New Technologies to Preserve and Access Historical Recorded Sound
June 2013

Background

Sound was first recorded in the 1850's by the French inventor Edouard Leon Scott de Martinville who mechanically captured sound waves and traced them on paper. His "phonautograph" was a mechanical precursor to the modern storage oscilloscope but originally featured no possibility for reproduction of the recorded information. Sound was first recorded and reproduced by Thomas Edison, in 1877. Edison also mechanically captured sound waves, but embossed the vibrations on a tin foil cylinder. The impressions lodged in the foil surface could then be used to drive the recording process in reverse, resulting in an audible playback. From that time, until about 1950 when magnetic tape came into broad use, mechanical media such as foil, wax, plastic, shellac, and lacquer were the predominate materials which held recorded sound. Today, vast collections of historical sound recordings reside in the major archives such as the Library of Congress and the British Library, and in numerous other collections at museums, libraries, and academic institutions worldwide. The recordings contained within these collections are broad, diverse, and of great historical significance. Among the categories held in these collections are the following.

- Field recordings of linguistic, cultural, and anthropological materials
- Primary recordings of key musical artists, poets, and writers.
- Recordings of sources which underlie much of modern music such as the American and European folk traditions.
- Speeches & spoken words of historical figures.
- Radio broadcast transcriptions.
- Live performances and events.
- Early technical tests and experiments on recording methods.
- Public and private dictation and monitoring records, intelligence, and Presidential sources.
- All commercial record releases

In numerous cases these records are physically compromised due to wear and age or are considered too delicate to play with normal means – contact with a phonograph stylus (needle). Archivists want to both preserve these recordings, to meet the needs of any future interest, and to create broad digital access to the collections. In recognition of this, the U.S. Congress enacted the **National Recording Preservation Act of 2000** "A bill to…maintain and preserve sound recordings and collections of sound recordings that are culturally, historically, or aesthetically significant…, " (Public Law 106-474; H.R.4846). Thus, recorded sound preservation is a matter of national policy in the United States. In this context, the Library of Congress is now operating the new National Audio Visual Conservation Center, Packard Campus, a state-of-the-art facility to hold and preserve its entire collection, located in Culpeper, Virginia.

The preservation challenge for mechanical recording media revolves around its fragility and pre-existing wear or damage. The access challenge is to find an efficient way to massively transfer hundreds of thousands of discs, or other media, to digital form. In Berkeley we are addressing both these challenges by applying non-contact optical technologies and data analysis methods to the digitization and restoration of historical recordings. This research has been recognized and supported by major public and private institutions with a stake in various aspects of recorded sound history and scientific research (listed at the end of the text). Optical methods protect the samples from further damage and can circumvent many aspects of pre-existing damage. These methods are readily automated and allow the offloading of many aspects of the transfer process to software. This can represent a viable mass digitization strategy.

The basic idea of the Berkeley approach is to create a high resolution digital map of the surface of the sound carrier (disc record, wax cylinder, etc.). Given this map, image processing methods can be applied to overcome the effects of wear or damage, and the stylus motion can be digitally emulated. By calculating the motion of a virtual stylus moving through the map the audio content can be reproduced.

The Berkeley technology makes use of the following methods, some of which are also evolving dramatically, as they are important for many other applications, both commercial and academic.

- <u>Electronic Imaging</u>: the use of photo-sensitive electronic sensors to acquire images and make them available to a digital computer.
- <u>Image and Signal Processing</u>: the use of computers to mathematically analyze and alter images and waveforms represented in digital form.
- <u>Optical Metrology</u>: the use of electronic imaging, image processing, and precision motion control to derive quantitative information about the size and shape of physical objects.
- <u>Machine Vision</u>: a set of processes utilizing electronic imaging, processing, and metrology methods to recognize, classify, and analyze the geometry of real objects.

For the application to audio reconstruction, the implementation of these methods is novel.

The advantages and key attributes of the optical recovery process can be summarized as follows.

- Delicate samples can be played without further damage.
- Effects of damage and debris (noise sources) can be reduced through image processing since they can be objectively recognized as not matching the known shape of the groove. Thus, these discrete noise sources are resolved in the "spatial domain" where they originate and need not be considered as random effects in an audio waveform.
- Scratched regions can be interpolated.
- Dynamic effects of damage (skips, ringing) are absent.
- The method is largely independent of record material and format – wax, metal, shellac, lacquer etc. can be measured with the same procedures.
- Classic distortions and systematic errors (wow, flutter, tracing and tracking errors, pinch effects etc.) are absent or removed as geometrical corrections.
- No mechanical method is needed to follow the groove.
- Certain broken samples can re-assembled and played back.
- The acquired image data can be used to analyze the physical condition and characteristics of the sample such as groove width, defect rate, and other statistical quantities.
- Optically scanned data can be analyzed and archived as simple digital sound files (.wav etc) just as in any normal audio transfer process. In addition, the high resolution digital images

can be archived as standard image data for future re-analysis. No special formats or media are required.

Recording Technology

There are two basic formats for historical sound recordings and these are explained in Figures 1 and 2. The earlier cylinder format used a groove which undulates vertically out of (normal to) the surface.

