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Abstract:
The BRAVA project aimed at developing further the results of the AURORA project, to ensure the widest possible access to valuable archive material by significantly enhancing the efficiency of the video and film programme restoration process and preparing the restored material for dissemination via multi-resolution digital video broadcasting standards. The project results were expected significantly reduce the cost of broadcast archive restoration.

The Project achieved significant improvements in the domain of algorithms for digital restoration of image sequences.
The most promising results were implemented in a Real-Time Restoration Unit : the Archangel system. Other algorithms, more difficult to implement in real-time, were implemented as software plug-ins for Adobe Premiere. All the results of the Research are summarised in an internal document : the Final Research Report, that is available to all partners as a source for further developments.

The integration of the results into a functional environment was realised for two different exploitation modes : the tape-To-Tape Restoration system exploited the best of the Real-Time restoration Unit, giving the operator a fine-grained control on the restoration process through a dedicated Real-Time Control software tool, developed by INA and SGT. This system is now in exploitation both in INA and RTP, and gives satisfaction.

In addition to the tape-to-tape exploitation mode, an advanced trials was realised in a Disk--to-Disk exploitation mode, in an attempt to combine in one environment the best of Real-Time restoration tools (Archangel + Real-Time Controller), with the best of non-linear editing tools (timeline edition, access to individual pictures for fine-grained repair). This system was assembled and demonstrated during the summer of 2002 in INA, and although it is not exploited yet, it is considered that this new mode of exploitation will become predominant in a few years.

The present document is the **Final Project Report** of the Brava Project.

Keywords: Broadcast Archives, Video Restoration, Audio Restoration, Integration,

* Type : P-Public, R-Restricted, L-Limited, I-Internal
** Nature : P-Prototype, R-Report, S-Specification, T-Tool, O-Other

Note : This Deliverable is for Public Use.

1. Project overview

The Brava Project was supported by the European Commission within the Framework of the first Call of the IST (Information Society Technologies) Programme. The project was coordinated by Institut National de L'Audiovisuel , in partnership with Snell&Wilcox, leader in the domain of high-end video equipment, other broadcast archive owners (RTP), Universities (TU Delft, TCD Dublin), SGT.

The project aimed at developing tools for digital restoration of large amounts of broadcast archive documents (video and film), and for re-exploitation purposes. The project built upon earlier developments realised within the framework of the AC072 Aurora project.

The Brava project was of considerable importance for the preservation of the European cultural heritage. It was organised in tight relationships with the broadcast archive users. It provided tools for re-exploiting the huge archives programme stocks available from archives such as INA, RTP or RAI.

The effort was oriented towards restoration of archive programmes, up to the 'broadcast' quality level. This will provide the missing link to supply the emerging programme streams and bases with a complete range of programmes of multiple sources.

During the whole life of the project, a large Research group, composed of INA, S&W, RTP, TUD, TCD, addressed the numerous challenges posed by the exploitation of broadcast archive documents : film dirt and scratches, video drop-outs, flicker and unsteadiness, moiré, jitter, echoes…

The most promising results were implemented by Snell&Wilcox in a Real-Time Restoration Unit : the Archangel system. Other results, more difficult to implement in real-time were implemented as software plug-ins for Adobe Premiere. All the results of the Research are summarised in an internal document : the Final research Report, that is available to all partners as a source for further developments.

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2. Project objectives

The continuing explosion in the number of broadcast, satellite and cable channels in operation, coupled with the current development of video on demand, video and DVD publishing, and multimedia services, are creating an insatiable demand for programme material. This demand has made European broadcasters, archivists and film makers the custodians of a huge wealth of moving picture archive material. But the level of exploitation of moving picture archives is currently limited by the high cost and lengthy processing time required to restore archive material to meet the expectations of viewers. Efficient and cost-effective restoration is hence a key to large-scale

exploitation of television archives, such exploitation being itself necessary to guarantee the preservation of the audio-visual heritage.
Documents stored as 35mm or 16mm film are very often affected by deterioration due to ageing and/or improper storage and handling conditions. When transferred to 4.2.2 digital video, the full-bandwidth broadcast-quality format, the quality of the copy is very often unsuitable for direct exploitation.
Programmes stored on video tapes are prone to the same problems, but there is the additional complication that the video storage formats have become obsolete. It is generally difficult to maintain the playing equipment in good working order and it is sometimes almost impossible to find replacement parts. In consequence, artefacts resulting from difficulties in playback often affect the programmes.
In both cases, it is however possible to address these impairments in the video domain, after playback. The ACTS AC072 AURORA project succeeded in proving that it was technically possible to raise the quality and efficiency of the digital restoration of archive programmes. However progress was still needed in the automation and efficiency of the restoration process, coverage of the wide range of common defects, quality of the results, and HD video processing.

The BRAVA project aimed at developing further the results of the AURORA project, to ensure the widest possible access to valuable archive material by significantly enhancing the efficiency of the video and film programme restoration process and preparing the restored material for dissemination via multi-resolution digital video broadcasting standards.

