Image to audio conversion from mechanical media

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MUMT611

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Agenda

- Save the music
- Vinyl physics and standards
- Previous work in optical audio reconstruction
- Issues and conclusion

Disappearing music

- A large body of musical heritage is disappearing
  - Dust and fungus
  - Decaying
  - Fractured
  - Scratched
- Vinyl deteriorates each time it is played

Consumer demand

- Specialty services, products, and software popping up everywhere to digitize personal collections
  - Service
    - e.g. http://lp2cd.com/prices.htm
    - >$50 USD per CD for 33/78rpm
  - Product
    - Turntables with digital audio interfaces
    - e.g. http://www.numark.com
    - >$170 USD street price
  - Software
    - De-clicking and noise reduction tuned for vinyl
    - e.g. http://www.waves.com/content.asp?id=59
    - >$2400 USD for Waves Restoration package
- Where there is a demand ➔ there is $$$

Government demand

- National Recording Preservation Board
  - Mandated by National Recording Preservation Act of 2000
    - "A bill to establish the National Recording Registry in the Library of Congress to maintain and preserve sound recordings and collections of sound recordings that are culturally, historically, or aesthetically significant, and for other purposes" (Public Law 106-474; H.R.4846)
  - Objectives
    - Formulate selection criteria for recording registry
    - Develop National Recording Preservation Study and Action Plan (standards and laws for preservation and access)

Magnitude of the issue

- Millions of mechanically reproduced sound recordings in libraries worldwide
  - Time and manpower required for manual preservation unreasonable
- No standard for equipment used, metadata preservation, etc.
- We need to work towards
  - High quality automated methods
  - Preservation standards and workflows

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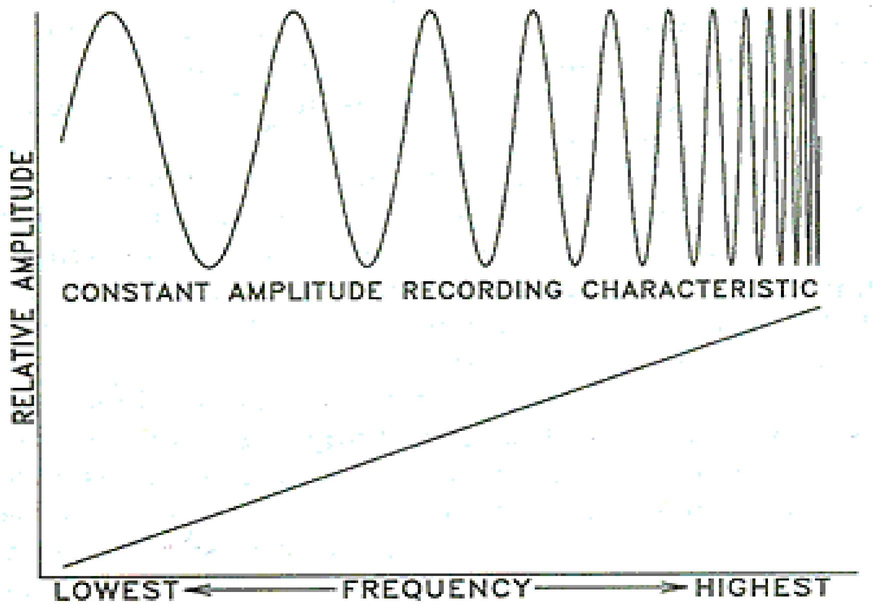
Constant amplitude cut

- Amplitude held constant over all frequencies
- Linear stylus velocity proportional to frequency

