The Vicentini sound archive of the *Arena di Verona* Foundation: A preservation and restoration project

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Abstract—**In the sound archive field, a long-term maintenance of the collective human memory in its original form is not sustainable. All physical carriers are subject to degradation and the information stored on such carriers is bound to vanish. Only a re-mediation action can prevent precious knowledge from being permanently lost. We present the first results carried out by a joint cooperation project between the University of Verona and the Arena di Verona Foundation, with the scientific support of Eye-Tech (Udine, Italy), which aims at establishing a HW/SW platform with the purpose of preserving and restoring the Vicentini archive of the Arena Foundation.**

I. INTRODUCTION

The opening up of archives and libraries to a large telecoms community represents a fundamental impulse for cultural and didactic development. Guaranteeing an easy and ample dissemination of some of the fundamental moments of the musical culture of our times is an act of democracy which cannot be renounced and which must be assured to future generations, even through the creation of new instruments for the acquisition, preservation and transmission of information. This is a crucial point, which is nowadays the core of the reflection of the international archive community. If, on the one hand, scholars and the general public have begun paying greater attention to the recordings of artistic events, on the other hand, the systematic preservation and access to these documents is complicated by their diversified nature and amount.

Since the paper used in 1860 (first audio recording by Édouard-Léon Scott de Martinville "Au Clair de la Lune" using his phonautograph) to the modern Blu-ray Disc, what we have in the audio carriers field today is a Tower of Babel: a bunch of incompatible analog and digital approaches (paper, wire, wax cylinder, shellac disc, film, magnetic tape, vinyl record, magnetic and optical discs, etc.) without standard playback systems able to read all of them. Be it in the analogue or digital domain, audio memories are stored on different types of carriers that are equally subject to a process of physical decay. In order to prevent the information from being eroded or completely erased, it is necessary to keep transferring the signal to new carriers.

As far as audio memories are concerned, preservation is divided into passive preservation, meant to defend the carrier from external agents without altering the structure, and active preservation, which involves data transfer on new media. Active preservation allows us to copy, handle and store the audio documents in virtual spaces that can be remotely accessed by large communities. Digitization is necessary to prevent the documents from disappearing, and it is desirable because it allows to distribute them on a wide scale. The commingling of a technical and scientific formation with historic-philological knowledge also becomes essential for preservative re-recording operations, which do not completely coincide with pure A/D transfer, as is, unfortunately, often thought. Along the years some guidelines have been sketched [1], [2]. The REVIVAL project is concerned with both passive and active preservation, although this paper focuses on the latter.

With its tens of thousands of audio documents, some of which extremely rare or even unique, the Vicentini archive of the Arena Foundation (Verona, Italy) has potential to gain highest cultural interest worldwide. In spite of this potential, a reconnaissance mission evidenced that a large part of the archive is at risk of vanishing, with a serious damage for the musical heritage existing in Europe: for this reason, a joint cooperation project (REstoration of the Vicentini archive In Verona and its accessibility as an Audio e-Library: REVIVAL) between the University of Verona and the

Arena Foundation, with the scientific support of Eye-Tech (Udine, Italy) started.

Sect. II describes the REVIVAL project objectives and the audio preservation/restoration laboratory created in Arena. After an overview of the Vicentini's archive in Arena Foundation (Sect. III), the first results of the project are presented: the audio preservation protocol (Sect. IV), the different approaches that can be adopted in the access copy (Sect. V) and an innovative audio restoration algorithm developed on purpose, i.e. for the particular characteristics of the Vicentini audio documents (Sect. V-A).

II. REVIVAL PROJECT

The devising of modern audio restoration operational protocols aims at avoiding the superposition of modernized phonic aspects during the re-recording procedures, which may distort the original audio content. This requirement is essential for a philologically correct preservation, that needs to be supported with all the knowledge that can be acquired with and aside the signal. This knowledge lies in the history of the compositional thought and of the musical technology connected with it. Audio preservation should be ascribed in the more general scientific field of musical analysis only when it is consistent with such principles.

