Signal Ingest in Uncompromising Linear Video Archiving: Pitfalls, Loopholes and Solutions.

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Abstract.

Digital repositories are confronted with numerous organisational, technical and workflow-related problems on the preservation and the access part of their mission. On the technical side, there are many small, sometimes overlooked issues that define the qualitative outcome of the archive's tasks. Two typical examples will be analysed.

We are facing a considerable amount of slowly deteriorating analog video footage of scientific content, located worldwide at academic institutions under more or less acceptable storage conditions. Immediate treatment of this material is a prime goal of many archives. However, a successful transfer to the digital domain - the only widely accepted method to save the content for future generations - requires advanced hardware both for the digitisation process and for the transfer to the final storage media. Errors introduced during the ingest process can easily multiply along the signal path, especially later on if extensive multidimensional signal processing, e.g. for extracting details, is applied. Critical components are the analog-to-digital converters and the synchronizing section of the input signal acquisition stage.

The playback devices - in most cases used equipment - should not be at the end of their life-cycle, and should be well serviced modules. This can become a major point of concern for archives, and sometimes requires substantial efforts to locate usable hardware and accompanying maintenance equipment or service manuals. All acquisitions usually have to be done under heavy budgetary constraints, therefore solutions based on low cost hard- and software are preferred. The presentation will outline an example established at the Austrian Phonogrammarchiv, and discuss its benefits and drawbacks.

Having finally set up a suitable environment for the signal ingest, scientific archives will always try to extract as much information as possible from the original footage. For video sources these activities will be focused mostly on tapes. Experiences have shown that there is always room for improvement when considering the best possible method of signal acquisition. As an example, the regular playback mode of U-Matic footage - a video format widely used at the university level two or three decades ago - leaves much space for an improved signal extraction. In theory it would be desirable to circumvent the built-in electronic circuits of the playback device since they combine the luminance and chrominance signal (this results in distortions of both components along the following analog processing path). A better solution would be a dedicated pickup circuit right at the video-playback head that enables an independent processing of both signals all the way to the analog-to-digital converters. This particular signal representation is much better suited for video and image processing, thus supporting future scientific research on the footage. It is worthwhile to ask for an optimised signal pickup now, even if the proper video- or image processing hard- and software is still to be developed.

The paper outlines the general guidelines for a uncompromising linear video archiving for analog signals and points out some of the more important key points for a future-proof ingest, as given in the example described above.

Introduction

The Phonogrammarchiv in Vienna was encouraged by its parental institution, the Austrian Academy of Sciences, to add video archiving to the already very successful operations of audio archiving done for almost a century. This led to a feasibility study that defined the organisational, technical and budgetary framework for the various tasks. After two years of introduction work these internal guidelines proved to be effective in most cases. However, some of the goals were quite difficult to achieve and some others still lack the implementation of prerequisites for their completion.

The paper describes the selection criteria for the hardware of one of the most critical modules - the ingest part of the capture station - and outlines the problems of digitisation on a typical example, the acquisition of a composite video signal of the popular U-Matic type video recorder. The latter represents a problem located and defined but not yet solved by the archive.

Digitisation

When considering signal ingest hard- and software, most of the smaller archives like the Phonogrammarchiv will be forced to do their calculations based on personal computers. The modular scheme of the system, the comparatively low costs of the basic system components and the large supply of add-ons will enable the archive to buy capable hardware, well adapted to the technical needs and in most cases within the financial boundaries. Unfortunately the software side of the package currently cannot keep up with the hardware modules with respect to the suitability for archiving purposes, so general purpose, partly adapted editing and backup software will be the only usable solution for archives for the foreseeable future.

When considering personal computers with their focus to consumer needs, one could easily be tempted to purchase items out of the large selection of multimedia add-ons, specifically video modules that offer great versatility and - on the first look - high performance with an off-the- shelf price unthinkable a few years ago. A closer look will soon reveal weak spots that might disqualify most of these add-ons for archival purposes. As always, when leaving the consumer market and head for higher levels of performance one has to accept an exponentially increasing price of these modules (then called "professional" or even "broadcast" devices). However, on the long run the goals set by the archival philosophy may justify the expenses.

On the road along the design process for a video capture station there will be a fork, leading either to a system for uncompromising linear and uncompressed signal representation, or to a processing station based on compressed signals. Following the linear path the costs will no doubt increase substantially, not only for the digitisation stages of the capture station but also for the hard disk arrays and other modules with follow-up costs, e.g. the storage system.

Ingest hardware

In any case - and partly in contrary to audio archiving - the basic performance of the personal computer must be close to the top level offered by the market, even when most of the time-critical operations are done by dedicated hardware, concentrated on the acquisition card.