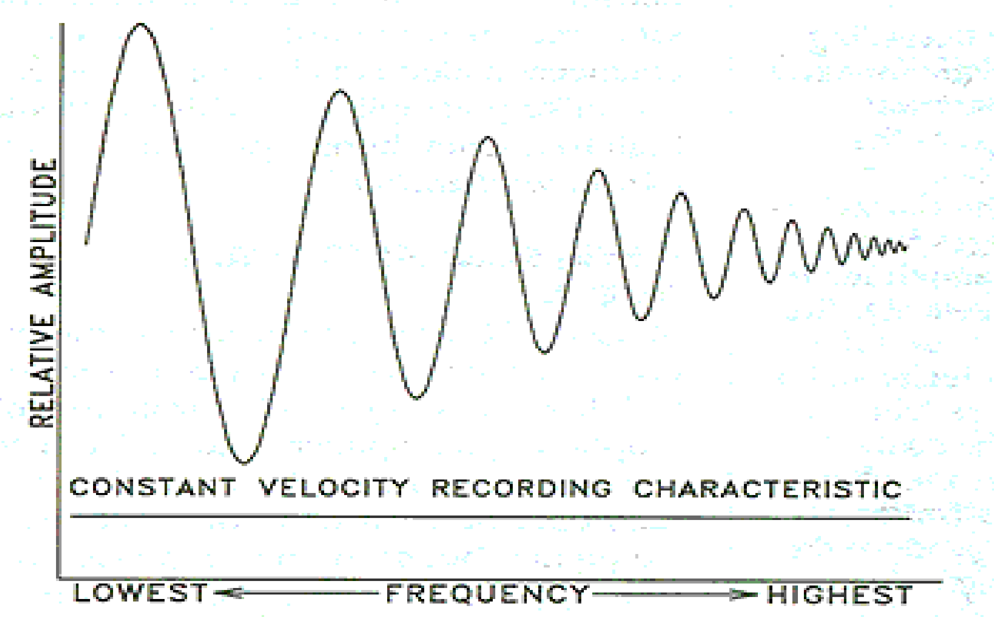
Constant amplitude curve [4]



Constant velocity cut

- Linear stylus velocity held constant over all frequencies
  - No frequency bias with velocity sensitive magnetic transducers
  - Optical system will have to differentiate the fitted path
- Max displacement = max velocity / (2 * pi * f)
  - Max velocity occurs at zero crossing
  - Radial compensation for velocity (faster traversal on outer grooves)

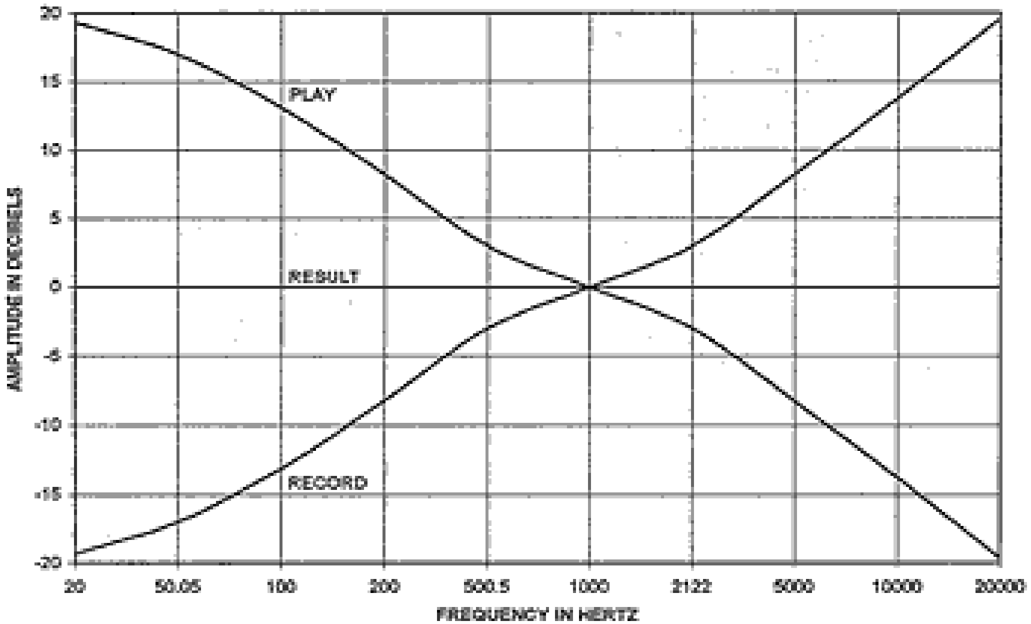
Constant velocity curve [4]



