

# RESTORATION OF ARCHIVED TELEVISION PROGRAMMES FOR DIGITAL BROADCASTING

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## ABSTRACT

The increasing number of television channels and the demands for access to 'national heritage of old films' has caused demands for restoration which can be applied so as to enable a wider range of archived material to be used. This paper begins by explaining the drawbacks of the current methods of archive restoration and concludes that successful exploitation of the vast archive possessed by broadcasters will be achieved only by an automated system able to work in real time but being capable of manual intervention. This is the starting point of the European AURORA consortium whose work is then described. The nature of common defects is discussed, together with the specification of user requirements of the system. Prototype hardware is then described, composed of two units which deal with large-area and localised effects, respectively. Finally, mention is made of assessment techniques, but it is too early to quote results as the project has not yet reached completion.

## INTRODUCTION

There is an important market for archive material because of its historical and scientific value. It is commonly used in repeats of old broadcasts and for the insertion of short-length material into news programmes or documentaries, as well as for historical research. Accurate and cost-effective restoration of this valuable source of information is essential but the prohibitive cost of archive restoration currently limits the level of penetration into the restoration market.

The need for restoration has, however, increased with the introduction of digital delivery. This is because such delivery uses compression techniques that rely heavily on the existence of redundancy in the picture, that is, the picture information is predictable to some degree. Artefacts commonly encountered in archive material use up a significant proportion of the digital capacity, leaving less capacity for conveying the 'real' information.

The pan-European AURORA (AUtomated Restoration of ORiginal film and video Archives) consortium was set up in 1995 to address some of the issues and problems encountered in archive restoration. All the AURORA partners have an interest in improving the quality of film and television archives: either they have archives of their own, are users of current archive restoration techniques or have an existing research base in this field.

This paper explores the research performed by the AURORA consortium into the possibilities offered by automated, real-time archive restoration, a process

that requires an efficient, modern and cost-effective solution. The project will conclude at the end of 1998 when pre-production prototype systems will be manufactured.

## CURRENT STATE OF THE ART

Film and video based material bears the inherent defects of its medium and the equipment on which it is generated, together with additional defects from capture and storage. The first stage of archive restoration is therefore transfer onto a more stable (digital) medium, such as computer disk or digital video tape and the second stage is restoration.

Most real-time restoration is limited to correction of colour and aperture distortion and noise reduction. The latter is limited to low levels because of the effect of 'dirty window' - the image moves against a fixed background of residual noise if the noise reducer works by temporal integration. However, it is thought that this situation could be considerably improved if the noise reducer used motion compensation.

Badly impaired programmes can only be restored by non real-time operations which compel the operator to spend a lot of time specifying complex suites of operations. Even then the result is often little better than the original.

The tools used today for restoring television programmes also suffer from a large number of different and incompatible interfaces. The operator is constrained to interact with the different systems in a

specific order. Even when tools have the possibility of storing edit-lists or timecoded sequences of instructions, the lack of a common centralised tool prevents the storage, in a single file, of all the necessary instructions to repeat the restoration process. As a consequence, it is not possible to change one restoration component without re-specifying all the others.

Some disk-based tools designed for special effects and non-linear editing are sometimes used for moving image restoration. These systems may have the following features :

- Uncompressed image storage on disks (optional compression)
- Random access to images
- Real-time playback of source and processed images (limited buffer size from a few seconds to tens of minutes)
- Some or all effects are computed on demand. This takes time, but the results are visible in real-time after computation.
- Dedicated to non-linear editing and/or to special effects.
- VTR control for importing and exporting images.

As far as restoration is concerned, these systems are generally used as rotoscoping tools, for semi-interactive dirt and scratch concealment, and for image stabilisation. Most of these features need a considerable operator commitment to give an acceptable result.

In some cases, filters may be applied to images, with very long batch processing times, to sharpen the image and to reduce noise and grain.

The main drawback of these tools is the very long time spent per image. For dirt and scratch concealment, a common claim is that one can restore several frames per minute (the work is usually of very high quality). As far as noise reduction is concerned, specialised noise reducers produce a superior result in real-time (in video resolution only). A second drawback is the lack of tools specifically designed for video restoration.

So it can be seen that archive restoration is expensive because of the amount of time spent by the operator on manual processing of the material. A system that worked in real-time would reduce the amount of time spent on restoring source material to something closer to the actual length of the material, rather than hours and days. An automated real-time

archive restoration system would be more cost effective, more efficient and less labour intensive than current methods.

