Data Recovery from Optical Media

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Presented at the THIC Meeting at the National Center for Atmospheric Research, 1850 Table Mesa Drive, Boulder CO 80305-5602

July 18, 2006

Outline

I. Background

II. Review of Previous Work (THIC 2004)

- Microscopic recovery (Kasanavesi)
- Dynamic Spin Stand (Milster's Group)

III. Data Recovery from Various damaged optical media (Li)

- Special Defect Detection Circuitry
- Knurled Disc
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- Sanded Disc

IV. Wavelet Signal Processing (Kannan)

- Introduction to wavelets
- Wavelet processing and results
- De-noising results

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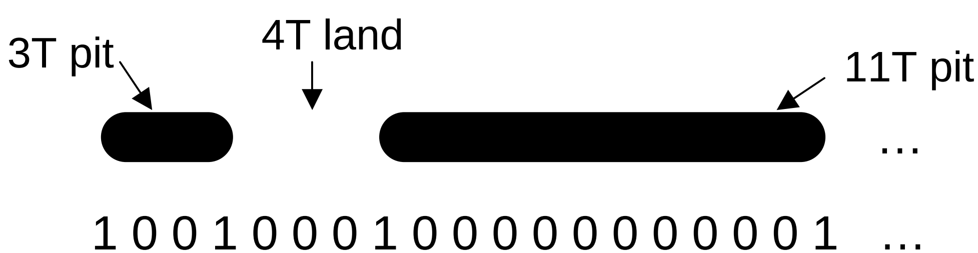
Background

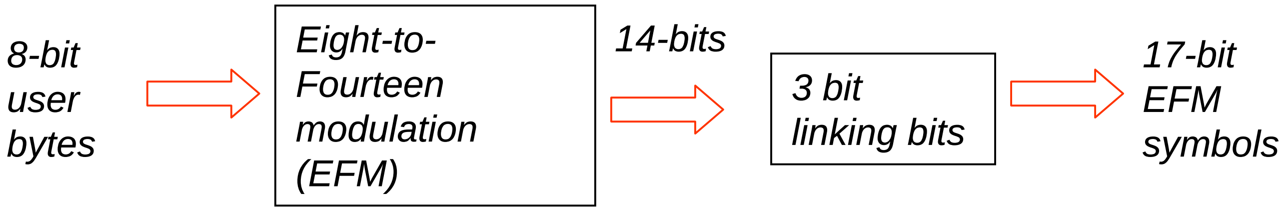
- Data on a CD are written on a spiral track of alternating “pits” and “lands”
- The pits and lands constitute an RLL data stream with following constraints
  - Minimum run-length constraint, d = 2 (3T)
  - Maximum run-length constraint, k = 10 (11T)



EFM

Eight-to-Fourteen modulation (EFM)

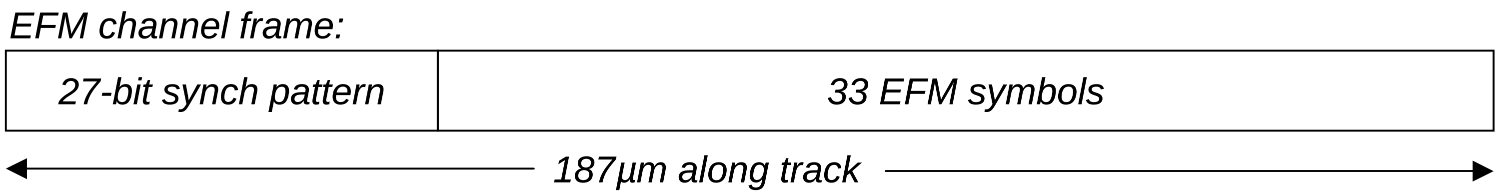
- User data undergoes EFM, where 8-bit user pattern is converted to a unique 14-bit EFM patterns adhering to the RLL constraints d = 2, k = 10..
- Three linking bits are then added to this 14-bit pattern to form an "EFM symbol"