It is the linear, uncompressed mode that requires expensive high speed processing modules on the acquisition card. On the other hand, being satisfied with compressed signals according to MPEG-2 standard or MJPEG derivatives (e.g. DVD or DV) - which should by no means be regarded as something unacceptable for most consumer purposes - would substantially lower the cost for processing and storage. The drawbacks for archives – mainly artefacts induced by the compressing algorithms - must be discussed before making any far reaching decisions that will set the value of the archived material for future processing.

Capture cards for personal computers are available in different configurations, both at the consumer and the professional level. We concentrate our discussion on cards offering analog inputs in addition to digital ones. Consumer cards will mostly provide analog inputs for composite video signals (luminance and chrominance, i.e. brightness and colour combined in one single signal) or Y-C signals (separated luminance and chrominance, but colour on one single signal path). Professional modules will also provide RGB inputs, also referred to as component signal representation, thus offering the highest possible quality by separately processing the primary colours, or a derivative called Y-UV, more popular on video systems and defined as a combination of the luminance signal and two difference signals calculated through a matrix by subtracting the luminance signal from the red and the blue component. Both types widely represent acceptably well (if not perfectly) the colour space perceivable by the human visual system and guarantee a better picture quality than composite or Y-C.

The most critical device within the digitisation circuits is the Analog to Digital Converter (ADC). Its technology and layout defines the accuracy of the conversion process. Various tests have shown that the human eye considers the 256 shades of grey levels delivered by an 8-bit ADC as an acceptable replacement for the continuous analog area between black and white within a video stream (this certainly does not hold for a still picture). Technically, a signal to noise ratio of 46dB is considered as a lower boundary for noise-free signals, a value theoretically achievable with ease for an 8-bit ADC, since the ratio of the video signal, measured peak-to-peak, to the average noise signal of an ideal 8-bit ADC is approximately 58dB.

Lowering the resolution of the ADC will lead to a "contouring" of areas originally varying in brightness in a continuous way, whereas the inherent resolution error of ADCs from 8-bit resolution upwards only appears as random noise, decreasing with higher resolution. This detect ability of noise or contouring also applies roughly to ADCs connected to the two signal lines of Y-C sources or the three lines of RGB (or Y-UV) devices.

Thus 8-bit ADCs are the lower limit for acceptable picture quality, at least theoretically. The technology to implement 8-bit converts varies widely, and so does the performance. The primary parameters of 8-bit ADCs for video processing (resolution, speed) create only minor problems for today's chipmakers. However, some of the more important specs (linear, monotone conversion; power consumption, temperature dependency) are still a challenge for the chip designer and influence strongly the development costs and the price on the market.

The acceptability limits mentioned above only hold if the performance of the 8-bit ADC is close to the theoretical limit. Unfortunately, some of the so called 8-bit converters used on low cost consumer conversion modules have - due to their technology or because of production tolerances - only 6 or 7 bits of actual resolution, with additional problems close to the upper speed limit and with very small input signals (also technology-related issues). But they offer very low cost and allow the production of complete acquisition modules for less than 200 Euros.

High performance 8-bit ADCs alone cost about the same, not to mention the costs for equally well selected operational amplifiers, filters or voltage references as supporting devices for these converters. Especially filters for separating the luma and chroma contents of the signal can be implemented in very different circuit topologies that range from simple low cost low- and high pass filters to complex trap or comb filters. These parts follow the same rules: a few cents for consumer devices that will do the job in some way or the other, tens or hundreds of Euros for high performance parts.

Therefore it is no surprise that video acquisition cards with analog inputs start at about fifty Euros for low cost consumer purposes and end up in the higher ten thousand Euros area for modules with high resolution converters (up to 14 or even 16 bits).

It does not make much sense for a small archive to look for converters offering more than 8 (real) bits of resolution as long as the archive is absolutely sure that there will be no further processing of the footage. The Austrian Phonogrammarchiv started with high grade 8-bit ADCs (cost for the versatile input module: around 14k Euros), well aware of the fact that, with additional funds available, an upgrade to 12-bit ADCs would be highly advisable. This philosophy partly came from some experience with audio signals, where new software enabled better signal processing when analog sources were sampled with the highest possible resolution (24 bits instead of the 16 bits dominating the first two decades of digital audio).

"If you want to extract the original signal, embedded in quite some noise, you have to know the noise as well, so do sample both as precisely as possible!"

Video processing software for scientific purposes, e.g. to extract details, still lags behind comparable audio tools, but that may change in the future. Thus preserving the video content as accurately as current technology allows is a worthwhile goal.