## AIMS OF THE AURORA PROJECT

The main aims of the AURORA project are:

- To analyse film and video archive material to identify the nature, frequency and relative severity of impairments
- To develop and test algorithms which offer more effective solutions for the removal or suppression of artefacts in the video domain
- To develop hardware prototype equipment to implement the algorithms and techniques to provide for the continuous automatic removal of artefacts complying with an outline system specification.
- To provide a system capable of performing interactive archive restoration in real-time.
- To assess the performance of the process system through extensive field trials.

## THE NATURE OF FILM AND VIDEO ARTEFACTS

One of the first pieces of work completed by the archive restoration team was to identify the range of impairments, the frequency with which each occurred and the importance of correcting them.

Video Defects		Film Defects	
Local area	Whole picture	Local area	Whole picture
Random noise	Camera shake	Scratch	Film judder
Video noise	Colour	Sparkle	Film grain
Break up	Drop out	Flicker	Flicker
		Dirt	Unsteadiness
			Missing frames
			Colour

TABLE 1: The major classes of defects identified

Many defects were found and catalogued and in total some 167 were identified from both video and film sources. Analysis based on the frequency and severity over which they occurred provided the basis of prioritising the need for correction. The most frequent and severe defects are shown in Table 1.

## USER REQUIREMENTS

The structure of the proposed restoration system was defined by devising a list of known functions for removing various types of artefacts. Some basic manipulations already existed in current restoration equipment, including non linear editing, mixing, keying, DVE (2D) and colour correction, but most functions were new and unique to the project. Table 2 shows a sample of these. It was important that a real-time correction system should be self-adaptive to the severity of the defect, according to the content of the image (details and motion), but also retain the capacity to be optimised manually.

From the knowledge of the drawbacks of current systems, one can draw up an outline of a possible future television archive restoration system :

The system will be fully integrated : the operator will simply tell the system what he wants to have as a result, without specifying how to do it. For example,

“Here there is a piece of dirt, find it and do your best”

All the operations will be stored in a “Restoration Plan”, which can be edited up to the last minute, and the final restored programme will be conformable on demand (for example when the destination VTR is available). This requires that the integration is complete enough to prevent the operator from being tempted to use the different tools manually, without storing his settings into the Restoration Plan.

The system will make considerable use of pixel-wise motion estimation and motion compensation. This is the only way of automating efficient noise reduction and dirt & drop-out concealment. For the moment, and still for several years, such real-time processing requires computing power largely beyond the capability of current software tools. Dedicated hardware has to be built.

It will run in real-time, tape to tape, for the largest part of its work. Batch processing of segments will be reserved as much as possible for complex effects limited to very short sequences.

Editing tools will be integrated, to allow, when necessary, a local correction, editing out or replacing scenes that are too damaged.

Examples of impairments	Non standard functions
<ul style="list-style-type: none"> <li>Noise, grain</li> <li>Sparkle, loss of emulsion, dirt, drop-outs</li> <li>Film and video scratches, hum, kinescope moire, fixed dirt, dirty window.</li> <li>Banding, PAL, phase error, non uniform colour, colour fading</li> <li>Trail, echoes, detail enhancement</li> <li>Unsteadiness</li> <li>Flicker</li> <li>Lens imperfections, image spreading, scanning spot size in camera tube, display spot size, multigeneration loss, channel bandwidth loss, VTR filter limitations</li> </ul>	<ul style="list-style-type: none"> <li>Noise/grain and continuous impairment correction</li> <li>Masks for erratic and impulsive impairments</li> <li>Compensation for fixed or structured impairments</li> <li>Colour and luminance stabilisation</li> <li>Filters</li> <li>Positional stabilisation</li> <li>Luminance stabilisation</li> <li>Edge correction</li> </ul>

TABLE 2: A sample of the non-standard functions to be provided by the proposed archive restoration system.

There will be a seamless integration between the real-time (tape-to-tape) mode, where the process is carried out continuously, and the off-line mode, where the user will be able to work down to the field level, or tune a set of parameters on a short looping sequence. Delays associated with pre-roll and post-roll of broadcast VTRs will be suppressed. These requirements result in the need for temporary disk storage of the video and audio signal. The size of the cache is no longer a limitation : video disk stores currently allow for typically one hour of uncompressed digital video storage. But the loading and off-loading of the cache have to run in the

background without affecting the interactive part of the work.