RIAA equalization

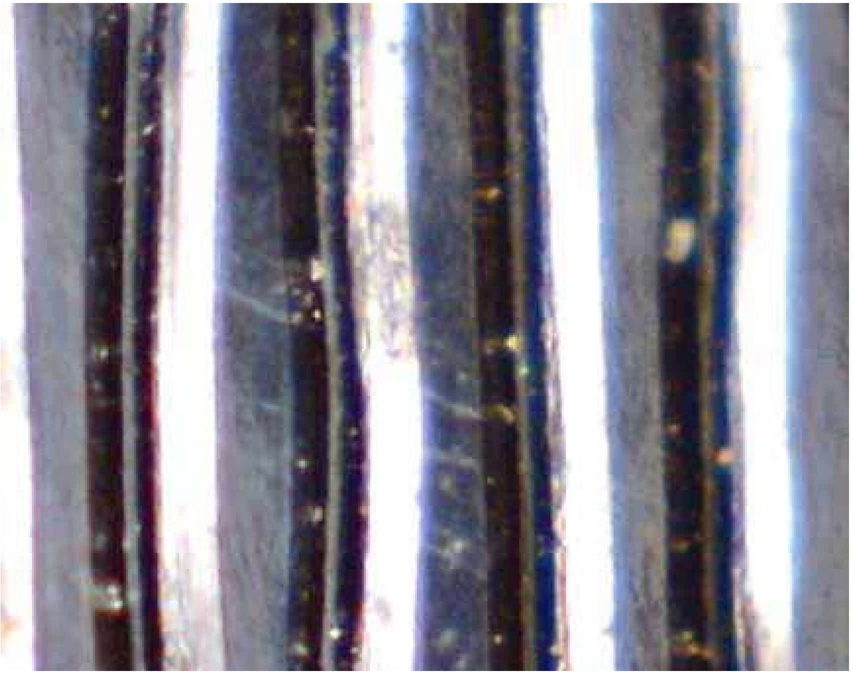
- Constant velocity vinyl issues
  - Groove spacing for lateral cuts at low frequencies (very large displacements)
  - High frequencies descend into noise floor of surface (very small displacements)
- Record with 6dB/octave attenuation below 500 Hz, 6dB/octave amplification above 2122 Hz
- Optical systems need to model compensating frequency curves

- RIAA Equalization curves [4]



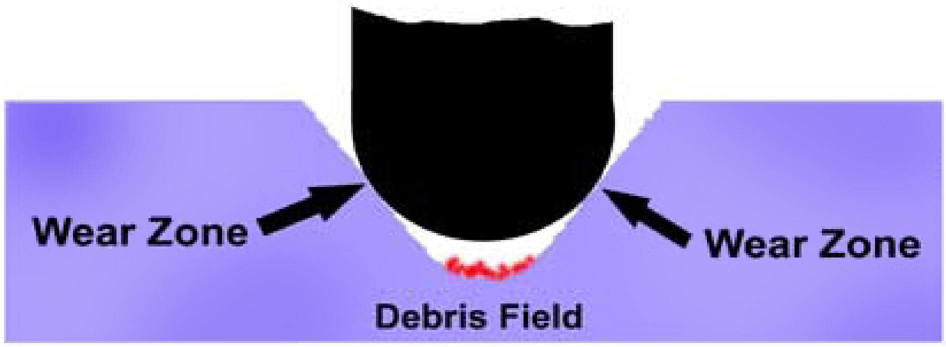
Cutting standards

- Wax cylinders, 78 r.p.m. mono
  - Lateral cut (2D) (see image on right [1])
- 33 1/3 r.p.m. stereo
  - Lateral and vertical cut (3D)
  - “V” groove, left and right channels stored in sidewall undulations (180 phase separation)
  - http://www.vinylrecorder.com/stereo.html



Other vinyl anomalies

- Surface noise due to material imperfections
  - Appears as high frequency noise
- Transient impulse noise (dust, scratches)
  - Optical method will remove by interpolation
- Wow and flutter
  - Irrelevant in optical method since realtime dependence on a motor is not an issue
- Vinyl wear
  - Image analysis can deduce areas of low wear (stylus dependent) and sample sweet spot



