Seeing voices: Imaging the earliest sound recordings

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With the help of techniques first used by particle physicists decades ago, scientists and archivists are preserving our precious aural heritage.

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Historic sound recordings of the late-19th and early-20th centuries represent a small but diverse snapshot of the world, taken as a great transition was under way. The age of information technology was arriving, and at the same time, traditional experiences and ways of life were being displaced, transformed, or eliminated. In the research sphere, first-generation anthropologists, linguists, and ethnographers—among the earliest researchers to adopt sound recording as a tool for scientific fieldwork—captured bits of that global transition. Instrumental and vocal performances that earlier could only be experienced live—in a theater, a church, a parlor, or by a campfire—could now be experienced over and over; the result was a huge increase in the appreciation and creation of musical and related performing arts. The heroic inventors of recording technology left us their experimental recordings, their apparatus, and their notes, documenting their creative process and the emergence of a modern technology. Early recorded sound is consequently a world treasure.

Nowadays most recorded sound is stored on digital media, but initially sound was stored analogously on a great variety of materials, including foil, lacquer, metal, paper, plastic, shellac, and wax, and in photosensitive emulsion. Recording formats included a variety of undulating grooves, latent images, and polarizations. Also wide ranging are the forms of degradation and damage, including abrasion, breakage, chemical decomposition, delamination, dirt, fading, mold, overplaying, oxidation, peeling, and warping.

The preservation and restoration of sound recordings must deal with all the factors described above and, not surprisingly, presents unique challenges. Several of us at Lawrence Berkeley National Laboratory, working in close collaboration with the Library of Congress and others, have studied the problem and developed some solutions. The work described in this Quick Study has allowed researchers and the public to listen to a variety of "unplayable" key historical documents. Still, many media and modes exist that remain to be addressed, and our work is far from done.

Getting in the groove

At the heart of our approach is a technique called optical metrology, which combines digital image acquisition and precision motion control with numerical image and data analysis. With optical metrology, we can precisely measure positions on a recording medium—in principle to the limits of optical resolution—without any mechanical contact to its surface. Then a numerical playback process extracts the recorded sound. Furthermore, a number of image processing and data analysis strategies allow us to mitigate the effects of degradation and damage.

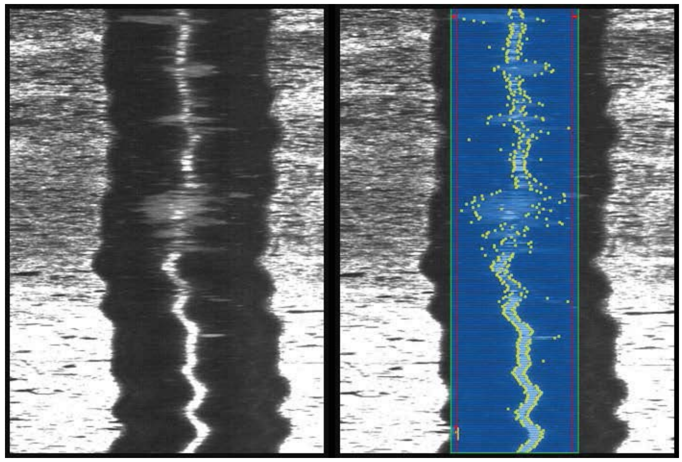
Optical metrology is now an industry with myriad commercial and scientific applications. But particle physicists were among the first to use it. In the early 1970s, they applied the technology to develop machines that automatically scanned films taken of tracks in bubble chambers. In our particle-physics group, we have used optical metrology extensively to profile the shapes and alignment of silicon wafers that serve as position-sensitive particle detectors in the ATLAS experiment at CERN's Large Hadron Collider. Indeed, the entry into recorded-sound research came about when some of us saw a connection between that wafer-characterization process and the optical profiling of a sound carrier.

Early recorded sound was created mainly in grooved formats. The "records" that carried the sound were usually cylinders or discs. (For an archivist, "disc" with a "c" refers to an analog sound carrier.) For cylinders, the groove typically undulated vertically, perpendicular to the surface. In discs, the undulation was typically transverse to the surface. (Later stereophonic LPs and 45-rpm singles had a groove with both vertical and lateral variation.) The depth of a groove could be as little as a few microns to as much as hundreds of microns. Undulations, correlated to the sound amplitude, ranged from a fraction of a micron to hundreds of microns. The length of a groove, if unwound, would exceed 100 meters. Evidently, orders of magnitude separate the size of a record and the size of the variations that represent the stored content.

