reduction systems). Since the film speed is 456mm/s (for 35mm), a 10KHz signal period is 0.0456mm wide in the optical soundtrack. The input images used for this work came from a frame-by-frame scanner with a 1536 lines definition. According to a frame height of 16mm (4 perf.), the image resolution is ca. 100 pixels/mm ($\approx$2500 DPI) and one period of a 10KHz signal ranges over 4 pixels.

To collect samples for further work, we designed a specific line-scan based digitizer able to sample 48000 lines per second, thus good enough for processing in high frequencies (meeting the requirements of the "X"-curve). But the quality of the images illustrating this paper were good enough for our first trial, since we emphasize on restoration techniques for these heavily corrupted tracks. The moisture here almost wiped out complete areas of optical information. Our aim is to output segmented images (two classes: black and white) for easy conversion to audio signal. The images should be symmetrical about a central axis and at least, the black/white border line should be a causal curve.

3. STATE OF THE ART

In 1999, Streule [2] proposed a soundtrack restoration system using image processing tools. Concerning the restoration, Streule only treats defects caused by dust. The proposed technique is mainly based on the soundtrack symmetry.

J. Valenzuela appears as the inventor of several patents on soundtrack scanning and restoration (see for instance United States patent 7,123,339). He proposes a short description of his technique in [3]. The restoration is very simple, and is based on median filters and erosions. It can only deal with the smallest defects.

Richter, Poetsch and Kuiper proposed in [4] a method for defect localization in multiple double sided variable area soundtracks. This method applies first a low-pass filter to the image. After binarization, the remaining defects are sufficiently large to be easily detected. The authors did not consider the problem of eliminating the defects.

Spots detection is also used by Kuiper in [5]. The spots being lighter than other parts of the image, a threshold isolates them. A succession of morphological operations is then applied for a better spot localization and for the removal of isolated pixels. Unfortunately, in most cases, the spots are not really lighter than the rest of the image. For that reason, this method cannot always be used.

Therefore, it seems the research on this field is at its beginnings. The published approaches do not allow to treat the whole range of defects we have found in our database, or that we have identified through the expertise from the staff of the French archives (for example over- and under- exposure of optical soundtracks).

4. RESTORATION METHOD

The proposed restoration method consists of the following steps:
- Image filtering.
- Quasi-distance calculation of the filtered image.
- Symmetry axis detection.
- Image segmentation by watershed.
- Symmetry enforcer and edge correction.

An image f is modeled as an integer function of an appropriate subset of $\mathcal{Z}^2$. We will use a 4-connectivity, and the associated structuring element will be denoted B. The morphological dilation and erosion with B are respectively denoted δ_B and ϵ_B. Furthermore, $nB = \delta_B((n-1)B)$, $(n > 1)$.

4.1. Filtering

The goal of this step is to reduce the defects in the initial image without denaturing it. The defects mainly found in our data base are white marks on dark regions. Consequently, a morphological opening by reconstruction has been used :

$$\gamma^{rec}(f) = \delta_f^{\infty}[\epsilon_{nB}(f)]$$

where $\delta_f^{\infty}(.)$ is the geodesic reconstruction under f, i.e. the geodesic dilation under f iterated until idempotence.

This operation fills the holes in the dark regions of the image which are smaller than the structuring element nB. It is illustrated in Fig. 2.

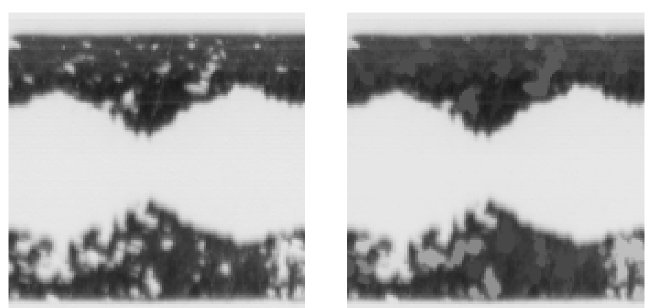

Fig. 2. Image before and after opening by reconstruction.