EFM Frame

Division of data on the CD

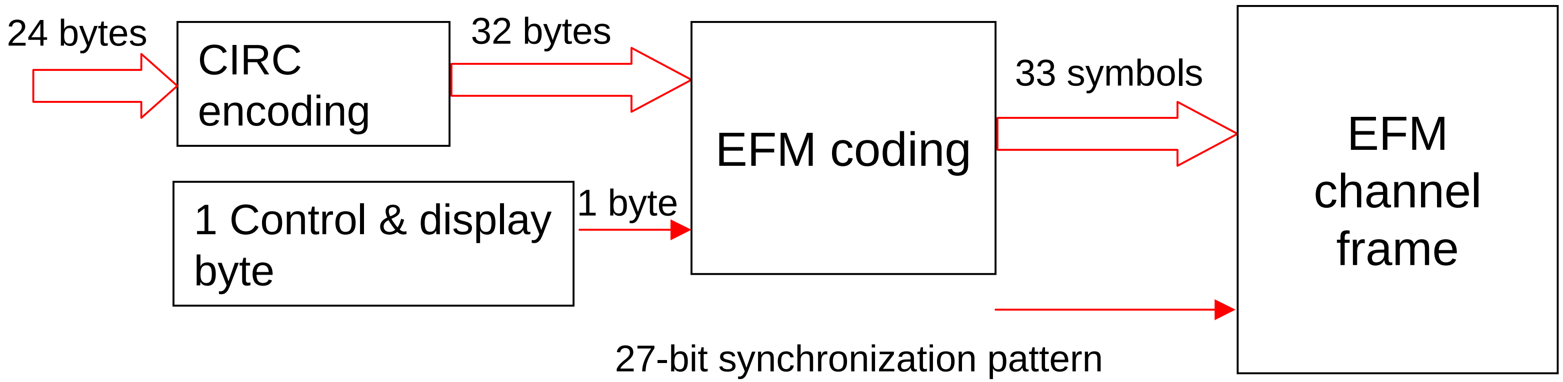
- A basic unit of information stored on a CD is called an "EFM channel frame". It consists of
  - ✓ Synch bits – 27 (11T pit followed by a 11T land)
  - ✓ Control and display bits – 17 (1 symbol)
  - ✓ User data – 408 (24 symbol)
  - ✓ Error correction coding bits – 136 (8 symbols)



One EFM channel frame – 588 bits (33 symbols + 27 bits)

CIRC Encoding

- Data that are recorded on a CD arrives in blocks of 24 bytes each.
- User data bytes are encoded using Cross Interleaved Reed Solomon Coding (CIRC) that adds 8 parity bytes for error correction.
- Each data block is interleaved among 108 different data blocks to allow data correction for large burst errors.

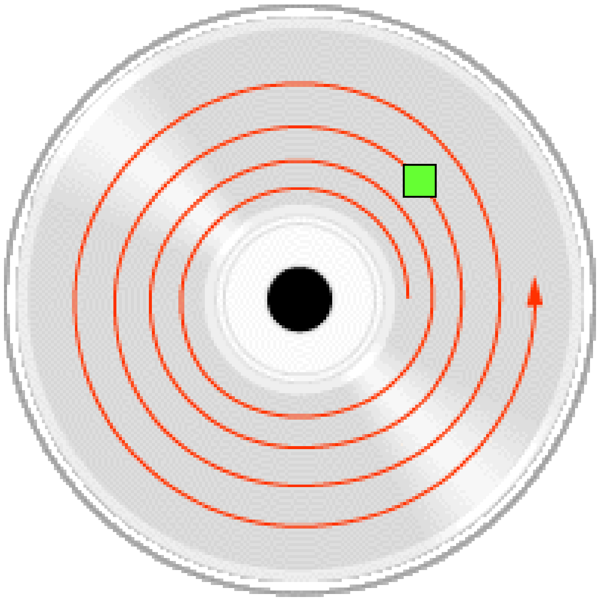


Remember: An EFM channel frame has 33 symbols and a 27-bit synchronization pattern.

ATIP Information

Absolute Time In Pre-groove (ATIP)

- ATIP is an imbedded time code that indicates the time elapsed by the laser drive since the beginning of the first EFM channel frame.
- While reading data, the compact disc rotates at a constant linear velocity of 1.2 m/s.
- Exact physical location of the recovered real data bytes can be obtained from the Absolute Time code.