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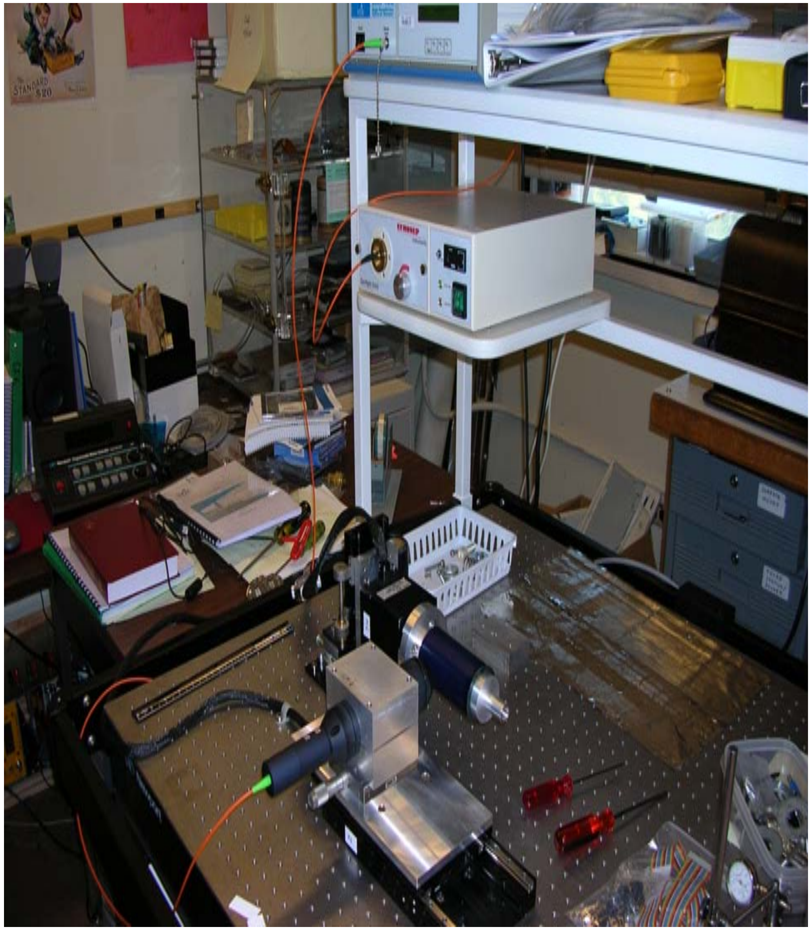
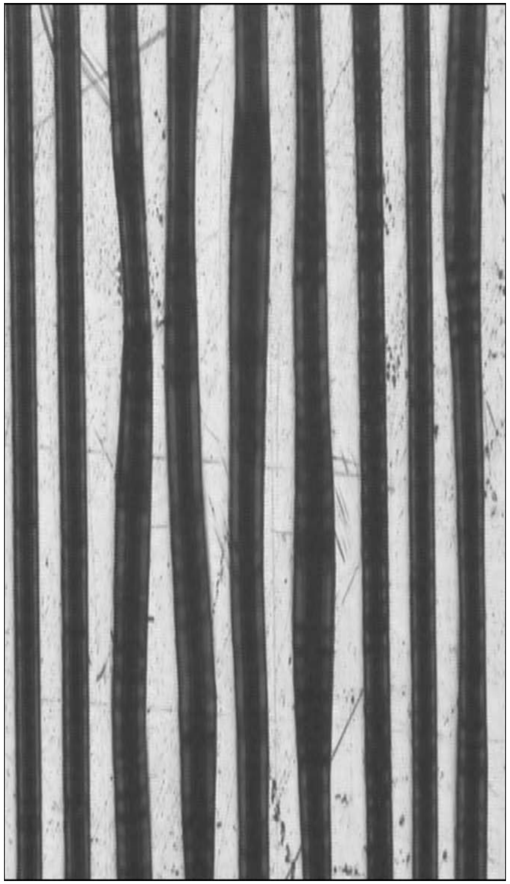


Why Optical?