## THE HARDWARE PROTOTYPE

Initially a signal processing chain consisting of a parallel or serial arrangement of individual modules, each performing a unique operation, was devised. This was abandoned after investigating the nature of the defects; instead, processing would take place according to the type and severity of defect encountered by the system. Small, random and irregular features such as noise, dirt and scratches can be corrected using pixel by pixel methods and large-scale artefacts like unsteadiness and flicker that affect the entire picture would be best corrected using whole-area or block-based correction methods.

As a result, a hardware solution was developed, which was to be composed of two prototype units. These would provide a separate solution for large scale and small scale impairments using the whole-area and pixel-by-pixel corrections respectively. The prototype would also have an automatic defect detection and flagging system and provide an experimental graphical-user interface to allow interactive user-access to the various functions.

The modules comprising the AURORA hardware prototype are shown in Figure 1. The pre-processed video signal is flicker corrected, then passed onto both the motion estimation system and the unsteadiness correction unit. The appropriate global vectors from the motion estimator are passed onto the unsteadiness corrector for processing, before local area scratch and dirt removal and spatial noise reduction. The final step is motion compensated recursive noise reduction, which requires high quality forwards and backwards motion vectors in order to work correctly. If these vectors are not provided, then processing stops at the output of the spatial

filter.

The accurate prediction of motion between successive fields (or frames in film) is a key element in picture construction, especially where large areas of a frame are missing. Without this technique, blurred images and aliasing would soon become a problem and introduce a new array of faults into the archive material.

One of the AURORA partners already had considerable experience of the Phase Correlation technique (1) and this was imported as a subsystem to the AURORA hardware. The system is actually a combination of two methods of motion estimation: broad movement measurement and pixel-by-pixel measurement, which have been combined to give the most accurate picture repair.

The noise reduction unit and the unsteadiness and flicker unit both make use of motion estimation in their processing chain.

## The Prototype Unsteadiness And Flicker Unit

### Unsteadiness.

Picture unsteadiness can be detected from global motion vectors derived from phase correlation and corrected by shifting the picture so that it appears steady.(2) The picture is also enlarged slightly to prevent picture edges becoming visible.

### Amplitude flicker

Low frequency flicker from both film and TV cameras will have the same intensity in both fields, so a correction algorithm was developed to globally correct the intensity across each frame.(3)

The misalignment caused by twin lens effects can be corrected by identifying motion vectors from the

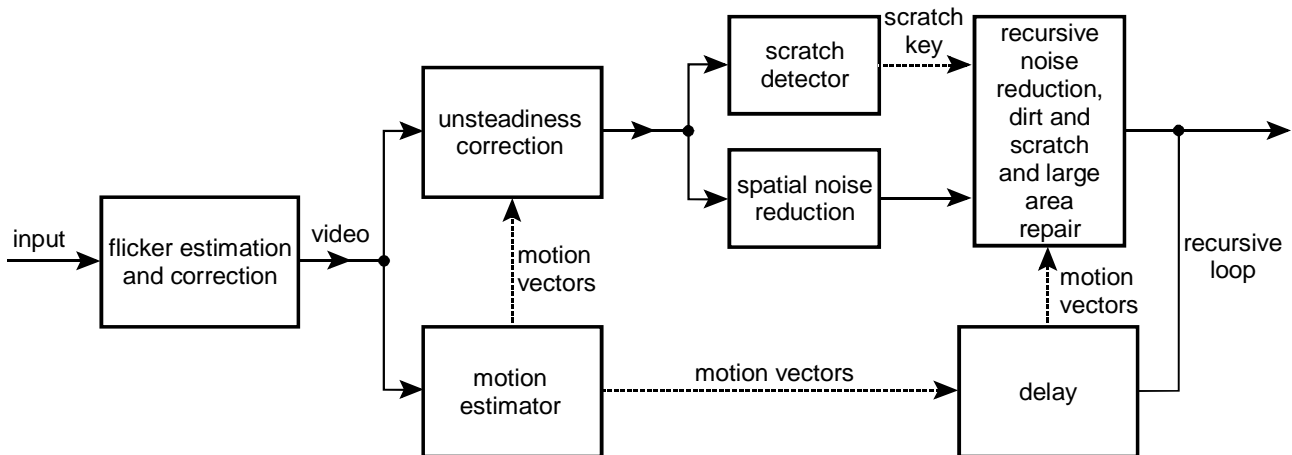


Figure 1 - Block diagram of the real-time restoration units

inter-*field* displacements, and then fitting a surface to each of the fields which describes the spatial variation of the vectors, while the brightness variation is corrected as for amplitude flicker.(4)