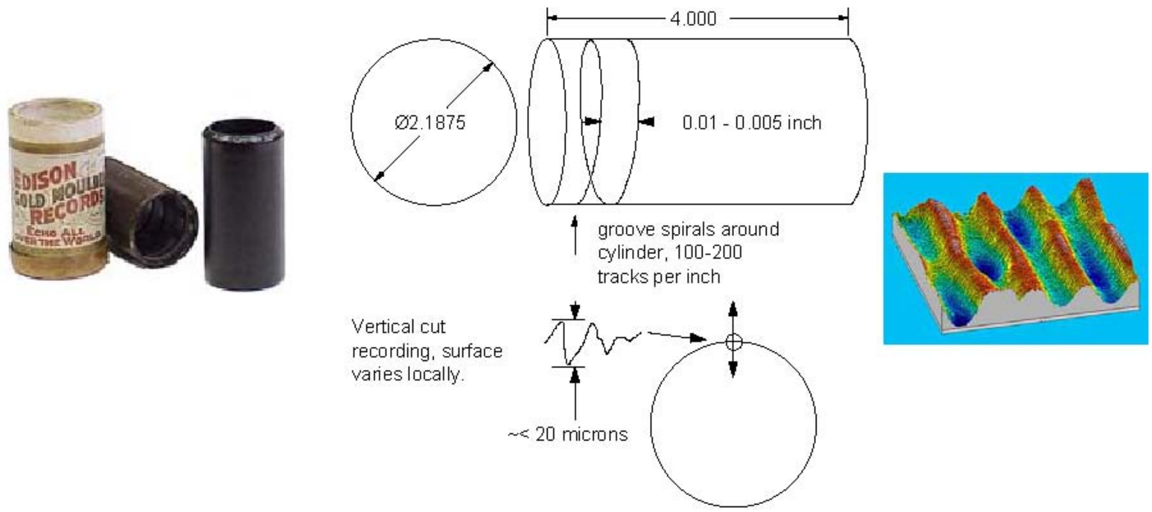

Figure 1: Cylinder records, composed of wax or plastic, carry sound in a helical groove which undulates vertically, normal to the surface. An (approx) 1 x 1 mm section is shown at right. The stylus rides in the valleys.

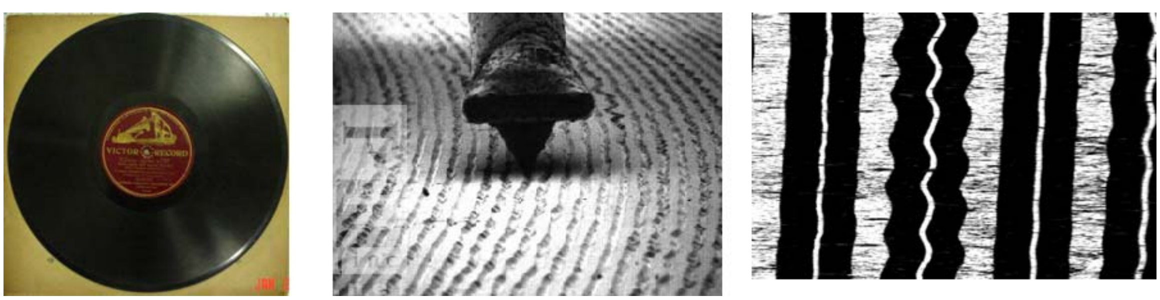

Figure 2: Historical disc records, composed of shellac, wax, plastic, lacquer, or metal carry sound in a spiral groove which undulates laterally in the surface plane. Typical groove width is 150 microns

The later disc format (which represents most of the archival holdings) employed a groove which undulates laterally in the plane of the disc.

There are a smaller number of examples, in special cases, where these distinctions are mixed.

Some early experimental disc recordings, for example, used a vertical modulation, and Edison continued that as a commercial format. Plastic dictation belts used in the mid-20th Century were effectively cylinders with a lateral groove.

Optical Scanning

There are two specific implementations of the Berkeley technology under development. One addresses high speed capture of disc media and the other, higher resolution capture of cylinders, and certain discs.

The high speed disc capture approach is explained in Figure 3. The basic research and development of this was carried out in Berkeley in 2002-2004 and published [1]. In early 2005 the National Endowment for the Humanities (NEH) approved and funded the IRENE project to develop a system for high speed disc capture for use at the Library of Congress, based upon the Berkeley research. This system was built in Berkeley and installed at the Library of Congress in August of 2006 for evaluation (Figure 4). In 2009 the system was moved to the NAVCC in Culpeper, Va. for production testing. The imaging is based upon high resolution digital micro photography and captures a two-dimensional (2D) representation of the disc surface.