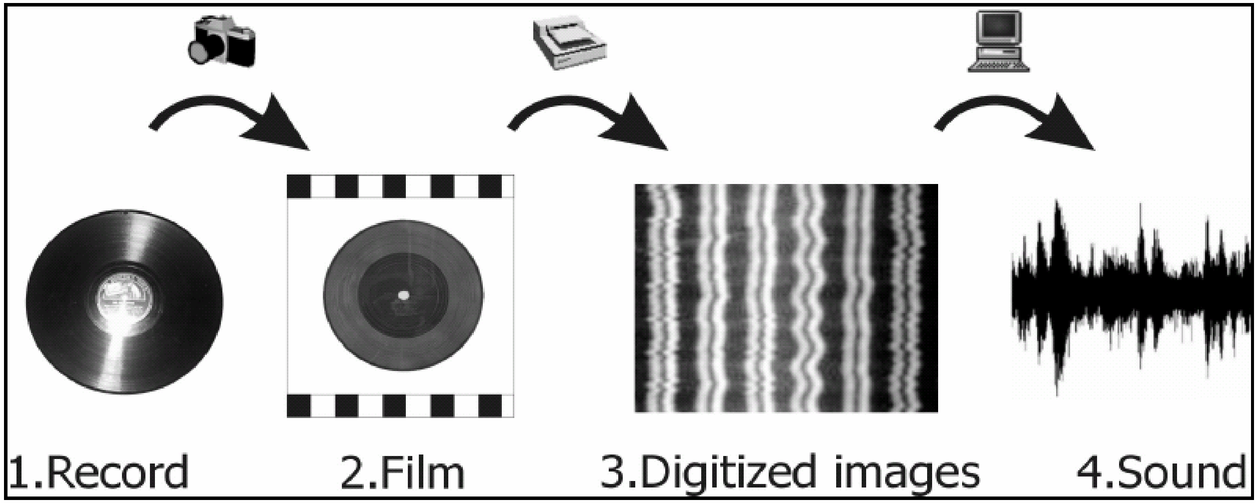
- Play broken records
- Works with extremely fragile records (acetate) and other strange media (steel records, metal stampers, coloured vinyl, etc.)
- Sound restoration and recovery at the source in spatial domain as opposed to post-processing in time/frequency domain
- Possibility to recover sound information lost mechanically (stylus mass-spring behaviour across surface)
- Avoid wear and tear areas
- Store image once and improve audio conversion techniques over time
- Laser turntables are susceptible to noise and wear and cannot read coloured records



VisualAudio

- Stotzer et al. 2004 (University of Fribourg)
- Three steps
  - Take picture of 78 or 33 1/3 rpm
  - Digitize film using rotating scanner
  - Extract radial displacement (undulations from trajectory)

- VisualAudio system [3]



VisualAudio noise analysis

- Random granularity of analog film adds white noise
- Optical distortions due to bad focusing and non-constant illumination
- Resolver jitter of rotating scanner causes vibration distortion
- Extracted required noise standard deviation on one edge allowed to reach target SNR for constant amplitude and constant velocity records
  – Used test records with test tones and extracted SNR from spectrum
  – Goal: 60dB SNR for 33 r.p.m. and 40dB SNR for 78 r.p.m.
  – Preliminary calculations: Noise SD < 1.28um for 40dB SNR from RIAA equalized records

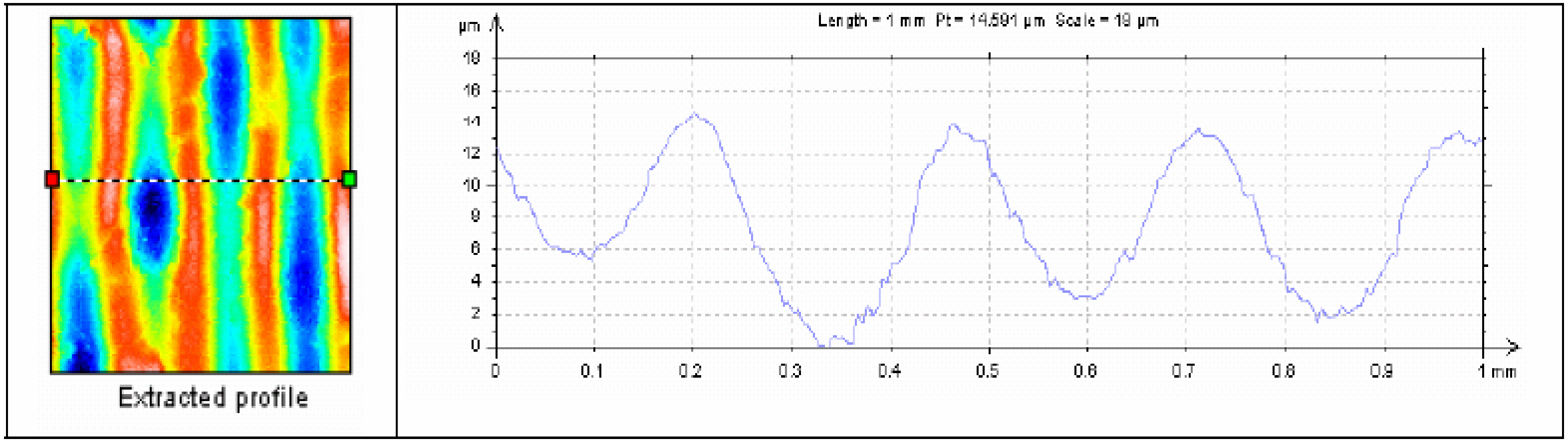
VisualAudio examples

- http://www.eif.ch/visualaudio
- Not clear whether it outperforms traditional stylus playback or CD remasters