Concerning REVIVAL, the first task was devoted to the development of an operational protocol specifically finalized to the preservation of the audio documents held by the Vicentini archive (described in Sect. IV). At the same time, a preservation/restoration laboratory was established at Arena Foundation, enabled by tape dryers and custom, non-invasive disc and tape players. An example of non-invasice player is the Photos of GHOSTS system [3], developed by the authors, able to extract audio data from recorded grooves of a shellac disc, acquired using an electronic camera. The images can be processed to extract the audio data also in the case of a broken disc. The software automatically finds the disc center and radius from the scanned data, then performs groove rectification and track separation. Starting from the light intensity curve of the pixels in the image, the groove is modeled and the audio samples are obtained. The equipment for the laboratory includes items for the editing, post-production, playing and recording, digital transfer, monitoring, and processing of audio documents as well as for the visual documentation of the whole preservation and restoration process. In the laboratory is used only open source software (often developed by the consortium), with clear advantages in quality, reliability, flexibility and cost. The selection criteria (of the audio documents to be A/D transferred) adopted trades off between:

1) original carriers in immediate danger of terminal decay;
2) documents in regular demand [4];
3) variety of carriers.

A project task focuses on the creation of preservation copies, destined to archive use, and finalized to the transmission of not only the audio, but also the information that characterizes the document together with the sound message (see Sect. IV). The creation of access copies (see Sect. V) provide means for access and prospective self-sustainability of the archive. Access copies will result from the application of novel audio restoration algorithms, developed on purpose (i.e. for the particular characteristics of the Vicentini audio documents). All the filters will be coded in C/C++ into VST plugins. A first result is described in Sect. V-A. By implementing advanced cultural engineering issues, REVIVAL in 2010 will design and prototype a on-line system for cataloguing and fruition of audio documents, allowing information sharing with the most important audio archives worldwide. Finally, tutorial sessions are regularly planned with permanent personnel working at Arena Foundation so as to ensure the transfer of skills and technologies along the project. This is necessary for further coverage of the results to the whole Arena archive, and for support to preservation programmes external to the Arena Foundation.

III. ARENA

In the summer of 1913, to celebrate the centenary of the birth of Giuseppe Verdi, the tenor Giovanni Zenatello and the theatre impresario Ottone Rovato promoted a lyrical festival in Verona: the Arena di Verona (Italy) became the biggest open-air lyrical theatre in the world, a supremacy it still holds today. In 1936 saw the light the *Ente Lirico Arena di Verona* (the autonomous organization for lyrical productions of Arena), which took the festival under its care, until it was transformed into a private law foundation in 1998, the Arena di Verona Foundation. Each summer, the venue keeps attracting an international audience - offering opera enthusiasts the best of a rich repertoire set in one of the most magnificent shells of ancient Roman ampitheatres.

A. *Fondo Vicentini*

In 2001 the heirs of Dr. Mario Vicentini donated to Arena Foundation a large sound archive consisting

Fig. 1. Some tape recorders in Vicentini archive.

Fig. 2. Some audio documents stored in Vicentini archive.

of tens thousands of audio documents stored on different carriers, hundreds of pieces of equipment for playback and recording (wire, cylinder and magnetic tape recorders, phonographs), bibliographic publications (including monographs and all issues of more than sixty music journals from the 1940's to 1999). Along with a history of the recording techniques documented through the carriers (from steel wire and wax cylinders to digital magnetic tapes), the archive traces the evolution of a composite genre such as opera, with an impressive collection of live and studio recordings (smaller sections of the archive consist of symphonic music and other classical genres). The estimated value of the archive is $2,300,000$ Euros. Figure 1 shows a small example of the equipments preserved by Vicentini. Figure 2 shows some audio documents stored in archive.

IV. REVIVAL PRESERVATION PROTOCOL

A reconnaissance on the most significant positions of the debate evolved since the Seventies inside the archivist community on historical faithfulness of the active preservation points out at least three different perspectives [5].

William Storm [6] individuates two types of re-recording which are suitable from the archival point of view: 1) the sound preservation of audio history, and 2) the sound preservation of an artist. The first type of re-recording (Type I) represents a level of reproduction defined as the perpetuation of the sound of an original recording as it was initially reproduced and heard by the people of the era. The second type of re-recording (Type II) was presented by Storm as a more ambitious research objective: it is characterized by the use of a different playback equipment than the original one, with the intent of obtaining the live sound of original performers, transcending the limits of a historically faithful reproduction of the recording.