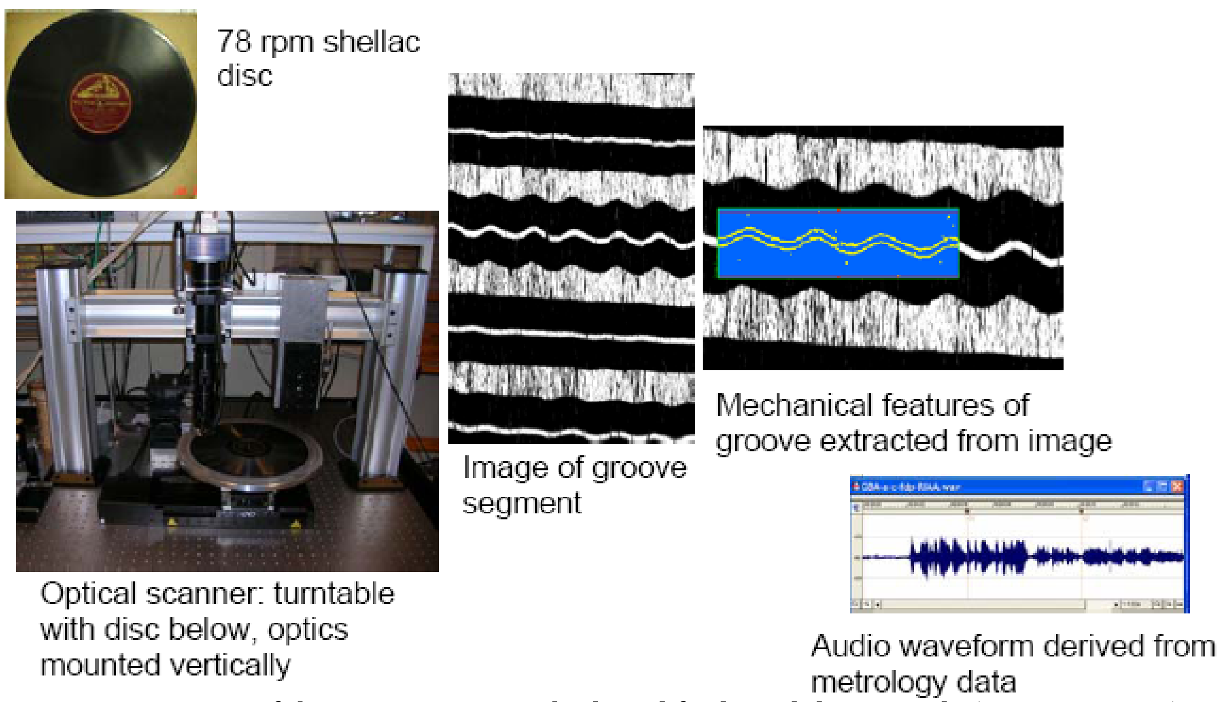

Figure 3: Depiction of the 2D scanning method used for lateral disc records (IRENE project).

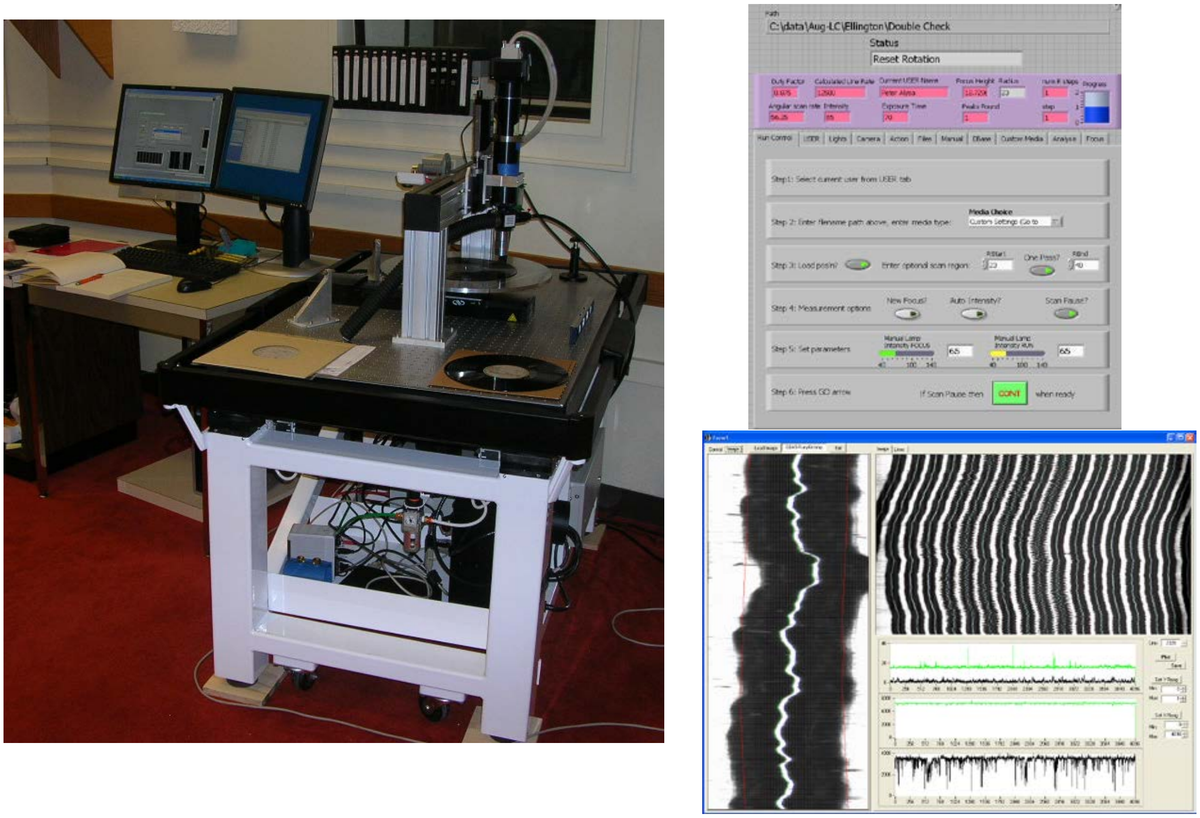

Figure 4: IRENE as installed at the Library of Congress. Insets to the right show the graphical user interface (top) and the data analysis display (bottom).

In order to measure media, such as cylinders, with a vertical groove modulation, a full three-dimensional (3D) surface profile is required. This is also the case if the full profile of a lateral groove is to be measured. With initial support from the Library of Congress and the National Archives and Records Administration, technology to address this has been under study since 2003. At that time, the basic method was demonstrated, and published [2].

To profile a surface, confocal microscopy is used. In this process, depth information is collected on a limited number of points. By scanning over the surface, a full 3D topographic map is created. Dramatic improvements in this technology, driven by a variety of commercial and medical applications, have occurred in just the past few years. Full surface profiling represents an advanced preservation strategy since the all aspects of the surface are sampled. Figure 5 explains the 3D surface profiling approach. With the installation of 2D disc scanning (IRENE) at the Library of Congress complete, it became appropriate to move the 3D scanning for cylinders and discs into a form where it could be evaluated at a major archive and/or on an important collection. Over the period 2007-2012, the Institute of Museum and Library Services (IMLS) supported the further development and application of this technology. In 2009, the 3D scanning capability was installed at the Library of Congress as well. This technology was applied to a variety of special materials and early historical recordings, partly in an attempt to explore the limits of the technology and to confront the very difficult restoration challenges.

