Application of Non-linear Image Processing: Digital Video Restoration

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ABSTRACT — **Corruption or noise is a common problem in any field which makes use of images. If archive film or video material is to be broadcast it is desirable to remove unwanted noise/corruption from the original material, prior to broadcast. This paper describes a method for restoration of video images corrupted by "scratching", using a combination of non-linear techniques.**

1 Introduction

To date image processing tools have relied heavily upon linear techniques. Their mathematical simplicity and the existence of a unifying linear systems theory have facilitated their design and implementation. This has enabled these linear techniques to perform satisfactorily in a wide variety of applications. However, many digital image processing/analysis problems cannot be solved by the more traditional linear techniques. It is in these sort of situations that non-linear digital techniques are of greatest value.

Here, we describe methods for restoration of corrupted video sequences, examples of which have been provided by the BBC Research and Development Department.

2 The Problem

The video sequences under consideration consist of 1 inch VTR sequences which have a continuous linear scratch, running along the length of the tape, probably caused by mechanical damage to a tape guide. However, since the tapes are helically scanned the VTR head sweeps over the scratch periodically as it rotates. The effect of this is to generate a sequence of "blips" at intervals as the television picture is scanned.
Two points worth mentioning:

1. When the head hits the scratch it causes a loss of signal/carrier which results in a bright flash. However, the scratch also disturbs the head and it takes some time to settle which causes a "comet-like" tail afterwards.
2. The physical location of the video signal as recorded on the tape actually floats around quite a bit, due to mechanical wobble etc. An electronic "time base corrector" is used to stabilize the signal coming off the tape and realign the video lines. If the TBC is turned off, the video signal will wobble, but the position of the flashes will be reasonably stable. However, when the TBC is switched on the video signal is stable, but the flashes now wobble. Therefore, in general, the position of the flashes is different in each frame, due to the action of the TBC, and hence, any process designed to remove them has to take this into account.

This type of scratch is quite common and, presently, the only way to cure the problem is to manually paint out the scratches on each frame using a video "paintbox" type effects unit. This is obviously a time consuming and expensive process.

Figure 1 shows the luminance field of a frame of just such a corrupted video sequence.

3 Restoration of the Corrupted Video Sequences

It can be seen from the description of the noise process and from 1, that the noise can be categorized into three types of "defect":

1. Dark horizontal "scratches", of quite short duration.

2. Bright "spots".

3. Bright horizontal "lines" covering almost the entire image width.

It is desirable when performing the restoration process to alter the information in the original image sequence as little as possible. It would therefore seem preferable to only perform restoration on those areas of the image sequence which are corrupted, leaving the rest untouched.

The process of restoration therefore consists of two basic stages: the detection of the defects and the consequent removal/filtering of these defects.

There is no guarantee that the position of the defects will vary with time, but there is equally no guarantee that there will be no overlap from frame to frame in the position of these defects. Currently, methods of film and video restoration rely on the fact that defects are non time correlated [4], [5], [6]. Defects are detected by the fact that there are significantly large differences between pixel values in adjacent frames. Unfortunately, if the defects have some time correlation, as may be the case with the video "scratching", these restoration techniques will fail. Other spatio-temporal techniques [1] [3] are capable of removing very small noise impulses, but are unable to remove larger noise artefacts and they preserve all lines within the image [2]. Due to characteristics of the noise under consideration these methods are unsuitable. The detection and removal of the defects is therefore conducted spatially, on a frame by frame basis.

Detection of each type of defect is performed separately. For each type of defect a map of the position of defects is produced. Filtering is then performed only on those positions detected as defects.

3.1 Defect Detection and Removal

3.1.1 Dark "Scratches"

If one considers how the human visual system is able to discern a horizontal dark scratch in an image one can conclude that a dark scratch is evident by the fact that the pixel values along the scratch are markedly lower than those pixel values immediately above and below it, together with information about the scratch length, i.e. "bright" scratches are long, dark scratches are "short". This information may be used in determining the position of horizontal dark scratches.

The image is scanned, pixel by pixel, and at each pixel position, the values of the pixels immediately above and below are compared with the pixel under consideration, i.e. the pixels in the same column position but in the previous and next rows are compared with the pixel under consideration. If both these pixels values are greater than a particular threshold above that of the pixel under consideration, then the pixel is labelled as a potential defect. That is, if P_0 is the pixel under consideration, P_{-1} is the pixel in the same column position but in the immediately preceding row, P_{+1} is the pixel in the same column in the same column position but in the immediately following row and *thresh* is the threshold value:

$$\text{IF } (P_{-1} < (P_0 - \mathit{thresh})) \text{ AND } (P_{+1} < (P_0 - \mathit{thresh})) \text{ THEN } P_0 = \textit{potential defect}$$

Fig. 2 shows the potential dark defects found for a threshold value of 30 for the luminance image shown in Fig. 1.

The "potential defect" binary image is then filtered with a series of close-openings with reconstruction of increasing size, using a one-dimensional, horizontal, structuring element. This filtering is making use of the apriori knowledge that the scratches are thin horizontal lines and is performed in order to remove those pixel positions which have been incorrectly determined as defects.