Schüller [1] and (cited in) [7] points directly towards defining a procedure which guarantees the re-recording of the signals the best quality by limiting the audio processing to the minimum. He goes on to an accurate investigation of signal alterations, which he classifies in two categories: (1) intentional and (2) unintentional. The former includes recording, equalization, and noise reduction systems, while the latter is further divided into two groups: (i) caused by the imperfection of the recording technique of the time (distortions), and (ii) caused by misalignment of the recording equipment (wrong speed, deviation from the vertical cutting angle in cylinders or misalignment of the recording in magnetic tapes). The choice whether or not to compensate for these alterations reveals different re-recording strategies: (A) the recording as it was heard in its time (Storm's Audio History Type I); (B) the recording as it was produced, precisely equalized for intentional recording equalizations (1), compensated for eventual errors caused by misaligned recording equipment (2ii) and replayed on modern equipment to minimize replay distortions; (C) the recording as produced, with additional compensation for recording imperfections (2i).

George Brock-Nannestad [8] examines the re-recording of acoustic phonographic recordings (pre-1925). In order to have scientific value, the re-recording work requires a complete integration between the historical-critical knowledge which is external to the signal and the objective knowledge which can be inferred by examining the carrier and the degradations highlighted by the analysis of the signal.

Starting from these positions, REVIVAL defines the preservation copy as a digital data set that groups the information carried by the audio document, considered as an artifact. It aims at preserving the documentary unity, and its bibliographic equivalent is the facsimile or the diplomatic copy. Signal processing techniques are allowed only when they are finalized to the carrier restoration. Differing from the Schüller position, it is our belief that – in a preservation copy – only the intentional alterations (1) should be compensated (correct equalization of the re-recording system and decoding of any possible intentional signal processing interventions). On the contrary, all the unintentional alterations (also those caused by misalignments of the recording equipment) could be compensated only at the access copy level: these imperfections/distortions must be preserved because they witness the history of the audio document transmission.

The A/D transfer process should represent the original document characteristics as it arrived to us. According to the indications of the international archive community [2], [4]: 1) the recording is transferred from the original carrier; 2) if necessary, the carrier is cleaned and restored so as to repair any climactic degradations which may compromise the quality of the signal; 3) re-recording equipment is chosen among the current professional equipment available in order not to introduce further distortions, respecting the original mechanical analogies; 4) the sampling frequency and bit rate must be chosen in respect of the archival sound record standard (at least, 48 kHz / 24 bit, following the slogan: *the worse the signal, the higher the resolution*); 5) the digital audio file format should support high resolution, and should be transparent with simple coding schemes, without data reduction.

The process of active preservation, produces a particularly large and various set of digital documents, which are made up of the audio signal, the metadata and the contextual information (the term metadata indicates content-dependent information that can be automatically extracted by the audio signal; contextual information indicates the additional content-independent information).

In order to preserve the documentary unity it is therefore necessary to digitize contextual information, which is included in the original document and the metadata which comes out from the transfer process: the information written on edition containers, labels and other attachments should be stored with the preservation copy as static images, as well as the photos of clearly visible carrier corruptions. A video of the carrier playing – synchronized with the audio signal – ensures the preservation of the information on the carrier (physical conditions, presence of intentional alterations, corruptions, graphical signs). The video file should be stored with the preservation copy. The selected resolution and the compression factor must at least allow to locate the signs and corruptions of the support. The resolution of 320x240 pixels and a DV JPEG compression, with no more of 65% of quality is considered a satisfactory tradeoff by REVIVAL. In this way, REVIVAL uses metadata extraction methods to describe the carrier corruptions presented in [9].

Finally, a descriptive card (consistent with the database of the audio archive) with all the information on the A/D equipment used and the original document, will be stored in the preservative copy. In the case of phonographic discs the playback speed of the equipment (phonograph or electric turntable) is compared with Photos of GHOSTS [3], which is a useful reference because it is not subject to mechanical variations. The results are able to explain the pitch variations of the signal: this is a necessary metadata in the audio restoration task.