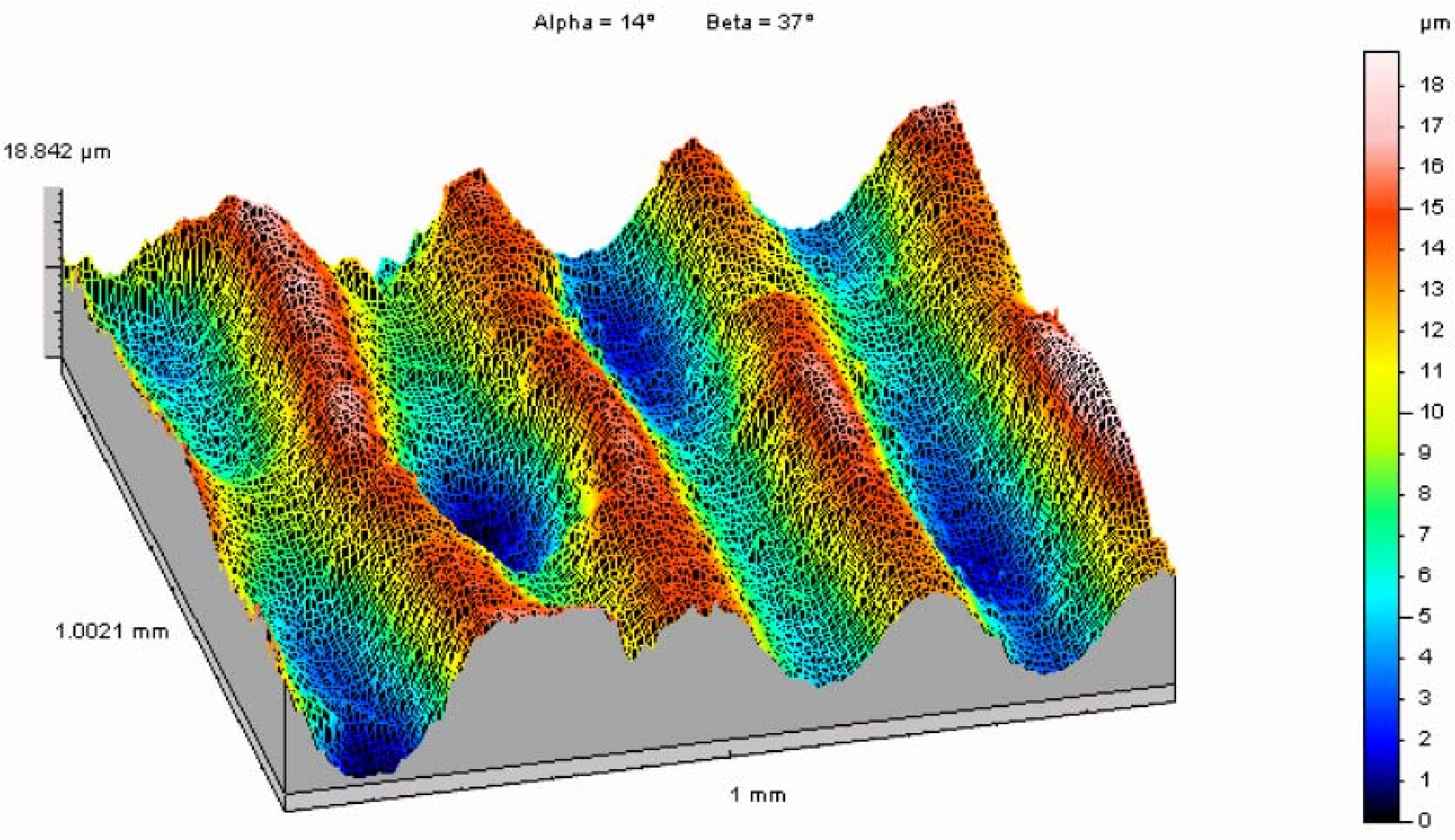
Lawrence Berkeley National Laboratory Optical Metrology

- Fadeyev, Haber 2003
  - 2D lateral cut audio reconstructions on 78 r.p.m.
- Fadeyev, Haber, Maul, McBride, Golden 2004
  - World's first attempt to sonify 3D record surface
  - Below is a profile of a 3D field view of a record
  - Borrowed methods from semiconductor wafer processing