The key objectives for the project were :

- To develop high-level analysis tools which are capable of analysing the image and optimising the restoration process by controlling each of the individual stages used in the restoration.
- To develop real-time prior-to-restoration content analysis software tools for archive material to report on quality and necessity of restoration process.
- To develop a working hardware/software test bed, which would become a prototype system demonstrator to show and evaluate the equipment and software tools created in the project.
- To explore the possibility of preserving more of the original film bandwidth by scaleable high-resolution techniques and up-sampling to produce restored material suitable for high resolution display.
- To significantly improve on the AURORA equipment and processes in terms of restored picture quality, range of addressed defects, processing efficiency, fine-grained control, and image accuracy.
- To integrate audio restoration tools into the AURORA restoration system, and solutions for soundtrack restoration, with respect to audiovisual programmes specificities : real-time, coordinated processing, synchronisation problems, "sound holes", bandwidth problems.
- To develop software plug-ins for industry standards editing software tools..
- To perform large-scale trials of the resulting system using professional restorers in a working restoration environment.

The efficiency of video and film programme restoration process was to be enhanced by improving the control of the automated restoration system and by exploiting cues obtained from a real-time high-level video analysis tool. The purpose of the high-level analysis was to detect complex frame-to-frame changes in image contents that are likely to be misinterpreted by the automated restoration system. This would be achieved by taking contextual information into account using large spatial and temporal windows. Such an approach is necessary because the previous automated restoration system operated on a local pixel basis with a small spatial and temporal aperture.
Under certain circumstances, the limited aperture caused the restoration system to take poor decisions and thereby to introduce visually disturbing artefacts into the restored image sequences. By protecting the image regions indicated by the analysis tool, the introduction of visually disturbing artefacts

would be avoided. This strategy would significantly reduce the large amount of time spent manually removing artefacts resulting from system failure.

Europe's archives are vast and, due to their high costs, restoration suites are in limited supply. This means that the restoration suites must be deployed efficiently and only to those film and video documents that truly require restoration. Therefore, pre-analysis is necessary to determine what film and video is likely to benefit most from restoration, and how costly it will be. The second purpose of the high-level video analysis tool was to assess the quality of image sequences, complementing operator expertise. The assessment would be done by making an inventory of the impairments that affect an image sequence and by determining the severity of these impairments.

The project was to develop a prototype that would replace many of the current manual video and film restoration processes by providing real-time processing of a wide range of defects and have many automated features to provide restoration at or close to real time operation, hereby meeting the needs of professional archive restorers. This would be realised through the development of new techniques which would be evaluated on a hardware/software test bed.

3. Project results and achievements

The main Brava Project results are :
1) the Archangel Real-Time Restoration Equipment
2) the Real-Time Control software tool
3) the Integrated disk-to-disk Restoration system
4) Software Restoration Plug-ins
5) the Final research Report

These are described in the following pages :

3.1. 1) The Archangel Real-Time Restoration Equipment

The prototype test bed resulting from the BRAVA project has been further developed and is now available as a family of professional next generation products, aimed principally at broadcasters, archive holders and post production houses.

The major applications are for;
- **Broadcasters Re-mastering Material for Transmission**.
- **Programme Producers Using Archive Footage** – used for documentaries, historical series, natural history, travel, music etc
- **Broadcasters and Content Owners Re-mastering for DVD**.

The equipment is available in a number of formats dependent on application. All use Archangel Ph.C (Phase Correlation motion compensation) to give highest picture quality results.

- **Archangel Ph.C –** This equipment processes the full range of artefacts addressed in the BRAVA project. It comprises two 6U, rack mounting modules and processes the following signal features in close to real time working (typically around three times the running time).

Unsteadiness	Dirt	Linear Filter
Luminance flicker	Noise and Grain	Video Dropout
Tramline scratches	Two inch scratches	Non-linear enhancer
Multiband Spatial Filter		

- **Archangel Ph.C - Rollcall** – In addition to offering the full range of Archangel Ph.C features, this version is equipped with Snell and Wilcox Rollcall technology to enable remote working. The two processing modules can be located in a central processing area remote from the restoration desk.

- **Archangel Ph.C – Tangent Synergy Control System** - This system incorporates a Tangent Devices Synergy Control Panel, enabling users currently equipped with commercially available Tangent Synergy Control software to fully integrate Archangel into their existing control processing system.

Three "Cut down" versions of **Archangel Ph.C** are available. Each offering specific facilities enabling users not requiring the full range of restoration processing to access BRAVA technology at an affordable price;

- **Steadfast –** This 6U rack mounting module, processes global (full picture) unsteadiness and flicker artefacts.

Puritan – A 6U rack mounting module detects and compensates for random Noise and Dirt artefacts on a pixel by pixel, line by line basis.

Shakeout – A 3U module which detects and compensates for picture instability (such as camera shake) in video originated programme material.