4.2. Quasi-distance

The morphological quasi-distance is a morphological operation recently introduced in 2005 by S. Beucher [6]. The residual operator of the quasi-distance is defined as:

$$t(f) = sup_{i \in I}(\epsilon_{(i-1)B} - \epsilon_{iB}).$$

For i large enough, the resulting erosion gives a constant image, which ends the computation of t. The resulting residue is often non explicit. We associate to this operator the morphological quasi-distance q, based on analysis of the evolution of the residues in each pixel of the image. We indicate, for each pixel, the value of the index i for which $\epsilon_{(i-1)B} - \epsilon_{iB}$ is the largest. If there are several such values, we take the smallest one from these. Finally:

$$q(f) = inf\{i \in I/t(f) = \epsilon_{(i-1)B} - \epsilon_{iB}\}.$$

The quasi-distance operator is illustrated with a one- dimensional example in Fig. 3. Its application to a soundtrack image is shown in Fig. 4.

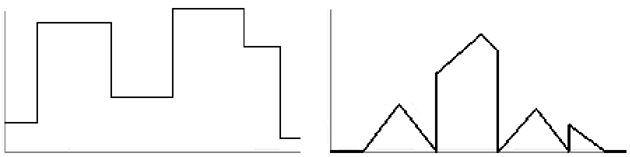

Fig. 3. 1D image and its quasi-distance.

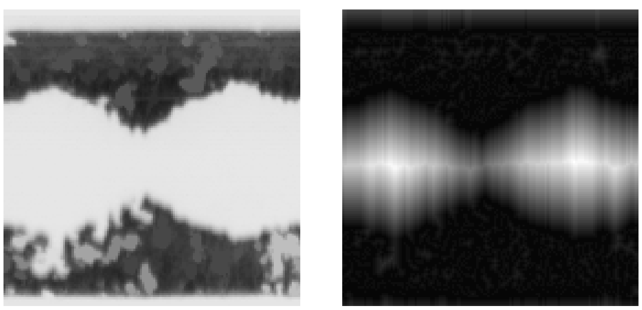

Fig. 4. Filtered soundtrack and its quasi-distance.

Note that a similar result could have been obtained by means of a threshold followed by the computation of a classic distance function, but the choice of the threshold value is always a delicate problem, which is avoided with the proposed approach. Moreover, efficient algorithms for the computation of the quasi-distance have been developed [7].

The resulting quasi-distance will be used in the following steps for the symmetry axis computation and for the determination of the watershed markers.

4.3. Symmetry axis detection

In practice, the quasi-distance is a good approximation of the distances from the pixels of the light region, to the dark ones. The symmetry axis is then close to the crest points of the quasi-distance. These pixels are not always aligned. For that reason, we compute a linear regression starting from the crest points in order to obtain a straight line.

4.4. Segmentation

In order to segment the image in such a way that the frontiers of the segmentation correspond to the contours of the soundtrack, we have decided to use a morphological watershed from markers. Firstly we compute the gradient of the image, and secondly we compute an appropriate set of markers.

We have chosen to use the morphological gradient g, defined below as the difference between dilation and erosion:

$$g(f) = \delta_B(f) \backslash \epsilon_B(f).$$

In our images, we want to segment three distinct parts : the light central region and the two dark side regions. The symmetry axis has been chosen as marker for the central region. The two other markers correspond to two lines parallel to the axis. The distance between the central marker and the side ones is given by the maximum value of the quasi-distance, plus a small value, which has been empirically set to 5 pixels.

A watershed is computed from these markers on the gradient image. From its result, a binary image is obtained (see Fig. 5). The resulting image is globally satisfactory, but it might not be symmetric, and the contours may present some unwanted concavities (*i.e* the black/white border line is not a causal curve), as in the example below.