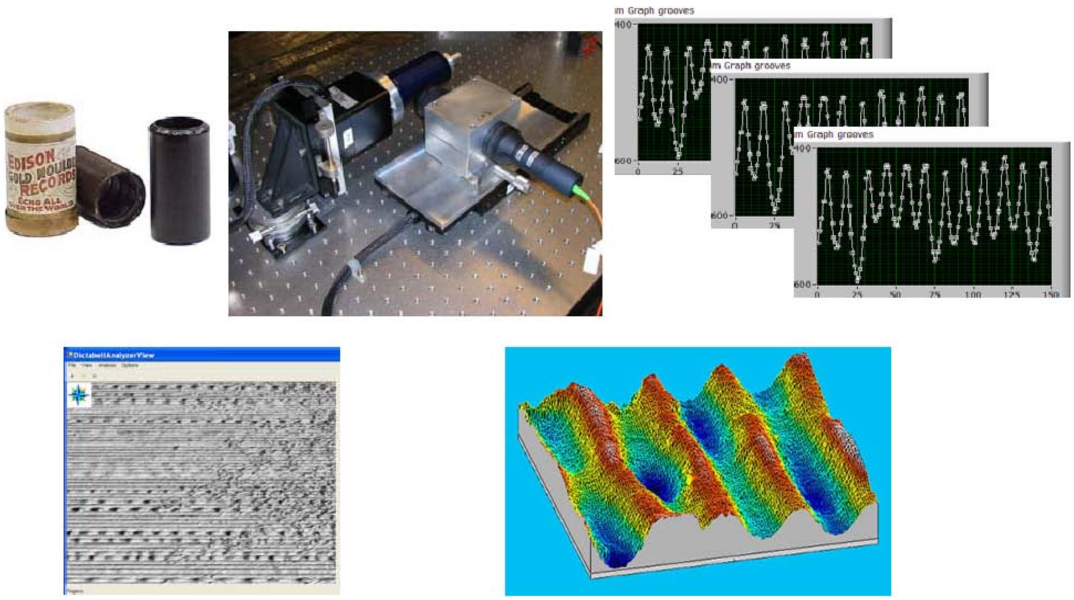

Figure 5: Depiction of the full 3D surface profiling approach. Upper-center shows the scanning instrument utilizing a confocal probe and precision motion control. Successive scans of the surface are at upper right. The vertical axis indicates depth, and the horizontal axis is along the cylinder length. Typical groove depths (widths) are 10 (250) microns. Lower plots show composite images of the measured surface.

A variety of measurements and sound reconstructions have been performed with the Berkeley technology. These can be accessed at project websites [3] where presentations are also posted [4]. As an example of a reconstruction, Figure 6 shows an audio waveform measured with the optical method, and with a stylus and turntable.

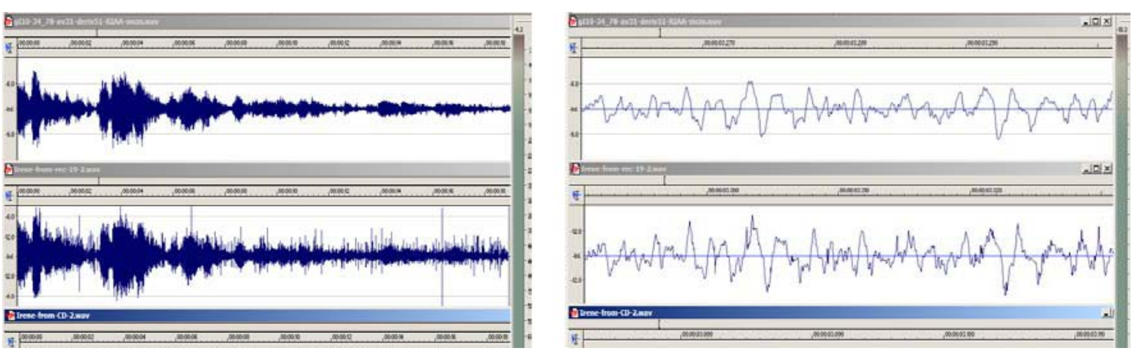

Figure 6: Audio waveform measured optically (top) and with a stylus and turntable (bottom) from the same 50 year old 78 rpm phonograph record. Left plots are on a ~20 second time scale, right plots are 40 milliseconds in duration. Note clear reduction of noise spikes due to processing and clean-up of acquired images.

The IMLS 3D development grant ended in 2009 with the installation of a 3D scanning system at the Library of Congress. That effort succeeded in demonstrating a 3D scanning system for cylinders which digitized a full recording in 20-30 minutes. Considerable progress was also made evaluating 3D scanning on discs. Following up on the 3D grant, IMLS awarded the project a second three year grant based upon the proposal “Advancing Optical Scanning of Mechanical Sound Carriers: Connecting to Collections and Collaborations”. The goals of this effort, which ended in 2012 were two fold. The first was to bring both the 2D and 3D scanning technology into contact with collections both at the Library of Congress and more remotely. A relatively portable scanning system has therefore been constructed and installed for use in a disc transfer project in India. The second goal was to carry out a series of special projects on small collections or items of particular interest. Included here were studies of copper galvano (negative) cylinders, fieldwork cylinders, broken cylinders and discs, and early experimental recordings produced by Alexander Graham Bell and Charles Sumner Tainter at the Volta Laboratory, in Washington, D.C. in the 1880's [5]. Some examples of these special materials are shown in Figures 7 and 8.

Figure 7: From the left (a) Greyscale (depth) image from Hearst Museum wax cylinder showing clear damage from fibers on the surface (~1910). (b) Example of experimental Bell recording, wax on paper, from the Smithsonian (early 1880's) (c) Example of copper cylinder galvano mold from the Berlin Phonogramm Archive (early 20th century). (d) The Dickson Cylinder from the Edison National Historic Site, first film soundtrack experiment (1893).