- Extracted profile across a wax cylinder [2]

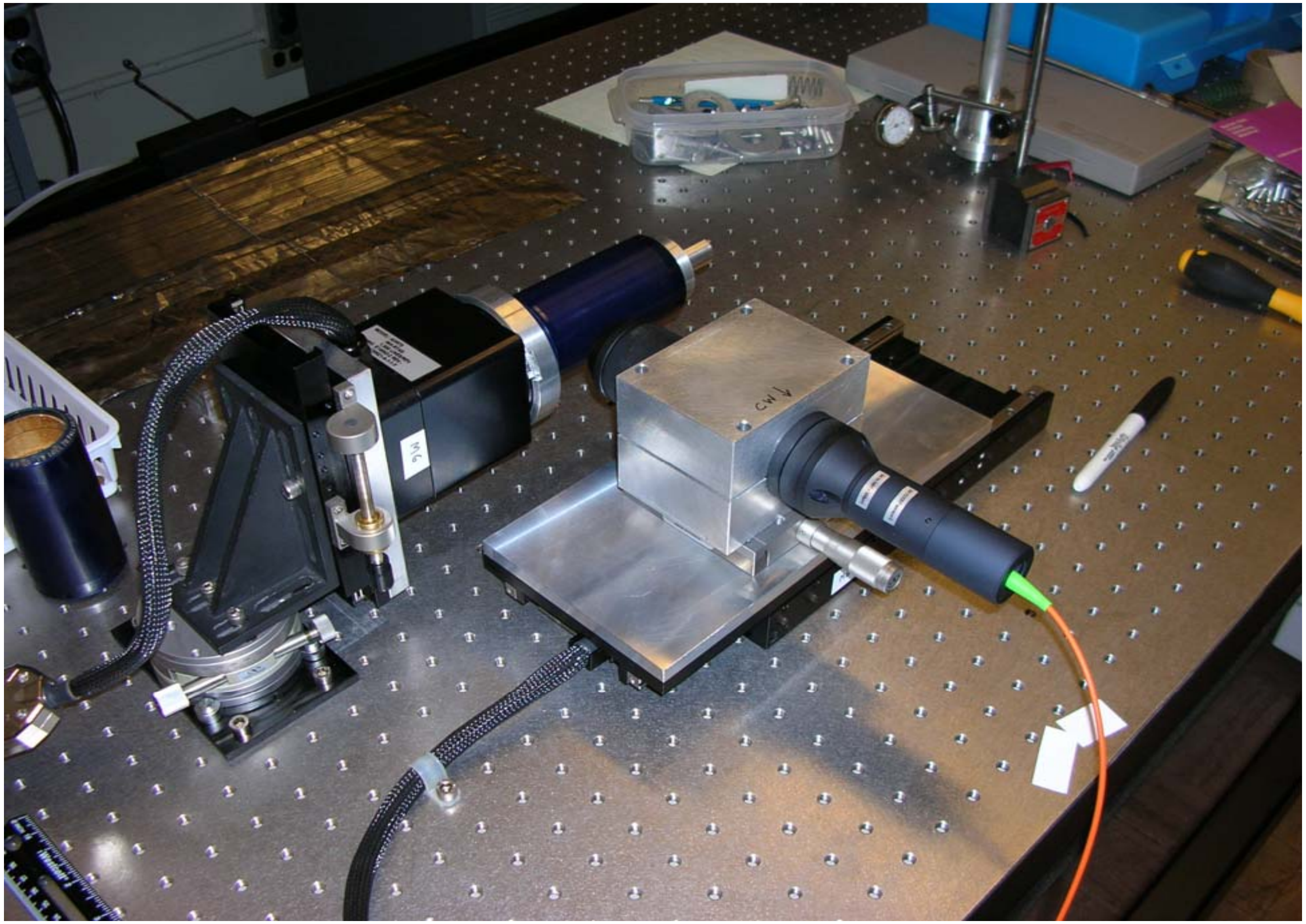


3D surface map



- 1x1mm region of a wax cylinder, 6um data point granularity [2]

Scanning system



- Confocal probe (metal linear stage on right) and wax cylinder (black rotational stage on left) [2]

General method

- Capture image digitally
  - Electronic camera (2D)
  - Confocal laser scanning probe (3D)
- Model groove
  - Polynomial fitting
  - Fs = (linear surface speed) / (spatial period) should satisfy Nyquist criteria
- Subtract groove curve from unmodulated trajectory to get stylus path
- Differentiate stylus path (constant velocity)
  - Excess frequency content filtered out (FFT)
- Resample to audio rate 44.1kHz