The total length of the helical track is about 5,800m.

Review Of Previous Work

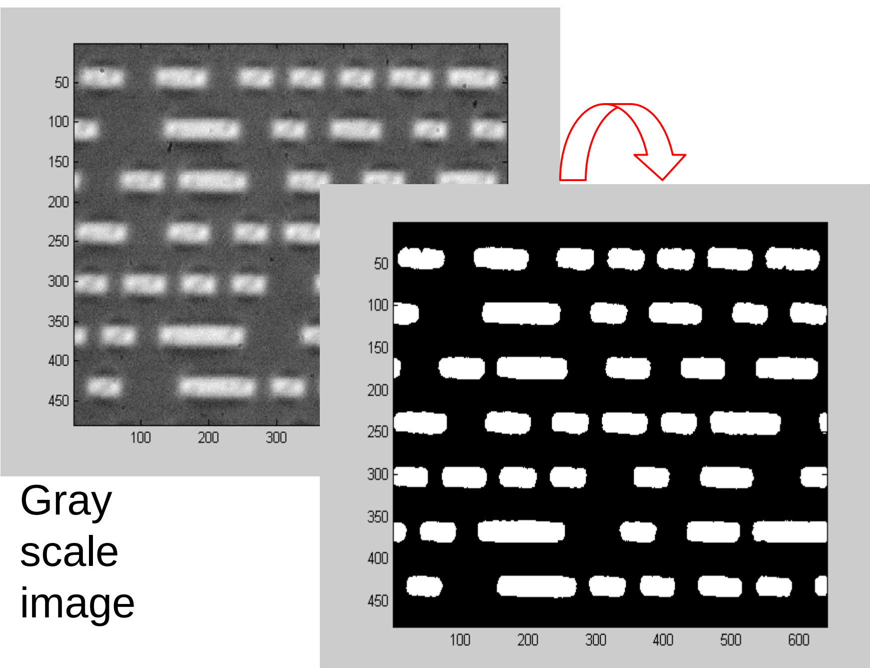
Three-step modular approach

- Module 1 – Derived signal recovery
  - ➢ Microscopic recovery (Kasanavesi)
  - ➢ Dynamic Spin Stand (Milster's Group)
- Module 2 – Real data recovery from derived signals.
- Module 3 – Data descrambling and ATIP recovery from real data bytes.
  - – Data descrambling is done to recover the user bytes from the interleaved data bytes.
  - – ATIP information is obtained by decoding control bytes from 98 consecutive frames.

Image Processing

- The "raw" gray scale image frames are converted into binary image frames using gray-level thresholding and median filtering.
- The binary images are integrated in the horizontal direction to recover information about the track centers.

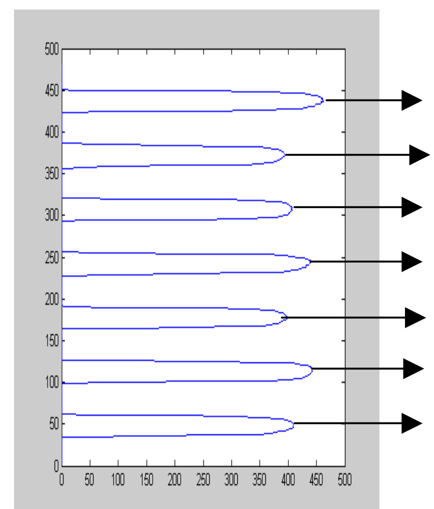
The peaks identify the position of the track centers in the image frame