3.2. 2) The Real-Time Control software tool

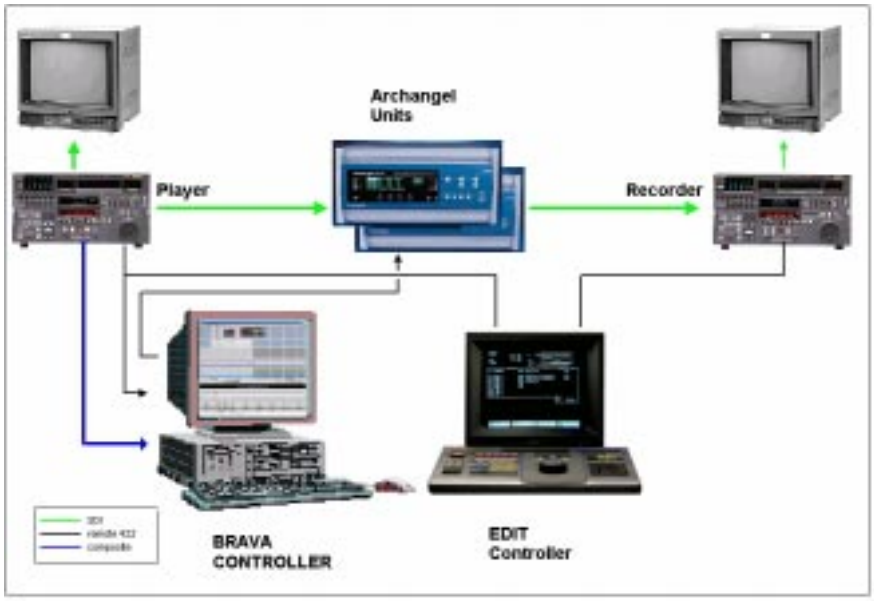
The **Real-Time Control Software tool** is a software control tool designed for controlling accurately the **Archangel Real-Time Restoration Equipment.** It is working on a Linux-based system, and can be inserted in almost any editing chain (tape-to-tape or non-linear). It gives to the operator a clear view on the source programme, with automatic shot detection and activity reports, and allows the user to prepare parameters for the **Real-Time Restoration Equipment** work**.** The **Real-Time Control Software tool** always knows the current position in the source programme, allowing the operator to apply his parameters settings from current position, to or from current or a specific shot, or between marks. From this point, each time the source position is changing, the parameters to be applied are sent to the **Real-Time Restoration Equipment** at the exact time, if necessary taking into account the delays.

In a separate mode, the same software tool can be used as an **Expert Evaluation software tool**, to assist an operator in preparing the work for the restoration process, and in evaluating the cost and the quality that can be reached. This software runs as a slave to a VTR trough Sony RS422 protocol or LTC timecode decoding. It runs a real time on the fly analysis of the parts of the programme that are played. The analysis tool extracts data from the images, in order to make the restoration step faster and easier. The operator can log down comments, take note of specific problems, and navigate freely

through the programme. The result of the expert evaluation session is a composite report, the operator's annotations, completed by an automated analysis. This composite report is directly available in the Real-Time Control operation mode.

In principle, all operations during the expert evaluation and the restoration sessions take place linearly. The operator plays the programme in real-time through analysis equipment during the expert evaluation session, and through processing equipment during the restoration session. In both sessions, the user-friendly graphical interfaces allow the operator to give easily on-the-fly instructions to the system. The system allows the operator to focus all his attention on the picture, not on the interfaces. However, at any time, the operator can stop the linear operations, come back to a specific point, change a setting or correct a problem, and resume operations.

The tape-to-tape Brava system described above was installed early October 2001 in a dedicated technical room, and the control tools (monitors, remote control for the BVE2000, display and control for the Real-Time Control software tool), were installed in the exploitation room. After verification that all the controls were performing correctly, the system was presented to the restoration operators in INA on 15/10/2001. Since then, improvements and adjustments were made, but the **Real-Time Control software tool** is considered to work satisfyingly, according to the operators themselves.

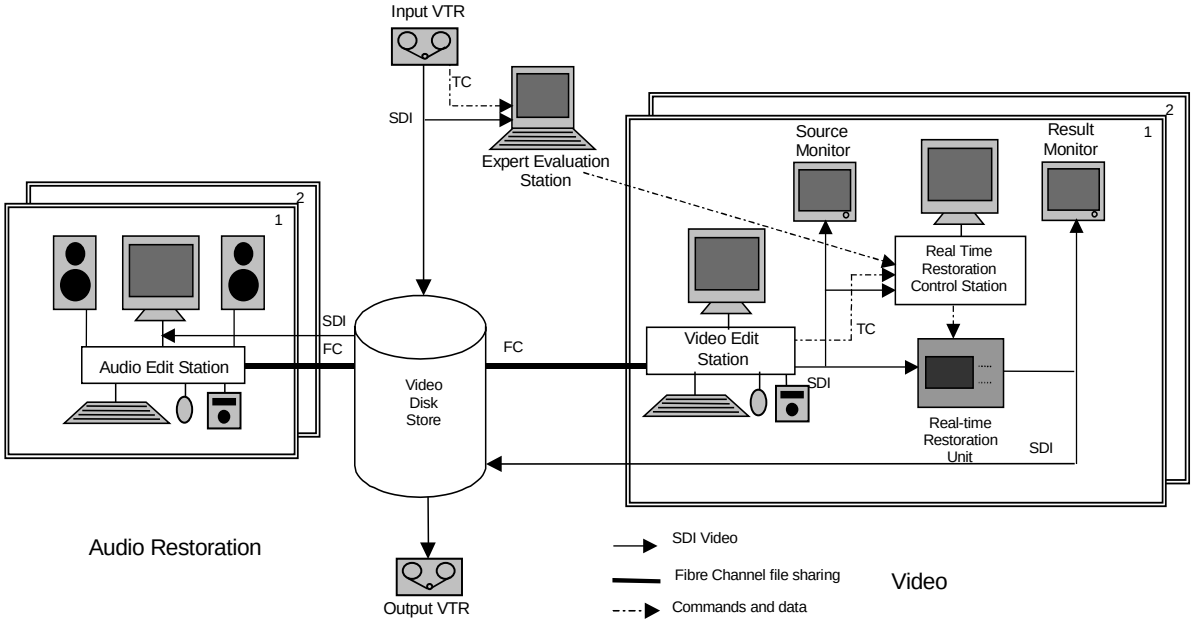


The Brava Real-Time Control in a tape-to-tape environment

3.3. 3) The Integrated disk-to-disk Restoration system

In addition to the tape-to-tape exploitation mode, an advanced trials was realised in a Disk--to-Disk exploitation mode, in an attempt to combine in one environment the best of Real-Time restoration tools (Archangel + Real-Time Controller), with the best of non-linear editing tools (timeline edition, access to individual pictures for fine-grained repair).