Fig. 3 shows the "actual defect" image which is the result of the filtering of the potential defect image shown in Fig. 2.

The corrupted image is then filtered only at those positions detected as defects. A median filter is used to estimate the pixel values for those positions detected as defects. The window used (or support) of the median filter is shown in Figure 4. This basically consists of those nearest pixels in the rows above and below the pixel under consideration.

It was found that the best subjective results were obtained when the detection and filtering stages were repeated consecutively using progressively smaller values of the threshold value. Threshold values of 30, 25, 20, 15, 10 and 5 were used.

3.1.2 Bright "Spots"

Intuitively, we can see that we are able to discern a bright "spot" due to the fact that the pixel values of a "bright spot" are markedly higher than the majority of the pixel values of the surrounding pixels. Thus, we are able to label a pixel as a bright spot using this information.

The image is again scanned pixel by pixel. At each position, the pixel under consideration is compared with the neighbouring pixels, shown in Fig. 5. If the pixel value at the position under consideration is greater by a certain threshold than all the neighbouring pixels then the pixel under consideration is labelled as a "bright spot". In the case of bright spots the threshold value is set at 40.

These bright spots are then filtered using the median filter as already described.

3.1.3 Bright "Lines"

The bright lines are dealt with in a very similar manner to the dark streaks. Instead of a pixel being labelled as a defect if the values of the pixels in the preceding and following rows are both less than the value of the pixel under consideration minus a threshold value, in this case a pixel is labelled as a defect if the values of the pixels in the preceding and following rows are both greater than the value of the pixel under consideration plus a threshold value. That is, if P_0 is the pixel under consideration, P_{-1} is the pixel in the same column position but in the immediately preceding row, P_{+1} is the pixel in the same column position but in the immediately following row and *thresh* is the threshold value:

IF $(P_{-1} > (P_0 + thresh))$ AND
$(P_{+1} > (P_0 + thresh))$
THEN $P_0 = potential\ defect$

Fig. 6 shows the potential bright defects found for a threshold value of 15 for the luminance image shown in Fig. 1.

The potential defects image is filtered in the same manner as for the dark streaks to obtain the actual defects image. Fig. 7 shows the actual defect image which is the result of the filtering of the potential defect image shown in Fig. 6.

The detection and filtering stages for both the bright and dark corruption is performed on the luminance and both chrominance fields (Y, Cr and Cb) of each frame in the sequence.

4 Results

Fig. 8 shows the luminance field shown in Fig. 1 after having been restored using the process described.

5 Conclusions

A method has been described which is capable of restoring video sequences corrupted by scratches, the cause of which is probably mechanical damage to a video tape guide. Defect detection is performed purely spatially and hence the process is capable of restoring scratches which are time correlated. Examples of applying the process to real corrupted images have been shown.

6 Acknowledgements

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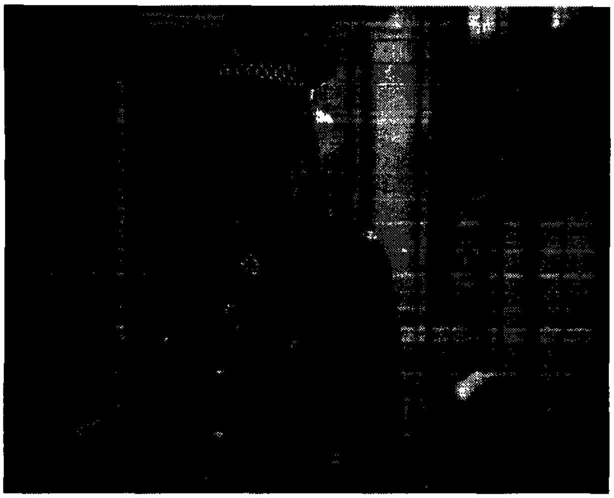

Figure 1: Degraded Video Frame.

Figure 2: "Potential" Dark Defects.

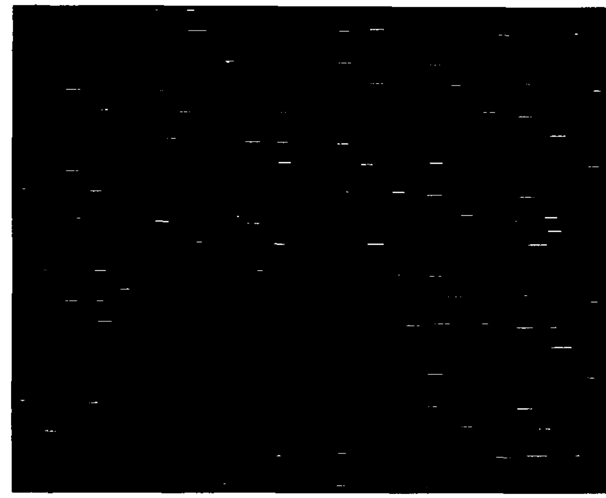

Figure 3: "Actual" Dark Defects.