Tradeoffs with CPU resources

- Magnification and field of view
  - Greater magnification increases resolution and reduces noise
- Overlapping frames
  - Want to minimize redundant data but safely capture all of the surface
- Mechanical motion of camera
  - Drift error which distorts overlapping frames
- For a field of view of 700x540um, a 10” 78 r.p.m. record would require up to 1000 Gbytes

LBNL audio examples

- http://www-cdf.lbl.gov/~av/
- These examples are from 2D images of 78 r.p.m. vinyl and can be at above website
- Audio clearly compares favourably to mechanical playback but falls short of CD quality

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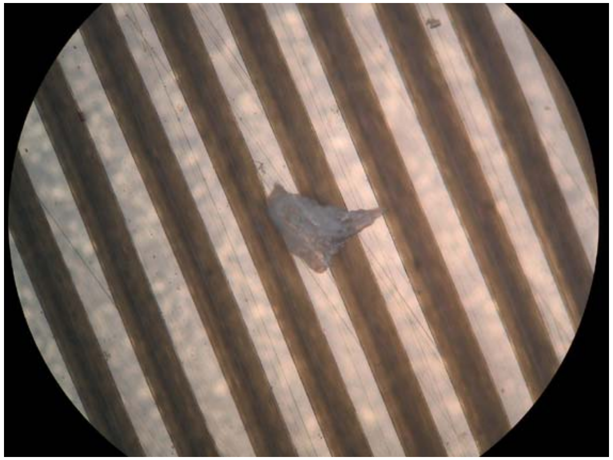
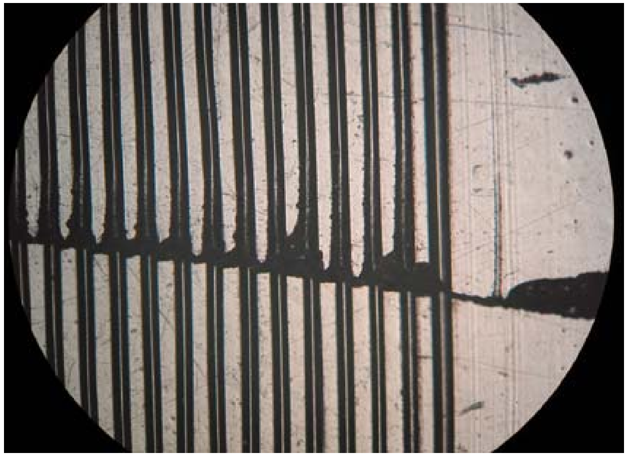
Issues in optical music reconstruction

- Stylus velocity is modeled through differentiation
  - Introduction of noise
- LBNL 2D system takes 50 minutes for 1 second of audio
  - Need to optimize for speed and automate
- Damaged sites can be quite large compared to groove dimensions
  - Require higher spatial sampling resolution in these areas for effective interpolation
- Current imaging methods use edge detection and make no explicit attempt to find unworn section of groove

Issues in optical music reconstruction





- The above images illustrate difficulties due to dust (left) and scratches (right) [3]

Conclusion

- There is a growing need to preserve our deteriorating musical heritage
- 3D and 2D optical reconstruction of high quality mechanically recorded music has been verified
- To the best of my knowledge, has not yet been applied to stereo 33 1/3 r.p.m.
- There is work happening in the DDMAL
  - $325K white-light interferometry microscope
  - Reduce scanning time
  - Develop image processing techniques

References

- [1] Fadeyev, V., and C. Haber. 2003. Reconstruction of mechanically recorded sound by image processing. *LBNL Report* 51983.
- [2] Fadeyev, V., C. Haber, C. Maul, J. McBride and M. Golden. 2004. Reconstruction of Recorded Sound from an Edison Cylinder using Three-Dimensional Non-Contact Optical Surface Metrology. *LBNL Report* 54927..
- [3] Stotzer, S., O. Johnsen, F. Bapst, C. Sudan, and R. Ingold. 2004. Phonographic sound extraction using image and signal processing. *Proceedings of the IEEE International Conference on Acoustics, Speech, and Signal Processing* 4: 289-92.
- [4] Galo, G. 1996. Disc Recording Equalization Demystified *. Journal of the Assocation for Recorded Sound Collections* 27:2*.*