The **Disk-to-Disk Restoration System** runs in an environment summarised in the following diagram :



The principle is to replace the tape-to-tape editing system by a non-linear editing system, that additionally gives to the operator the following functionalities :

The **central media storage system** is a SAN (Storage Area Network) with a Thomson Nextore 4-channels video disk server. The programmes to be restored are imported as 50Mbps MJPEG files on the server. The SAN has a RAID cluster of 14 34-Gb disk drives (12+2 spares). The servers, the SAN controller, the Nextore server, the Edit Station, have Fibre Channel access to the storage. The files are accessible faster than real-time across the whole Fibre Channel Network.
The audio files are stores as uncompressed ".vaw" files (one per audio channel).
The restored programmes are also stored as files, before being recorded onto Digital Betacam tapes.
The different processes (loading, real-time restoration, video editing, audio restoration, off-loading), are able to run independently, on a non-exclusive file access basis.

The **Non-Linear Editing Station** is a **Discreet Edit** Station, which has Fibre Channel access to the files to restore. It gives the operator all the necessary tools for editing the programme, replacing damaged frames, or applying real-time tools such as crop, or basic colour control.
The **Combustion software** is integrated with the **Edit software**, which allows an easy selection of a short section of the programme for applying 'dust-busting' when necessary.

The **Audio Restoration Stations** are one **Protools** and one **AudioCube** stations, which have access to the audio ".vaw" files through the network. They can use their own audio restoration plug-ins, in addition to the ones that were developed in the framework of the Brava Project.

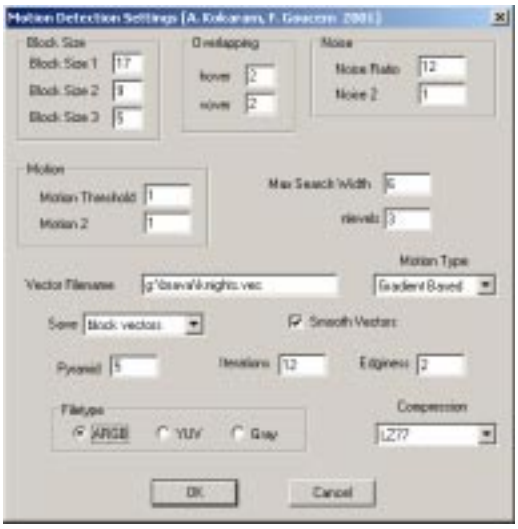
This system was assembled and demonstrated during the summer of 2002 in INA. The potential for such an organisation is clear, and was demonstrated. However it requires a fair amount of integration, and solving all the technical questions related to inter-systems communication requires additional effort. Therefore the system is not exploited currently as presented here, although it is expected to be further developed and used within a few years.

3.4. 4) Software Restoration Plug-ins

A number of software plug-ins have been developed at TCD during the course of the project. The platform chosen was Adobe Premiere. Premiere does not have a simple mechanism for allowing the user to interact with plug-in parameters and therefore considerable effort was devoted to allowing this capability. The list of plug-ins and their functionality are as follows.

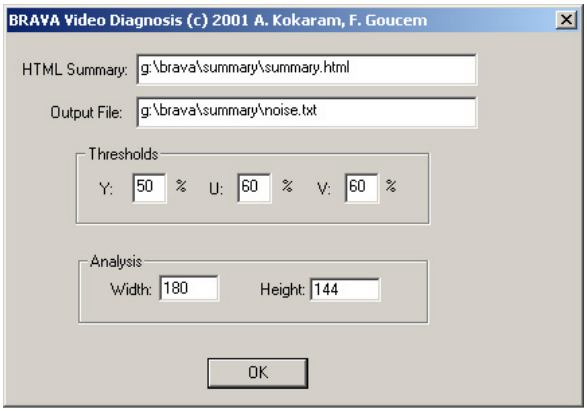
Motion Estimation

Many of the video processing algorithms in the suite of plug-ins need motion information of some sort. Since this remains one of the more computationally intensive aspects of restoration, an interesting proposition is to provide this module as a pre-processing step which can be done virtually without any user intervention. The module accepts a few simple parameters and implements a gradient based motion estimation scheme developed prior to BRAVA. A screen shot of the user GUI is shown opposite.