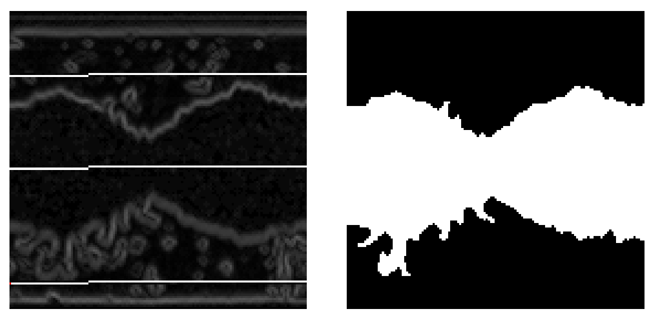

Fig. 5. Gradient image with markers; resulting segmentation.

4.5. Symmetry enforcement and edge correction

To enforce the symmetry of the image, and to correct its edges, we proceed as follows: in each line perpendicular to the symmetry axis, if a black pixel is separated by a distance d from the symmetry axis, all pixels on the same line, which are separated from the symmetry axis by a distance larger than d become black. This simple and efficient procedure corrects the remaining defects. It is illustrated in Fig. 6.

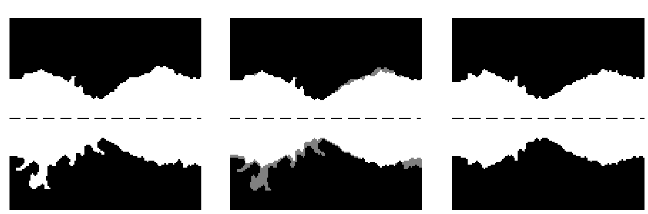

Fig. 6. Symmetry enforcement and edge correction.

5. RESULTS

Figs. 7 and 8 show two restoration examples. The original soundtracks are severely damaged. We can see that when only one side is degraded, it is restored thanks to the other side, and that a correct segmentation is obtained. Only when both sides are severely degraded on the same vertical line the result is unsatisfactory. Finally, our algorithm correctly restores the peaks of the signal, but the valleys might be partially filled when frequencies are very high.

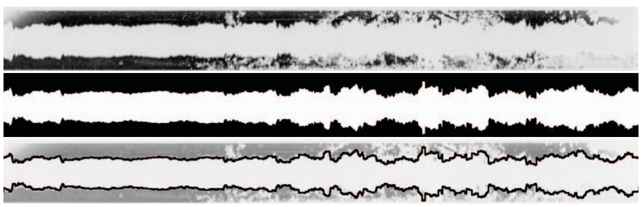

Fig. 7. Example with a very degraded soundtrack.

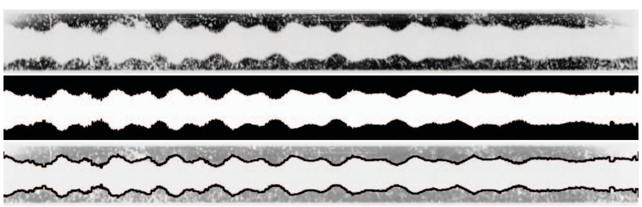

Fig. 8. Example with a less degraded soundtrack.

An important rule that was adopted during the design of the proposed restoration method is to have as few parameters as possible. There are currently only two parameters that need to be chosen by the user : the size of the initial filtering, and the margin for the placement of the side markers. In practice, for the tests that have been done, their values were empirically chosen and kept constant for all the images.

6. CONCLUSION

We have presented a variable area soundtrack digital restoration system. The restoration method uses a novel morphological operator: the morphological quasi-distance. We tested our algorithm on several images and, according to motion picture archivists, the results are very visually satisfactory.

Indeed, only a subjective visual assessment of the resulting images is done. Since the optical pickup is replaced by a line scan camera, all the subsequent components of the ”A”-chain should be digitally modelled (including possible non-linear response of the photodetector, dynamic responses of the preamplifier and noise gates). At last, samples (tunes, music, voice) should be collected in order to undergo an auditive assessment.

There is currently ongoing work on the improvement of the algorithm when dealing with soundtracks containing high frequency signals; on the treatment of over- and under- exposure defects; and on the processing of stereo soundtracks (a module aiming at the separation of the two tracks is being developed).

Moreover, a specific scanner has been built around a reformed sepmag player in order to start a large scale acquisition and restoration campaign and to validate the method for a very broad set of problems.

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