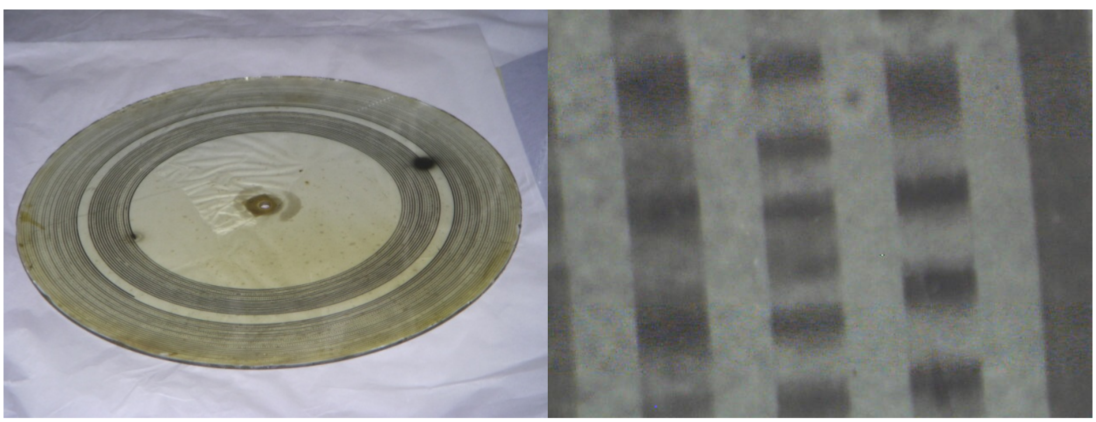

Figure 8: Experimental Bell-Tainter photographic recordings, Smithsonian Institution. Media consists of a glass disc sensitized with emulsion, exposed to a sound actuated light source, early 1880's.

The special collections studies are a unique opportunity to enlighten the early inventive period in the history of sound recording and to create new access to materials of particular interest to the research community.

Over the course of these developments, the project has had the opportunity to scan and restore a substantial variety of early, or otherwise significant and interesting recordings, some which would be considered unplayable by other means. The list includes,

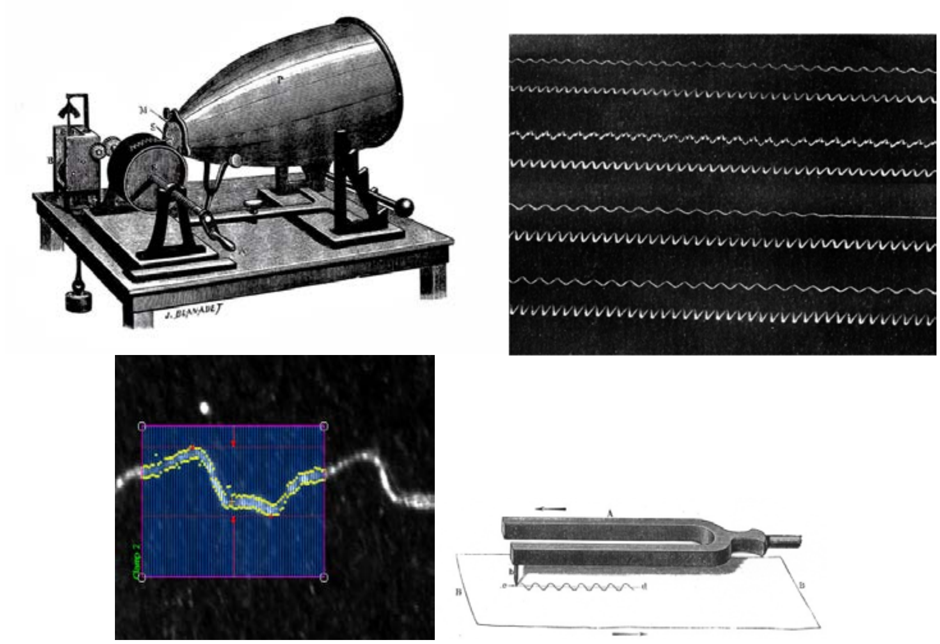

Figure 9: Upper left is the "phonautograph" built by Leon Scott de Martinville in the 1850's. Center shows a tracing on blackened paper. For each pair of traces, the upper trace is recorded audio while the lower trace is a timebase measurement from a tuning fork (lower left) vibrating at 250 cycles per second. Such images may be analyzed using the IRENE algorithms (right) in order to extract the audio content. See example links listed below.

- **Phonautograph**: Beginning the 1850's French inventor Edouard Leon Scott de Martinville began to experiment with the "phonautograph", literally sound-self-writer, a machine which could inscribe audio signals on paper (Figure 9), intrinsically unsuitable for playback in the 19^{th} Century. In 2008 the tracings on phonautograms recorded by Scott in 1860 were digitized and passed through the IRENE algorithm resulting in clearly recognizable speech, the earliest examples known of a recorded voice [6].

- **Edison Foil**: Thomas Edison, in 1877, was the first person to record and reproduce sound. He used tinfoil, rather than paper, and could emboss the audio signals, allowing for a playback stylus to retrace the waveform. His earliest experiments are apparently lost or only fragmentary. By mid-1878 copies of his machines were being sold and demonstrated. In 2012 a tinfoil in the collection of the miSci (Schenectady, N.Y. museum of Science and innovation), recorded in St. Louis, in June of 1878, was scanned using the 3D confocal probe and fully reconstructed [7] (Figure 10). It is the oldest recording of an American voice, and of an instrumental music performance, yet played back, in modern times.