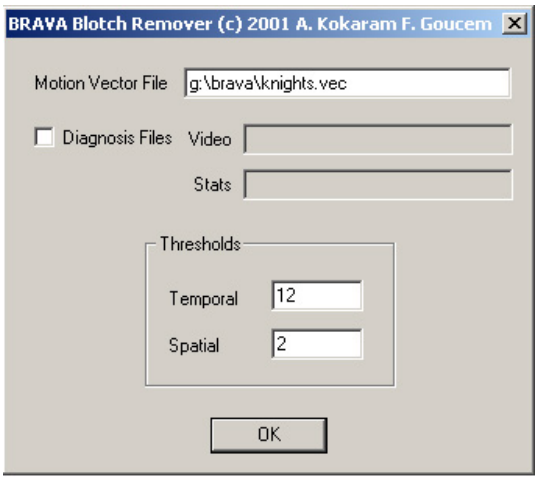
Diagnosis

This plug-in generates a shot list and indicates to the user which frames may contain high activity and therefore difficult to restore regions. Its output is an index generated in .html format that can be viewed in a web browser.



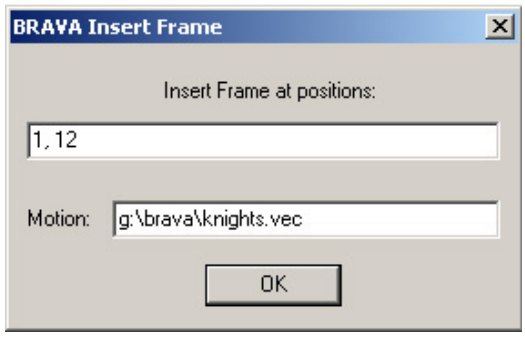
De-Blotch

This plug-in detects and removes blotches (Dirt, Sparkle). It uses a pre-generated motion file containing the motion information for a clip.



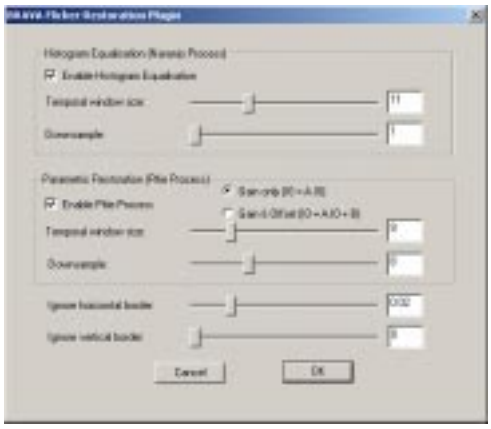
Frame Insert

This plug-in generates totally new frames to be inserted at sites indicated by the user. This may be necessary when Premiere has not captured data properly. It also required pre-generated motion information from the motion estimation plug-in.



De-Flicker

This plug-in estimates and removes intensity flicker. The user can select a simple or more computationally intensive algorithm. It does not require pre-generated motion information.

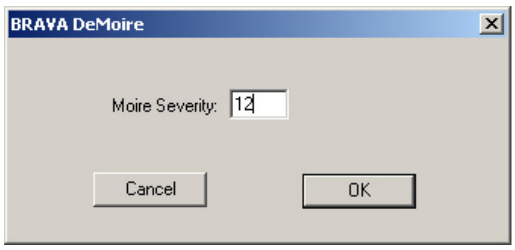


De-shake

This plug-in stabilizes shake in a particular clip. It uses pre-generated motion information and there are no user parameters since it copes well with a wide variety of translational shake.

De-Moire

This plug-in removes Kinescope Moire from a clip. There is only one parameter and no motion information is necessary.



3.5. 5) The Final research Report

This document reports on the research activity in the BRAVA project during February 2000 to September 2002. The intention is to formally outline the various strands of research activity in the project thus far. The report describes both diagnostic tools for archived image sequences as well as new techniques for addressing specific artefact problems. The first part of the document gives the

reader a coherent overview of the directions being examined and details are left for subsequent sections.

The BRAVA project concerns itself with the restoration of archived film and video. This implies the removal of a host of artefacts that affect archived material e.g. Dirt and Sparkle, Noise, Camera/telecine Shake, Flicker, Line Jitter, Moiré, Line Dropout, Dirty Splices and many more. The overriding goal is to create mechanisms that allow the **automated** restoration of the material. Traditionally, a block diagram of a restoration system would show a chain of modules that would address each artefact separately. Certain modules are fundamental to the operation of any image sequence process e.g. motion estimation. These could be shown as complementing the chain of restoration modules. The outer blocks of Figure 1.1 show what may be thought of as a traditional restoration chain. The expectation is that each module would operate autonomously. While this is in general realisable for a few modules, in reality this is a myth. Restoration remains a time intensive task despite the availability of automatic artefact reduction modules.
There are two reasons for this.
– The operator must select modules appropriate for the artefacts present in the sequence. This is because the modules may not necessarily always identify when their particular targeted artefact is present. Therefore using a moiré reduction module on a movie that has no moiré, could be risky in terms of final picture output.
– It is simply not possible to build modules for artefact suppression that incorporate image sequence models which account for all eventualities of object motion. Certain types of object motion e.g. movement of cloth, water, smoke, will always cause problems for a practically realisable motion estimation process.
This process is at the heart of many of the useful modules in the restoration chain and the failure of the motion estimator can cause drastically poor results later on in the chain. The restoration operator therefore copes with these shortcomings by choosing the right parameter settings as necessary, perhaps even on a shot by shot basis. Increasing complexity in the combination of image behaviour and artefacts leads to increased time spent in parameter setting. Of course, the majority of the sequence is likely to be processed without difficulty by the traditional restoration chain. However, it is that 5% of the sequence that shows ‘unpredictable’ behaviour, which occupies much of the operators time.
The project research therefore targets three broad range of activities as follows.
1. A principal goal is to design techniques which somehow insert the ‘restoration operator knowledge’ into the restoration chain. This implies being able to preview the sequence, perhaps at a very coarse resolution, and infer the areas of the image sequence that would cause most of the problems for the operator. Such a ‘diagnostic’ module would allow the operator to better predict the time needed to restore an hour of movie. The diagnostic engine would also be able to suggest the restoration modules that would be needed for treating a particular module and even parse the sequence into shots that could be treated with the same parameter settings. Each of these processes would reduce the operator time spent on the system. This idea of ‘Diagnosis for the Restoration Workflow’ is a major new concept and this document describes two pieces of work in the consortium that address the issue. The overall system might be thought of as indicated by figure 1.1 including the Diagnosis module at the core of the system.
2. The second area of activity is improved artefact treatment. There are links between this activity and the diagnosis work. The major effort in improved artefact reduction is in improved blotch treatment. This is because removal of blotches is a local operation that is highly dependent on the integrity of the motion estimator output. When this fails due to complex motion (called *Pathological Motion* in BRAVA), the subsequent removal process, which is essentially a cut and paste operation, causes serious picture damage. There are two avenues being followed in this respect and these are discussed later in the document.
3. Finally, the consortium has addressed three new artefacts: Moiré, Line Dropout and the problem of echo cancellation. The problem of Moiré is a very difficult one because it the process of degradation yields to a complex model. The issue of echo cancellation is applicable not only to archived media but