To obtain the information needed to extract the sound from those objects, we had to have excellent control of focus, range, alignment, and calibration throughout the acquisition process. Such a measurement process results in gigabytes of data for a single record. A decade or so ago, the requisite control, acquisition, and data-handling requirements might have been daunting; now they fit comfortably within the technical specifications of a variety of commercial components.

We employ different measurement strategies for the lateral discs and the vertical cylinders. For discs, we use digital microphotography and capture sufficient detail to locate the edges where the sloping walls of the groove meet the flat bottom of the record; the figure shows a typical edge reconstruction. With the proper choice of optics and illumination, and with multipixel image analysis, we can obtain submicron edge resolution. Once the edge has been detected, we can extract the sound.

The grooves in disc-shaped records encode sound in their side-to-side oscillations. At left is an image of groove undulations acquired with the optical scanner at Lawrence Berkeley National Laboratory. The wide black regions are the sloping walls of the groove and the narrow white line is the groove bottom. The image at right shows the result of an edge-detection algorithm applied to the groove bottom. For clean regions, the edges on either side of the groove bottom have a constant separation. In dirty or damaged regions, the edges are further separated or are displaced. Pattern-recognition software readily flags those damaged regions, which can be numerically repaired by interpolation or other procedures.



Images of grooves capture the basic redundancy and consistency of sound recordings. The same information is stored across the entire groove. So we can average the edge positions on either side of the groove bottom to increase the signal-to-noise ratio. The regular groove structure also means that during image processing, pattern detection algorithms can find dirt, scratches, and other damage.

Digital photography cannot capture the groove-depth variations that encode sound in cylindrical records. But there exist a number of three-dimensional surface profiling methods for a variety of inspection and measurement applications. We studied those and adopted a form of confocal microscopy for our application to sound restoration and preservation. A typical confocal microscope images a point source of light through a lens and beamsplitter onto a surface, then the light reflects back through the optics onto a conjugate detector. The lens is moved coaxially, and when the spot at the detector comes into focus, the distance to the surface can be determined. The confocal microscope will scan the light spot over the surface to build up a 3D topography.

In our application, instead of moving a lens, we use a microscope that disperses a point source of white light into colors, which code depth, and then detects the reflected signal in a conjugate spectrometer. On a flat surface the microscope has a depth resolution of about 50 nm, a point size of 3.5 μm, and a measuring range of 350 μm. The system operates 180 parallel measurement channels arranged as a linear array with 10 μm between adjacent points. Such specifications are well matched to the micro- and macro-scale features of early sound recordings.

With our imaging and data collection technologies, we can digitize early recordings in a practical time frame. For example, with 2D digital photography, a typical 3-minute, 10-inch, 78-rpm phonograph record—perhaps the most common early sound carrier—can be measured and processed in about 15 minutes. Applications with the 3D confocal scanner typically take longer. Measurement time varies from 20 minutes to several hours, depending on the desired resolution, time sampling (frequency of measurements needed to digitize the analog waveform), and the speed at which the recording was made. Processing time is less than measurement time and is getting shorter as computers get more powerful.

Our vision is for optical metrology to move beyond special cases and singular historic items and for it to enable the systematic digitization of at-risk or damaged collections for which standard playback methods are not useful. My colleagues and I have constructed and placed machines at a number of sites and plan to continue to build a community of users for the technology. We hope the methods we have developed will enter wider use in service of the great research collections and the technology will be sustained and advanced by ongoing development.

What goes around comes around

The Berkeley sound-restoration project started as an outgrowth of detector development for particle physics. Today our particle-physics group is designing and testing a new generation of particle detectors; sometime in the early 2020s, they should see operation in fundamental-physics experiments planned for the upgraded High Luminosity Large Hadron Collider. For example, we designed a long, flexible printed circuit to hold a dozen precision sensors but struggled to measure and inspect it efficiently—and more than a thousand such circuits will ultimately be needed. My student Brian Amadio is now surveying it by wrapping it around a large plastic cylinder and scanning it with the same digital-photography technology used to scan phonograph discs. We are also studying the feasibility of applying the 3D confocal technology to related inspection needs. Eventually we may scan those 1000-plus items needed for the large detector. Our work in particle physics and aural preservation has taught us that challenging technical problems that require multiple measurements and the collection of huge amounts of data often have common or related solutions.

Additional resource

▶ C. Haber, "Sound Reproduction R&D Home Page," http://irene.lbl.gov.

The online version of this Quick Study includes images of media on which early sound was captured and historical notes and sound files of restored early recordings. ■