- **Volta Collection:** Beginning around 1880, Alexander Graham Bell, and a group of associates, established a research collaboration to further develop sound recording and other technologies. Located in Washington, D.C., the Volta Laboratory Association was active until the mid-1880's and deserves credit for exploring most of the analog audio formats which were later adopted. Their most lasting contribution was the wax cylinder which formed a basis for the early commercial recording industry, dictation technology, and was used widely for field research recordings in ethnography, linguistics, anthropology, and musicology. Working in collaboration with the Smithsonian Institution National Museum of American History, 3D and 2D scans of a variety of items from this collection have been made in the period 2011-2013.

- Graphaphone: This is an 1881 experiment to record sound on a wax coated cylinder (Figure 11). The entire mechanism had to be scanned. The resulting audio [8] is the earliest wax recording yet reproduced.
- Electroformed disc: In October of 1881, Charles Sumner Tainter, one of the Volta Associates, documented an experiment to mass reproduce disc records through stamping. 3D scans have been made, and reproduced, of this "master disc" [9] (Figure 12) which is a documented electrotype of a wax disc cut with a lateral groove. In some sense the commercial recording industry itself can be seen as descending from this experiment.
- Photographic discs: In 1884-1885 the Volta Associates experimented with optical recording methods. Emulsion coated discs were exposed to a light beam modulated by audio signals. These experiments preceded the later adoption of motion picture optical sound tracks by some forty years. In 2011 some of these discs were scanned using the 2D/IRENE method and audio was recovered [10]. An example is shown in Figure 8.
- Wax discs: Bell and the Volta Associates created a variety of wax discs on diverse substrates. Some of these were meant to be played back with jets of compressed gas or fluid streams. A number of these have been scanned in 3D and reconstructed. One disc (Figure12) from 1885 contains the documented voice of Bell himself [13].

- **Talking doll:** Beginning around 1887 Edison experimented with a miniature playback mechanism which could be fitted inside a "talking-doll". This was perhaps the earliest commercial use of sound recording. A prototype mechanism with audio recorded on a since deformed metal ring, was scanned in 3D in 2011 and restored [12]. (Figure 14). This may also be the earliest recording of a women, who here is heard to recite "Twinkle Twinkle Little Star".
- **Dickson:** Around 1893 Edison and William Dickson experimented with sound recording synchronized to motion pictures. The Dickson Cylinder (Figure 7) is broken into two pieces. It was partly transcribed by stylus playback in the late 1990's. In 2012 a 3D scan of the entire cylinder was completed by temporarily holding the pieces together with polyethylene straps.
- **Bishop:** In 1891 King David Kalakaua of Hawaii was recorded by a representative from the Edison Company, in San Francisco. This cylinder, in the collection of the Bishop Museum, was scanned in 2011 but only small, essentially inaudible audio was found on the artifact.
- **Berliner:** Beginning in the late 1880's, Emile Berliner popularized the disc record format, with a lateral groove, first explored by Bell in 1881 and described also by Edison around the same time. Berliner's companies eventually became Victor, EMI, and Deutsche Grammophone. Commercial Berliner discs have been scanned and restored using both 3D and 2D methods.
- **Wax Field Recordings:** Ethnographers were among the early adopters of sound recording as a research tool. The Phoebe Hearst Museum of Anthropology at the University of California

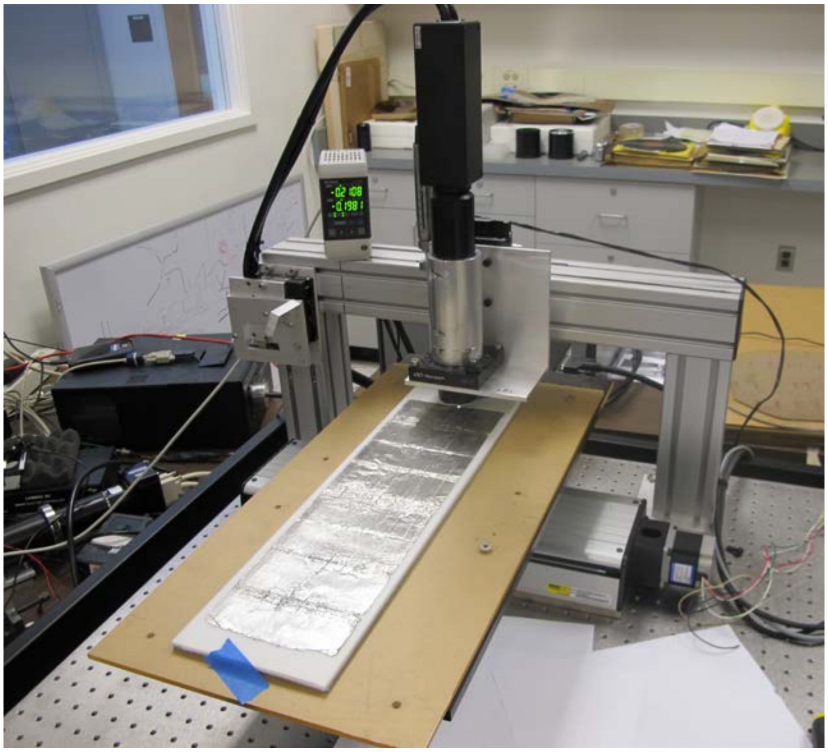

Figure 10: View of the 1878 St. Louis Edison Tinfoil being scanned with the confocal probe in Berkeley in 2012. The probe performed a raster sweep in order to cover the entire foil.

at Berkeley has a collection of ~3000 wax cylinders recorded by Professor Alfred Kroeber and associates documenting Native Californian cultures in the period ~1900-1916. As a pilot digitization study, some 70 cylinders from this collection were scanned in 3D and analyzed. The full results have been posted at a protected site and samples are also publically available [13]. Over the course of this study ~20 cylinders were scanned and analyzed per week.