also to the area of image enhancement. The consortium has also addressed the problem of line jitter with a new dynamic programming approach.

Although the Final Research Report is not a public deliverable of the project, most of the results were published as conference papers : These papers are listed in section 10.2.2 Published Papers, but they are also available on Brava web site, http://www.ina.fr, 'Published Papers' page.

4. Methodologies

4.1. Workplan

The Brava Project started on Feb 1st 2000. The partners already knew each other, and had significant experience of collaborative work between them, because they had previously successfully completed together the AC072 Aurora project. The organisation of the work respected the standard User requirement - Specifications - Development -Integration -Tests Scheme, but was specific in that the User Requirements and System Specifications were developed in a very short time (5 months altogether). This is due to the fact that the User requirements and System Specifications could rely on the previous experience of the Aurora project, and that part of the effort was already available, such as test results, distortion reference documents and tapes, system layout. Given the relatively short duration for the project (initially 28 months), and the fact that the developments included hardware developments, it was inappropriate to plan for software prototyping. However, to reduce the risks, two prototypes were planned : one that would work in tape-to-tape mode, involving relatively simple integration, the other, working in disk-to-disk, much more complicated, involving integration of a large number of tools. Integration of the tape-to-tape system succeeded in time for the Tests to be performed. The disk-to-disk integration went up to the proof-of concept stage, but could not be fully tested before the end of the project, in November 2002. The Management, Research, and Dissemination workpackages ran in parallel, with frequent interactions, with this 'critical path'.

4.2. A strong Research group

Given the relatively short life of the project, it was unlikely from the beginning that all the research results would be available for implementation. However, the project already benefited from the knowledge developed in the framework of the previous Aurora project, which fed the development teams with useful results that could be implemented in real-time equipment, and as Plug-ins. Some of the research results from Brava were also incorporated, but it is considered more likely that these results will be available for future developments. The Research team meetings always also involved the development teams, resulting in a considerable cross-fertilisation. It is considered that a strong research team, as created during the Aurora and Brava projects, is an essential condition for the development of successful tools for restoration, during the project, and in the framework of future collaborative projects involving the same partners.

4.3. Real-Time

Among the objectives of the project, it was clearly stated that the project would have to deliver tools that could be used for restoring in real-time a wide range of different archive products. This requirement was not in the view of streamlined unattended restoration, but because the economics of the archive market limit considerably the viability of broadcast archive programmes restoration, if it requires too much operator time. Therefore, given that restoration is never instantaneous, the easiest path is to provide to the operator a direct feedback of the restoration, that will allow him, by trial and error, to set up properly the needed filters. As a consequence, it was clear from the beginning, that the core of the system would be a SDI in/out device, that would process directly the input on-the fly, with a minimal delay, and that this device, complemented with the appropriate real-time playback and recording systems, would allow the work to be done in a minimal amount of time. The development

exploited the best of the Aurora project results, and pushed it further in to a robust real-time processing system, exploiting on several electronic boards the best of the FPGA and DSP technology available. Given the considerable amount of computation to be realised, the grid computing, multiprocessing, vector processing approaches would have resulted in a much more complex and unreliable system.

4.4. Integration

The best real-time black box is never as clever as to be run unattended. Therefore the means of controlling the restoration process were to be given to the operator. The strategy here was to provide the operator with the suitable tools for controlling the source and recorder, and the behaviour of the real-time equipment. It was planned from the beginning to put considerable effort on the integration steps, developing in software on a Linux real-time platform the suitable tools for controlling the process. The first integration step was achieved when a real-time tape-to-tape restoration system was finalised. This system was integrated and tested on the two user sites, RTP, and INA. The next step was to extend this effort towards a full disk-to-disk system, incorporating into the same environment a non-linear editing tool, a paintbox, the real-time restoration unit, the tools for controlling the restoration process, centralised SAN storage, and audio restoration tools. Although this effort did not result in a completely viable system, the effort continues towards this goal, and it is expected that this environment will be exploited in a near future.