Gray scale image

Binary image

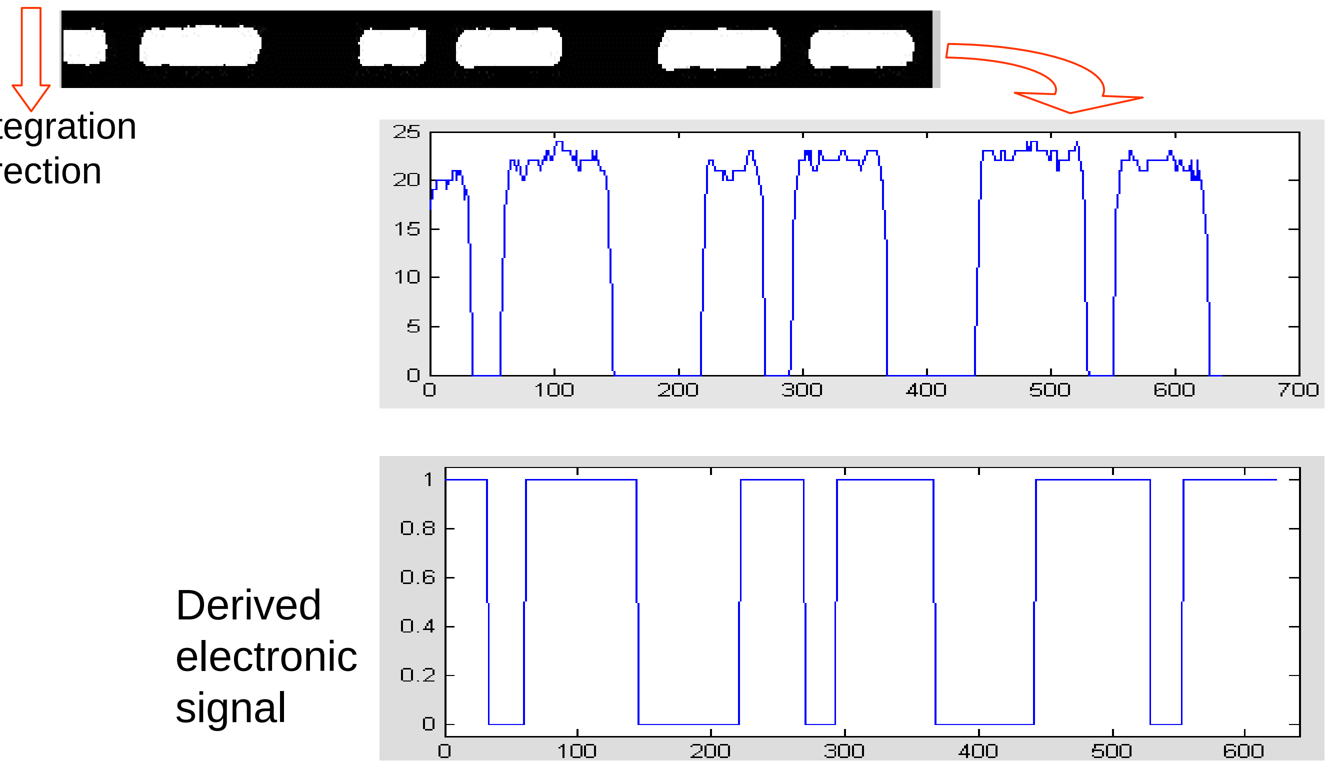
Integration direction



Track centers

Derived electronic signal from a single image frame

Integration direction