Converter upgrade modules sometimes are combined with another useful device for high performance sampling of analog video signals: a synchronizer that helps to adapt the digitising circuits to the occasionally less stable analog playback devices. The time reference components of the video signal (field and line change pulses) vary slowly, depending on the mechanical status of the playback device. Since most of the analog equipment used to playback older tapes has been heavily used (though - hopefully - regularly serviced) it is very likely that bearings and transport parts show some degradation, resulting in wow- and flutter-like disturbances (slow and fast changes of transport speed) and, as a consequence, in inconstant synchronising pulses. Specialised synchronizers do a better job in adapting the digital circuits to these sources than the rather simple modules on the add-on conversion cards. Usually, these external synchronizers also have additional sophisticated signal extraction filters, thus further maintaining signal quality before feeding it to the converters.

Professional converter/synchronizer modules usually are priced in the ten to twenty thousand Euro region. Costly, but possibly worth the expenses and therefore also on the shopping list of the Phonogrammarchiv in the foreseeable future.

It should be mentioned that the Phonogrammarchiv uses a high performance video measurement system to track possible errors introduced by older analog playback machines. Evaluation software was not needed so far, but since the archive is still in an introductory phase with respect to archiving analog sources, it may be necessary to add specific software (presumably developed in-house) to get some statistics and to set internal boundaries for the usability of the playback machines.

Signal extraction

Whereas the semiconductor industry is constantly developing better electronic devices and thus fulfilling the demands of the video industry in different ways, there are only very few companies that understand the needs of archival institutions with respect to specific problems connected with the digitisation of older analog recordings. This refers not only to the production of replacement parts for older playback machines, but also to new circuits to enhance certain tasks along the playback process. One of these tasks involves the pickup of the signal on U-Matic tape recorders. This recorder format has been popular in the seventies and early eighties. Though originally designed for consumer purposes, it proved to be reliable enough to become a favourite format at broadcasting stations. In Austria it has been used for scientific research at academic institutions, and so a considerable amount of footage rests unguarded under sometimes questionable conditions at different storage facilities, thus representing a potential archiving footage of substantial quantity.

U-Matic uses the colour-under scheme like most other analog consumer formats, where the luminance signal (originally located between DC and 5 MHz) is recorded on the tape by transferring it to frequencies above 2 MHz (and also by using frequency modulation, i.e. to represent different shades of grey by different frequencies rather than voltages), whereas the colour content originally modulated onto a carrier of 4,43MHz (European PAL system) is transferred to lower frequencies (627 or 924 kHz) with decreased bandwidth in accordance to the sensitivity of the human eye and the image processing characteristics of the brain. This signal processing scheme heavily relies on the stability of the transport mechanism within the recorder and the quality of the mixing circuits that shift the colour signal down to the lower frequency area and back to its original place. It should be kept in mind that the phase relation of the signal - that defines the hue of the colour - and the amplitude - as a measure of colour saturation - are prone to distortions along these processing steps. This is another good reason to use the synchronizers mentioned above, since they regenerate drifting or fluctuating signals with the help of internal short time storage modules.

Unfortunately, during playback these two signal components usually remain combined right from the pickup procedure of the video heads, are processed concurrently and partly by the same circuits along the signal path, and finally offered as a standard composite signal at the output connectors. Critical signal properties like colour amplitude and phase are slightly modified by this technique. Unwanted signal mixing, distortions and intermodulations may occur, deteriorating the signal quality and disturb later processing steps. The goal of the Phonogrammarchiv is to access a point close to the video head (possibly through the service connector of the recorder, if available) and to separate the two signal components for immediate digitisation. Further processing should be done completely on the digital level.

Circumventing part of the original electronic circuits in general is a critical task. The access to service manuals are a prerequisite for any improvements and is not always possible. However, the job is challenging and can make the difference between a reliable conventional standard playback procedure and an innovative way to access even more information about the signal on the tape (a tempting thought for archivists). One has to bear in mind that electronic circuits of the seventies, though significantly better than the first semiconductor circuits for tape recorders, still were based on conventional single transistors for amplifier stages. Modern, highly integrated operational amplifiers enable low-noise circuits that have a 10 to 20dB better signal/noise ratio and – in accordance to the calculations given above for the ADCs – add another 2 or 3 bits of usable resolution for the following converters.

Initial studies have shown the feasibility, but a possible research project has been put on hold, since a commercially available product doing exactly this job has been announced. Ideally, this device should extract the video content according to ITU-601 (4:2:2 sampling of Y-UV) or at least do a perfect sampling of an Y-C signal derived from the video recorder head signal.

Conclusion

Careful preservation of valuable analog video footage requires an analysis of the ingest procedure and an optimisation of the various processing steps along the signal path, including the ADC. The solutions will strongly depend on the budgetary frame and the future use of the footage. Generally, only the highest possible signal representation in the digital domain - the linear, uncompressed format (or a standardised lossless compression scheme) - will guarantee satisfying results if video or image processing algorithms are to be applied to the material.