5. European added value

It is clear that the developments realised within the Brava project could not have been realised without the strong support and the framework of a European project : the constraint of working together was rather an incentive, and resulted in a critical mass and a very successful cross-fertilisation that would have bee difficult to achieve otherwise. The constraints due to the deadlines imposed by the deliverables were also considerable inducements to work hard towards the achievements of the goals.

6. Exploitation

INA already consider that the international recognition of the success of the Aurora and Brava projects are already benefiting indirectly by bringing students, customers and visitors, to INA.
INA already exploit the prototype tape-to-tape system for restoring TV programmes for commercial exploitation. In that sense, INA have extended their commercial opportunities for archive exploitation, and reduced their costs by providing easier and better restoration of archive programmes.
As a developer, INA expect to distribute the real-time control software. The intention is to propose to customers a low-cost alternative to high-end restoration control tools. SGT are associated with INA with respect to commercial exploitation of the Real-Time Control software.

Snell and Wilcox is a privately owned company designing, manufacturing and marketing innovative high technology «State of the art» equipment. The company produces a wide range of professional broadcast and multimedia equipment, which it markets world wide covering all standard video formats. The company is committed to developing archive restoration products. A hardware product called «Archangel» is a commercial product derived directly from the BRAVA Test Bed. Several sets of this equipment are currently in daily commercial use. Close liaison is being maintained with these initial investors who are being supplied with hardware/software upgrades as appropriate. Other spin off developments called «Shakeout» and HD-Prefix are also benefiting from the effort pursued in the framework of Brava and are now commercially available.

As a User, RTP already exploit the prototype tape-to-tape system for restoring TV programmes for commercial exploitation. The research effort produced by RTP also opened the way to establishing a RTP R&D centre, with collaborations with the Brava partners.

As a University partner, the major benefit of TU Delft has been on the advancement of research through publications in the open literature. The PhD defence date of one of TU Delft researchers in the BRAVA-project has been scheduled for September 2003.

TCD are intending to work on three principal possibilities for exploitation. In one route TCD markets and exploits the plug-ins by dealing directly with end users. In an alternate route, TCD licences the technology to one or more entities in the post-production or broadcast market. The third route is to act as a consulting shop for restoration of specific, difficult problems encountered by the larger post-production houses.

7. Conclusions

It is considered that the Brava project was very successful. The extensive research effort in the field of video and audio restoration has produced considerable results, which were incorporated in successful commercial products for real-time restoration. The advanced experiment of using external Real-Time restoration tools in a non-linear editing environment demonstrated that the concept was viable, and although the system is not used in this exploitation mode currently, a downscaled version running in tape-to-tape mode is exploited daily for restoring archive programmes. Other outcomes are restoration plug-ins, and a Final Research report, that will be used by the partners as a reference guide for future developments.

The project produced numerous valuable research results, as attested by the high number of papers produced, resulted in products which are already, or will be soon, delivered on the market, and gained a high visibility in the direction of the broadcast industry.
All these results could not have been possible without the support of the Commission through the IST programme, and without a clear challenge posed to a group of motivated partners, through one focused project.

8. Annex:

8.1. Deliverables and References

Del. no.	Deliverable name	Lead participant	Del. type	Security*	Date
D1	User Requirements	INA	Report	Rest.	**1/4/2002**
D2	WEB site + Project Presentation	INA	Report	Pub.	**4/8/2000**
D3	System Specifications	INA	Report	Rest.	**7/7/2000**
D4	Dissemination and Use plan	Snell	Report	Int.	**12/9/2000**
D5	Detailed Software Specifications	INA	Report	Int.	**21/12/2000**
D6	Detailed Real-Time Specifications	Snell	Report	Int.	**12/4/2001**
D7	Software Prototype	INA	Proto.	Rest.	**15/10/2002**
D8	Real-Time Test Bed Prototype	Snell	Proto.	Rest.	**1/12/2001**
D9	Integrated Restoration Prototype	Snell	Proto.	Rest.	**30/6/2002**
D10	Final Research Report	TCD	Report	Int.	**26/11/2002**
D11	Final Evaluation Report	RTP	Report	IST	**21/2/2003**
D12	Final Project Report	INA	Report	Pub.	**21/2/2003**

**Int.* *Internal circulation within project*
Rest. *Restricted circulation list and Commission Project Officer only*
IST *Circulation within IST Programme participants*
FP5 *Circulation within Framework Programme participants*
Pub. *Public document*

8.2. Print and electronic material illustrating the results

8.2.1. Web site

The Brava project public web site is http://www.ina.fr.
The web site contains - a list of partners, a list/dictionary of impairments, a list of downloadable publications resulted from Brava, links to other restoration site, etc…

8.2.2. Published Papers

8.2.2.1. 2002

Anil Kokaram and Simon Godsill. *MCMC for joint noise reduction and missing data treatment in degraded video*. IEEE Transactions on Signal Processing, Special Issue on MCMC Methods, pages 189-205, Vol 50, Number 2, Feb. 2002.