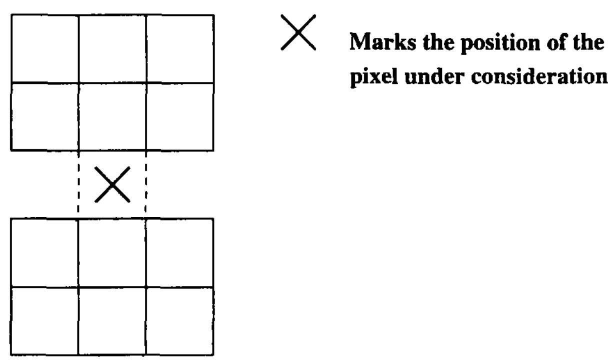

Figure 4: Median Filter Window used in Defect Removal.

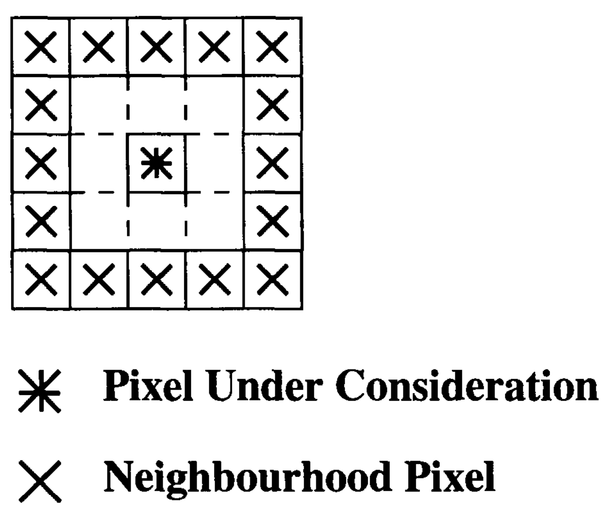

Figure 5: Neighbourhood pixels used in "spot" detection.

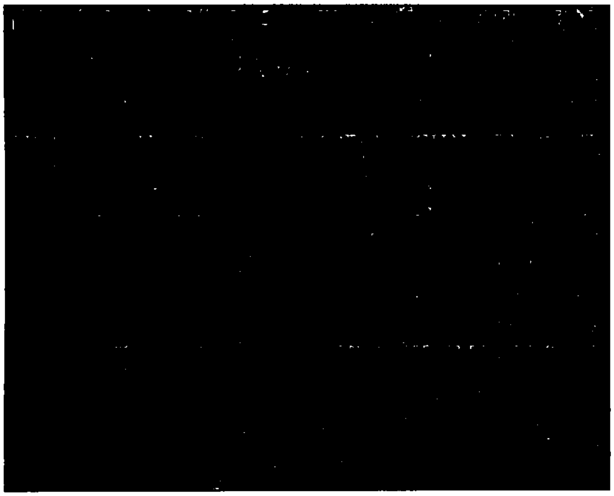

Figure 6: Potential bright defects.

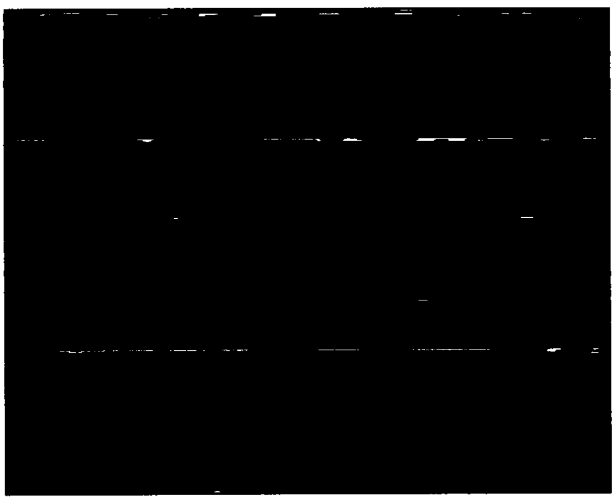

Figure 7: Actual bright defects.

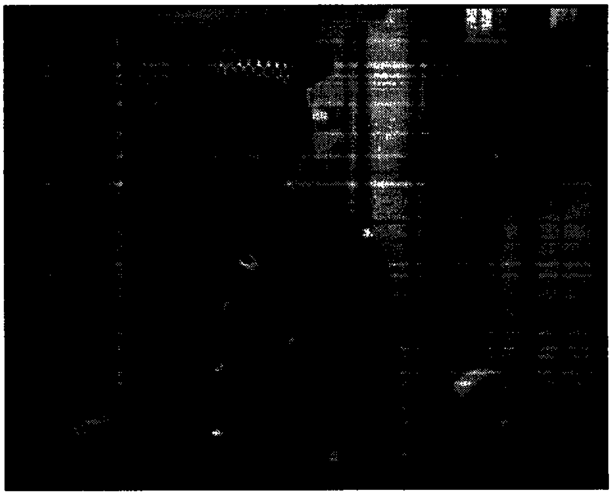

Figure 8: Restored Video Frame.