## **The Prototype Noise Reduction Unit**

### **Recursive noise reduction**

The recursive noise reduction hardware performs an average on a sequence of fields from the past, present and future.(5) Normally this highly effective technique can only be used when the motion of objects between frames is very small or minimal, but motion compensation allows it to be used in many more situations. Large missing areas or entirely missing frames or fields do not, however, provide a full set of forwards and backwards motion vectors, and for this case a non-temporal spatial noise-reduction system is required.

### **Spatial noise reduction**

Spatial noise reduction takes place using wavelets, which is an effective method of noise reduction, although it does not perform as well as recursive noise reduction. Filters based on this principle, such as median filters, are readily available, but could always benefit from improvements.

The spatial filter used in this project works by decomposing the picture via convolution with a wavelet transform function and use of low- and high-pass filters into a series of components containing low and high frequency information. The highest frequency components are generally noise and their removal does not result in a significant loss of detail from the image. The relevant frequency ranges are removed by use of a 'coring' or thresholding function, before the picture is reassembled.

This system has the major advantage that it does not require motion vectors and works on one frame at a time, but it does not give the same level of noise reduction as the recursive noise reducer. The output from the spatial filtering system forms part of the input to the recursive noise reducer, and when the motion vectors cannot be used, then the output from the spatial filter passes through the unit unchanged.

### **Large area reconstruction**

Large area reconstruction techniques are used for dirt, scratch and large drop-out removal.(6) They are usually performed by motion compensation followed by temporal interpolation.

Dirt detection is performed in real-time for a variety of blotch sizes on individual frames. All the edges in the picture are flagged, then single pixel blemishes

deleted by replacing them with the average of the surrounding pixels, first having ensured that there are no edges present. False alarms are triggered if the activity of the region does not change significantly after the operation.

Dirt detection can also be performed using the recursive noise reducer.

Scratches have very different properties to dirt. As they usually persist for more than one frame, they are not temporal discontinuities and cannot be treated as such. A scratch is not curved and it is assumed to extend across the entire vertical height of the frame. To detect scratches, which possess characteristic sidelobes, the image is vertically subsampled in order to suppress noise and enhance vertical line features. The signal is then thresholded and the candidate lines flagged. False alarms can be caused by vertical, straight and narrow objects such as railway lines and telegraph poles, and those incidents which are not false alarms are removed by spatial interpolation.

## **COMPLETE SYSTEM**

As mentioned earlier, there will always be parts of the material that cannot be adequately restored by the hardware and must therefore be processed in non real-time, requiring manual intervention. Part of the function of the hardware is to flag these portions so that the operator's attention can be drawn to them. They may then be processed according to a restoration plan, dependent on the information from the flags.

The processing in non real-time will be carried out on a work station, taking its input from a disk server and writing its output to another. The disk servers, in turn, will interact with digital video tape recorders which will form the primary input and output of the system. So the control of the devices and the routing of the signal between the real-time hardware units, servers and VTRs will amount to a further function of the work station.

## **ASSESSMENT OF THE SYSTEM**

Once a system has been designed it is important to know how well it works. Part of the AURORA work plan therefore includes assessment which will comprise two separate exercises.

The first exercise will involve a series of subjective tests, conducted with non-expert observers. The tests have been designed in co-operation with the EBU TAPESTRIES group and will comprise both double stimulus and single stimulus varieties. In the first variety, material will be processed that contains

predominantly a single kind of artefact whereas, in the second variety, combinations of artefacts will be allowed and the material will be longer.

The second exercise will seek the views of expert users by allowing them to work with the equipment, processing many hours of material. Reactions will be fed back to the system designers to help improve the prototype.

## CONCLUSION

This project, due to complete in late 1998, aims at producing and evaluating prototype hardware. It is hoped that the overall performance will significantly advance that currently commercially available and lead to the next generation of archive restoration equipment with the significant advantage of close-to-real-time cost effective processing.

The final phase of the project will be to undertake restoration trials by three broadcasters using a wide range of damaged archive material.

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