- **The Montana Fortune Teller:** An early novelty application of sound recording was in arcade machines. A cracked 1906 wax cylinder containing "random" fortunes was scanned and restored using the 3D methods.
- **Jack London:** Towards the end of his life, novelist Jack London, dictated correspondence onto wax cylinders. A few of these remain with damage to the wax from mold growth. Some have been scanned in 3D revealing the writer's voice and verified text from letters found in his collected correspondence.
- **Franz Boas Recordings:** In 1930 anthropologist Franz Boas filmed and recorded Kwakuitl culture at Fort Rupert in British Columbia. The recordings, on wax cylinders, were electrotyped at the Berlin Phonogramm Archive, resulting in wax derivatives. About 20 of these were scanned in 3D and the sound restored. Some improvement to the sound, as compared with stylus playback was found. The results have been posted [14].
- **Milman Parry:** In the 1930's, classicist Milman Parry collected South Slavic folklore on ~3000 soft aluminum transcription discs. This material forms the basis of research leading to the Parry-Lord oral-formulaic hypothesis of composition, and is in the collection of Harvard University. Such discs are problematic for playback due to an extremely small groove and the relative softness of the metal. Using the 3D scanner, a pilot study of some 25 discs from the collection was made and the results posted [15].

Figure 11: The 1881 Bell Graphophone, an Edison tinfoil machine which has been coated with wax as an experimental recording medium.

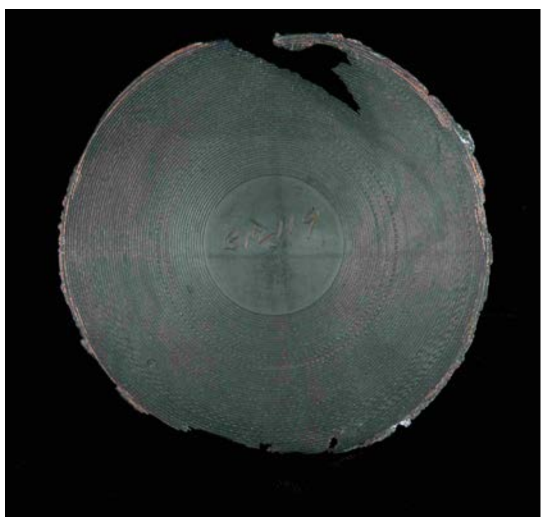

Figure 12: The 1881 lateral cut disc record master from the Volta Laboratory collection. This was electroformed from a wax original.

- **Howard Hughes:** Glass or aluminum discs coated with lacquer were used in the 1930 and onwards for radio broadcast transcription. When Howard Hughes won the Collier Trophy for Aviation his speech was recorded on a disc coated with cellulose nitrate lacquer. These surfaces are soft and easily damage. One such disc was scanned using the 2D IRENE method and reconstructed.
- **Janis Joplin**: Beginning in the 1940's and extending into the 1960's, vending machines existed for creating personal messages on lacquer or plastic discs. Janis Joplin recorded such

Figure 13: Wax on binder board disc from the Smithsonian Volta Laboratory collection which contains a recording of Alexander Graham Bell.

a disc as a message to her family prior to her career as a recording artist. The future artist is heard to banter and even sing, just a bit. She states "I have never heard my voice on record before." The disc was scanned in 2D and reconstructed.

- **Dictabelts:** These are soft plastic loops which were used for office dictation and telephone or other monitoring applications in the mid-20th Century. There is considerable US Presidential history recorded on these belts. A variety of studies and pilot 3D scans have been carried out on dictabelts and considerable software has been developed to study and analyze them.

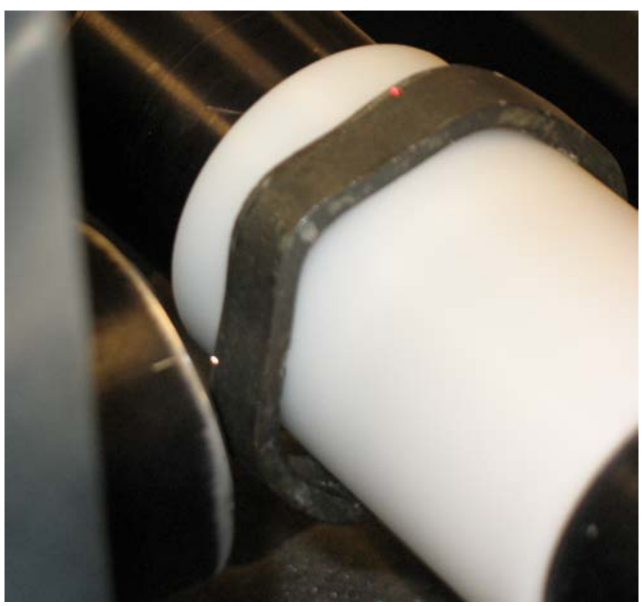

Figure 14: Talking doll prototype record mechanism. This deformed metal ring contains a recording of a woman reciting "Twinkle Twinkle Little Star". The confocal probe is on the left amd produces the small white spot of light. The red spot is a laser reflection used for focus control.

Potential Impact

Archivists have estimated that of order 1 million recordings could benefit from the Berkeley scanning technology. According to Peter Alyea of the Motion Picture, Broadcast, and Recorded Sound Division of the Library of Congress, "The solution to (the challenges of preservation and access) is to innovate in the area of reformatting technology. The Berkeley (technology) marks a major change in the history of audio technology and its relationship to the field of preservation. Rarely have audio archive specialists worked directly with scientists to address and solve specific audio preservation problems through the development of preservation targeted technology. The technology is non-invasive, posing no risk to the source media, can reproduce broken and otherwise damaged discs, and will not require trained specialists to perform the work. The system can reproduce sound that could not be extracted through traditional physical methods by examining and utilizing the complete surface of the groove walls to generate the audible output. Furthermore, statistical information can be derived from a vast number of discs to study idiosyncrasies of different disc cutting and pressing techniques, and wear patterns.