V. Access copy

Different approaches can be adopted in a combinated way with audio restoration algorithms, in accordance with the final purposes of the access copy:
1) Documental approach: in this case, the de-noise algorithms only concern the cases in which the internal evidence of the degradation is unquestionable, without going beyond the technological level of that time.
2) Aesthetical approach: it pursues a sound quality that matches the actual public's expectations (for new commercial editions).
3) Sociological approach: it has the purpose of obtaining a historical reconstruction of the recording as it was listened to at the time (see Storm, Type I).
4) Reconstructive approach: it has the objective to preserve the intention of the author (see Storm, Type II).

In this project, the authors are developing innovative algorithms, specifically dedicated to the restoration of the musical recordings stored in Vicentini archive, able to offer satisfying solutions to the problems connected with the time-varying feature peculiar to musical signals. The first algorithm developed, dedicated to the restoration of audio signal re-recorded from shellac discs, is described below.

A. A restoration algorithm dedicated to shellac discs

The most widespread techniques (Short Time Spectral Attenuation, STSA) employ a signal analysis through the Short-Time Fourier Transform (which is calculated on

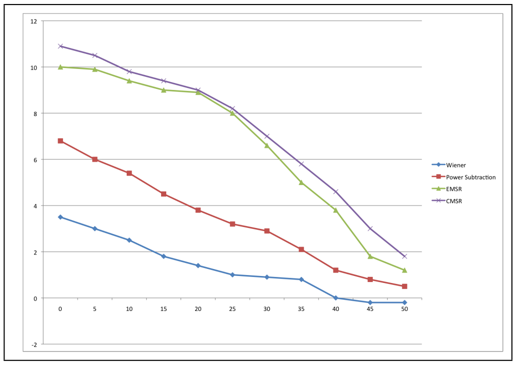

Fig. 3. Gain trend introduced by the filters in the frequency domain at the varying of the input SNR (SNR_{out}-SNR_{in} vs. SNR_{in} in dB). The best gain of the CMSR filter can be observed for all the SNR_{in}.

small partially overlapped portions of the signal) and can be considered as a non-stationary adaptation of the Wiener filter in the frequency domain. The time-varying attenuation applied to each channel is calculated through a determined *suppression rule*, which has the purpose to produce an estimate (for each channel) of the noise power. A typical suppression rule is based on the Wiener filter [10]: usually the mistake made by this procedure in retrieving the original sound spectrum has an audible effect, since the difference between the spectral densities can give a negative result at some frequencies. Should we decide to arbitrarily force the negative results to zero, in the final signal there will be a disturbance, constituted of numerous random frequency pseudo-sinusoids, which start and finish in a rapid succession, generating what in literature is known as *musical noise*.

More elaborated suppression rules depend on both the relative signal and on *a priori* knowledge of the corrupted signal, that is to say, on *a priori* knowledge of the probability distribution of the under-band signals [10]. A substantial progress was made with the solution carried out in Ephraim and Malah [11], aims at minimizing the mean square error (MSE) in the estimation of the spectral components (Fourier coefficients) of the musical signal. The gain applied by the filter to each spectral component doesn't depend on the simple Signal to Noise Ratio (Wiener Filter), but it is in relation with the two parameters Y_{prio} (SNR calculated taking into account the information of the preceding frame) and Y_{post} (SNR calculated taking into account the information of the current frame). A parameter (α) controls the balance between the current frame information and that of the preceding one. By varying this parameter, the filter smoothing effect can be regulated. Y_{prio} has less variance than Y_{post}: in this way, it is less probable that a musical noise occurs (see [11] for details).