Anil Kokaram, *Parametric Texture Synthesis for Filling Holes in Pictures*, IEEE International Conference in Image Processing (ICIP), September 2002

Anil Kokaram, *A Statistical Framework for Picture Reconstruction using AR Models*. European Conference of Computer Vision in the Workshop on Statistical Methods for Time Varying Image Sequences, Copenhagen 2002,

Anil Kokaram, *Practical MCMC for Missing Data Treatment in Degraded Video*. European Conference of Computer Vision in the Workshop on Statistical Methods for Time Varying Image Sequences, Copenhagen 2002

Anil Kokaram, Raphaël Bornard, Andrei Rares, Denis Sidorov, Jean-Hugues Chenot, Louis Laborelli, Jan Biemond, *Robust and Automatic Digital Restoration Systems: Coping with Reality*. International Broadcasting Convention (IBC), Amsterdam 2002.

Raphaël Bornard, Emmanuelle Lecan, Louis Laborelli, Jean-Hugues Chenot, *Missing Data Correction in Still Images and Image Sequences*. Accepted for presentation, ACM Multimedia 2002, Juan-les-Pins, France, December 2002.

Raphaël Bornard, *Mouvements pathologique et détection de défauts impulsifs en restauration d'archives*, RFIA 2002 ("Reconnaissance des Formes et Intelligence Artificielle", Pattern Recognition and Artificial Intelligence), Angers, January 2002, vol 2, pp 567-576.

Andrei Rares, Marcel J.T. Reinders and Jan Biemond, *Image Sequence Restoration in the Presence of Pathological Motion and Severe Artifacts*, Proceedings of the 2002 IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP 2002)
Andrei Rares, Marcel J.T. Reinders and Jan Biemond, *An Algorithm for Spatial Restoration of Image Sequences*, Proceedings of the Eighth Annual Conference of the Advanced School for Computing and Imaging, (ASCI) 2002
Andrei Rares, Marcel J.T. Reinders, Jan Biemond and R.L. Lagendijk, *A Spatiotemporal Image Sequence Restoration Algorithm*, Proceedings of the 2002 IEEE International Conference on Image Processing (ICIP), September 2002
Andrei Rares, Marcel J.T. Reinders and Jan Biemond, *Restoration of Films Affected by Partial Color Artefacts*, XIth European Signal Processing Conference (EUSIPCO 2002), September 2002
Denis N. Sidorov and A.C.Kokaram *Suppression of moiré patterns via spectral analysis*, in Visual Communications and Image Processing 2002, Editor C.-C. Jay Kuo, Proceedings of SPIE, Vol 4671, pages 895-906.
Denis N. Sidorov and A.C.Kokaram, *Removing Moiré from Degraded Video Archives*, XIth European Conference in Signal Processing (EUSIPCO 2002), September 2002

8.2.2.2. 2001

Anil Kokaram, *Advances in the Detection and Reconstruction of Blotches in Archived Film and Video*, Proceedings of the IEE seminar "Digital Restoration of Film and Video Archives", Savoy Place London, 16 January 2001,UK ISSN 0963-3308-REFERENCE NO: 2000/110
Andrei. Rares, M.J.T. Reinders, J. Biemond, *Statistical Analysis of Pathological Motion Areas*, Proceedings of the IEE seminar "Digital Restoration of Film and Video Archives", Savoy Place London, 16 January 2001,UK ISSN 0963-3308-REFERENCE NO: 2000/110
Andrei Rares, Marcel J.T. Reinders, and Jan Biemond. *Complex event classification in degraded image sequences*. In Proceedings of the 2001 IEEE International Conference on Image Processing (ICIP 2001), October 2001.
Andrei Rares, Marcel J.T. Reinders, and Jan Biemond. *Classification of complex event regions in old movie material*. In Proceedings of the Seventh Annual Conference of the Advanced School for Computing and Imaging, pages 175-181, May-June 2001.
Andrei Rares, Marcel J.T. Reinders, and Jan Biemond. *Motion-based analysis of fast-changing image content*. In Proceedings of the Twenty-Second Symposium on Information and Communication Theory in the Benelux, pages 197-204, May 2001.
(contribution) L. Joyeux, S. Boukir, B. Besserer, O. Buisson, *Reconstruction of degraded image sequences*. Application to film restoration, Image and Vision Computing, ISSN : 0262-8856, Volume : 19, Issue : 8, 01-May-2001, pp 503-516, http://www.elsevier.nl/PII/S0262885600000913
Stuart M. Sommerville, *ARCHANGEL Automated Real-Time Archive Restoration*, Proceedings of the IEE seminar "Digital Restoration of Film and Video Archives", Savoy Place London, 16 January 2001,UK ISSN 0963-3308-REFERENCE NO: 2000/110

8.2.2.3. 2000

Andrei Rares and Marcel J.T. Reinders. *Object tracking by adaptive modelling*. In Conference Proceedings of the 2000 IEEE International Conference on Image Processing (ICIP 2000), volume 3, pages 74-77, September 2000.

8.2.3. Public Presentations

Jean-Hugues Chenot, Brava: Integrating broadcast archive restoration into post-production environments, IBC'2001, 16 September 2001.
Jean-Hugues Chenot, Brava: Integrating broadcast archive restoration into post-production environments, Preservation Workshop, .BBC TV Centre, 22-24/5/2002.
Brava was presented at the public during convention IBC'2002, both in a stand offered by IBC in New Technology Campus, and on Snell&Wilcox's stand. Anil Kokaram presented simultaneously a joint paper on the Brava project : Robust and Automatic Digital Restoration Systems: Coping with Reality.

8.2.4. Printed material

'Rotten-Not Rotten' Archangel brochure
'Rotten-Not Rotten' Archangel DVD-ROM
The Brava Controller : leaflet distributed during IBC'2002