With more than a century rich with commercially produced and unpublished sound recordings of music, poetry, drama, literature, and story-telling, and radio broadcasts capturing speeches, entertainment, and news, we can not afford to lose this cultural resource. I expect the Berkeley (technology) to revolutionize the archival field and ensure that we do retain our recorded sound heritage."

This development of the optical scanning technology is an example of how the methods of STEM fields (Science, Technology, Engineering, and Mathematics) can be brought to bear on problems facing other fields of research and culture. In the past, the humanities and the sciences and engineering have intersected with great benefit. Examples include the use of radioactive dating and spectroscopy in archeology and art history, the use of digital signal processing and computation is the analysis of musical scores and the creation of new music and musical forms, and the entire field of photography, image acquisition, storage, and permanence. These efforts are exciting and inspiring for students who have, and will continue to, participate in their development. Cultural materials in the audio collections may come from communities which have been historically under-represented in science and engineering. These developments may serve to draw students from those communities into research academically, or as a career. As an example for use in educational outreach for both the physical sciences and the humanities, this research, and the topic of historical sound recordings have a broad and deep appeal to the public.

Future Directions

Optical scanning systems are presently in operation at Berkeley, at the Library of Congress, and at the R.Muthiah Research Library in Chennai, India. In 2014 a full scanning system will be commissioned at the Northeast Document Conservation Center (NEDCC) [16] in Andover, Massachusetts. This system should be available for transfer projects on fee-for-service basis. Plans are also in development to install a system at the Moscow Conservatory of Music. An important priority for the future is to make the technology more widely available to collections and also to sustain the basic research effort which will lead to further developments and improvements in the tools and analysis procedures. The NEDCC facility can certainly address a significant domestic need for the scanning technology. It will also be possible to build and distribute additional scanning systems. This may be required for other international applications, for large collections which cannot otherwise be moved, and perhaps for some government needs.

Among the most attractive applications for the technology in the future are for early fieldwork collections including those mentioned above, but on a larger and more complete scale.

Education and Outreach

The Berkeley project has provided a research opportunity for about 25 students from the STEM fields. The student participants have included University of California at Berkeley undergraduates and bachelor and masters students from the University of Applied Sciences in Fribourg, Switzerland. Students have made numerous contributions to the software and hardware aspects of the projects. One student undertook a systematic transfer project on Native American field recordings which was featured by the Institute of Museum and Library Services in a profile piece [17].

Nearly one hundred public presentations have been given on this research. It has also been the subject of a variety of pieces in the public media. Some are listed at the end of this report.

Research supported by the following:

The Institute of Museum and Library Services
The Library of Congress
The National Archives and Records Administration
The National Endowment for the Humanities
The University of California at Berkeley
The Department of Energy
The Mellon Foundation
The John Simon Guggenheim Memorial Foundation
The Smithsonian Institution

Collaborators

Key collaborators on the project include Lawrence Berkeley National Laboratory, The Library of Congress, The Smithsonian Institution, The University of Applied Sciences EIF Fribourg, Switzerland, the Edison National Historic Site, and the Northeast Document Conservation Center.

References

[1] V.Fadeyev and C. Haber, **J. Audio Eng. Soc**., vol. 51, no.12, pp.1172-1185 (2003 Dec.).
[2] V.Fadeyev et al, **J. Audio Eng. Soc**., vol. 53, no.6, pp.485-508 (2005 June).
[3] http://irene.lbl.gov/
[4]Recent presentation at the Library of Congress: http://irene.lbl.gov/LC-TOPS-2010-Save.pdf

[5] The Bell Volta Laboratory materials are posted at, http://bio16p.lbl.gov/ additional information can be found at:http://newsdesk.si.edu/releases/playback-130-year-old-sounds-revealed and http://blogs.smithsonianmag.com/aroundthemall/2011/12/from-the-collections-sound-recordings-heard-for-the-first-time/
[6] http://en.wikipedia.org/wiki/Leon_Scott
[7]http://bio16p.lbl.gov/tinfoil.html
[8]http://bio16p.lbl.gov/volta-release-2013.html
[9] http://bio16p.lbl.gov/volta-release.html
[10] http://bio16p.lbl.gov/volta-release.html
[11] http://www.youtube.com/watch?v=ZALUgxsnCOk
http://www.youtube.com/watch?v=qTpWD28Vcq0
[12] http://www.nps.gov/edis/photosmultimedia/early-talking-doll-recording-discovered.htm
[13] http://irene.lbl.gov/Hearst_examples.html a small subset on an open link

This is a link to full results of 3D scans of wax field cylinders of Native Californians created between approx 1900 and 1914 by Prof. Alfred Kroeber and associates at the University of California, Berkeley. Password Protected folder Hearst_Study\Hearst_Final.php

[14] http://irene.lbl.gov/Boas-2012.html
[15] http://bio16p.lbl.gov/parry.html
[16] http://www.nedcc.org/audio-preservation

Selected Media and Other Coverage

Recent CNN report on Alexander Graham Bell recordings:
http://www.cnn.com/2011/12/27/living/bell-digital-imaging/

Report on Edison tinfoil:
http://www.pbs.org/newshour/bb/science/july-dec12/recording_10-25.html

http://abcnews.go.com/blogs/technology/2012/10/americas-oldest-voice-recording-restored/

http://soundcloud.com/kpcc/edison-restored-qa-xtended-for

KQED television QUEST report:
http://www.kqed.org/quest/television/how-edison-got-his-groove-back

Video of a presentation at UC Berkeley: http://www.citris-uc.org/CRE-Oct18-2006

Phonoautograph from 2008, paper recording due to French inventor Edouard-Leon Scott de Martinville.

FirstSounds Collaboration
NY Times March 27, 2008
National Public Radio Report

Other media
NPR Morning Edition piece: http://www.npr.org/templates/story/story.php?storyId=11851842

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