Unfortunately, in the case of shellac discs an optimal value of α does not exist, as it should be time-varying (because of the cycle-stationary characteristics of the disc surface corruptions). Considering this, the authors have developed a new suppression rule (Canazza-Mian Suppression Rule, CMSR), based on the idea of using a *punctual* suppression without memory (Wiener like) in the case of a null estimate of Y_{post}. The pseudo-code is:

IF $Y_{post}\ (k,p) > 0$
  $\alpha = 0.98$
 ELSE
  $\alpha = 0$
END

The experiments carried out, confirm that the filter performs very well during the listening phase, with a noise removal decidedly better than the classic EMSR and the prerogative of not introducing musical noise, at least for $SNR \in [10 \div 20]$ dB (a typical value in the audio signal re-recorded from the shellac discs stored in Vicentini archive). Furthermore, the behavior in the transients is similar of the EMSR filter, without having the perceptual impression of a processing "low-pass filter" like. Figure 3 shows the gain trend introduced by CMSR in comparison with some standard filters (Wiener, Power Subtraction [10], EMSR) at the varying of the noisy signal SNR, considering 20 shellac disc recorded from 1910 to 1930[1]. The term gain indicates the difference between the de-noised signal SNR and the input signal SNR. For all input SNR, the CMSR has a good performance.

The audio alignment method described in [9] is used to compare the differences and similarities between the audio signals stored in the preservative copy and the restored signals. In this way, possible errors occurred in the audio restoration processing are automatically pointed out.

B. Experimental results

As a case study, we selected the double-sided 78 rpm 10 shellac disc Brunswick 58073, recorded in New York on February the 23rd 1928. We considered the song: Rosina Gioiosa Trubia, *Sta terra nun fa pi mia* (*This land is not for me*). Figures 4 and 5 show the (Welch) periodograms (about 15 seconds) of the signal, respectively digitalized by means of a turntable and a phonograph, and restored using CMSR. It can be appreciated that the spectrum of the restored version strictly follows the

[1] A characteristic sample of the archive

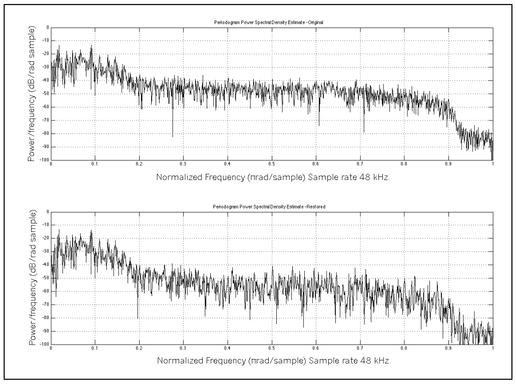

Fig. 4. Periodograms of the audio signals digitized by means of a turntable (top) and restored with CMSR (bottom).

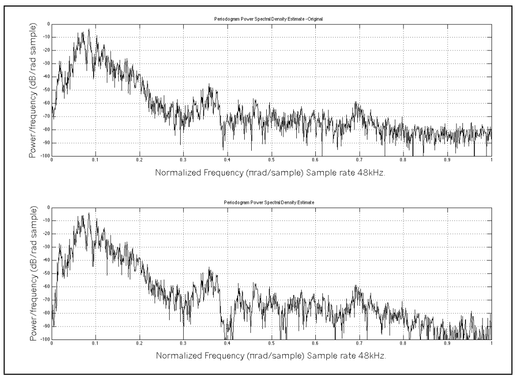

Fig. 5. Periodograms of the audio signals digitized by means of a phonograph (top) and restored with CMSR (bottom).

original one up to frequencies where the noise power density equals that of the musical signal. In addition, differently from what would be obtained with a simple low-pass filter or classical spectral subtraction methods, the restored version "follows" the musical spectrum even in higher frequencies. This aspect is perceptually important and it is appreciated by experienced listeners.

In particular, to use the CMSR to reduce the noise of an A/D transfer by phonograph could be a good approach to obtain a historical reconstruction of the recording as it was listened to at the time.

VI. Conclusion

With its tens of thousands of audio documents, some of which extremely rare or even unique, the Vicentini archive of the Arena di Verona Foundation has potential to gain highest cultural interest worldwide. In spite of this potential, a large part of the archive is at risk of vanishing due to the wear of time. The paper presented the REVIVAL (REstoration of the Vicentini archive In Verona and its accessibility as an Audio e-Library) project, which objective is to establish a HW/SW platform for i) preserving, ii) restoring, and iii) cataloguing the audio documents stored in the archive. Besides its musicological impact, the project aims at fertilizing synergies with national and international public and private bodies, interested in supporting as well as taking advantage of large-scale preservation programs.

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