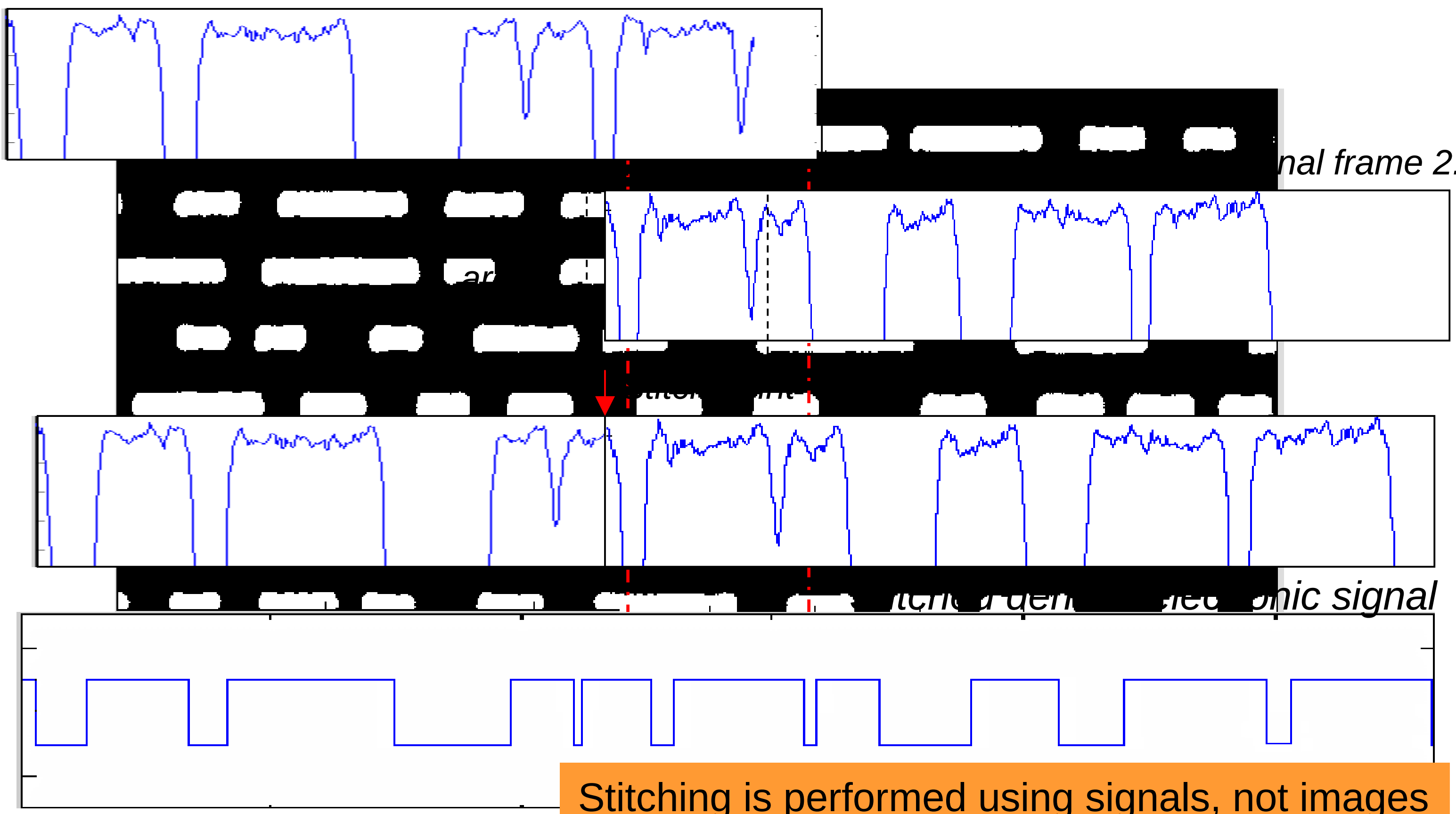
Thresholding

Derived electronic signal

Module 1 - Derived Signal Recovery

Automated stitching of contiguous image frames

Electronic signal frame 1:

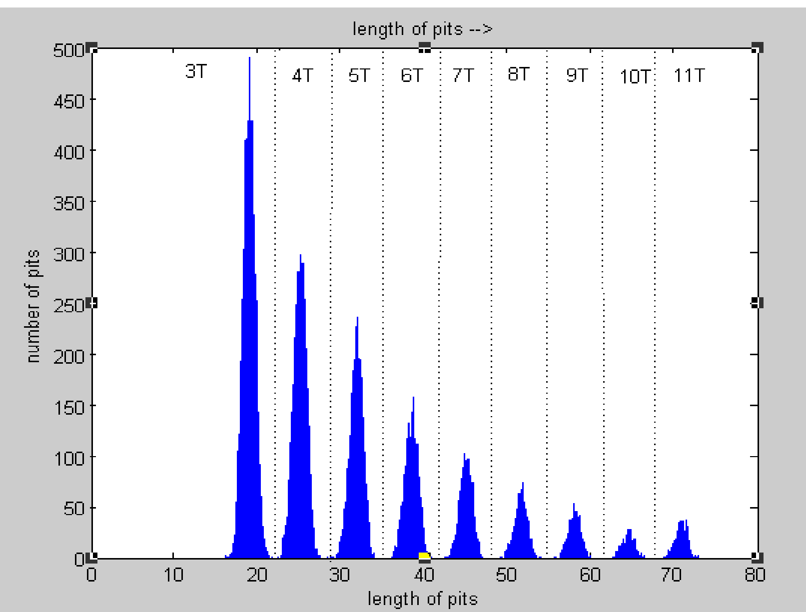


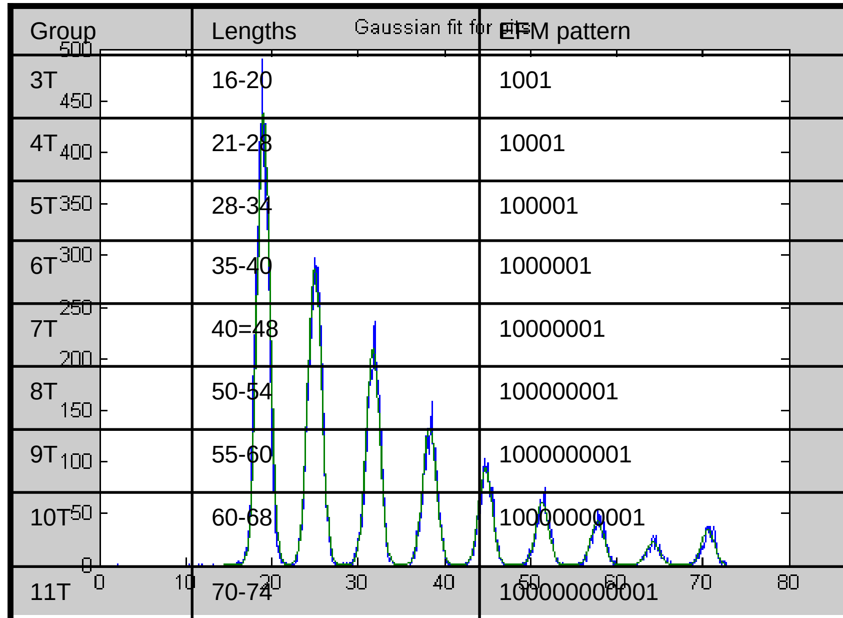
Stitching is performed using signals, not images

Module 2 - Real Data Recovery

EFM signal recovery

- The pit/land lengths of the derived electronic signals are grouped into 9 categories corresponding to the 9 run lengths of the actual EFM pattern (3T through 11T).
- Once all the lengths of the pits and lands are divided into 9 groups, Gaussian fit is done on the bins to clearly demarcate the bins (Milster).
- Each length of the pit/land of the electronic signal is compared with these groups and appropriate EFM pattern is assigned.



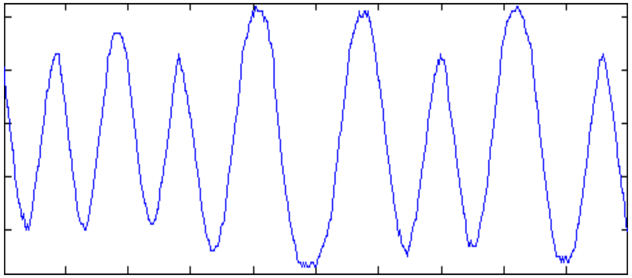


Group	Lengths	EFM pattern
3T	16-20	1001
4T	21-28	10001
5T	28-34	100001
6T	35-40	1000001
7T	40=48	10000001
8T	50-54	100000001
9T	55-60	1000000001
10T	60-68	10000000001
11T	70-74	100000000001

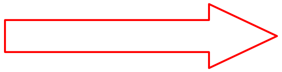
Module 1 - Dynamic Spin Stand Data Recovery

Motivation

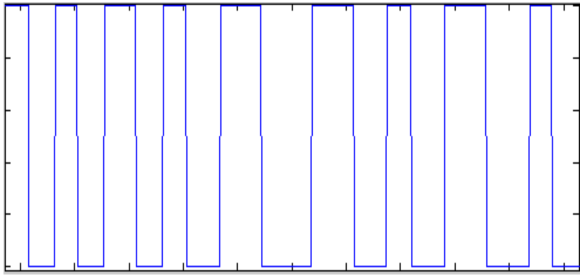
- Microscope data recovery is mainly acquisition limited.
- It takes hundreds of hours to acquire and process image frames using microscope.
- A dynamic spin stand (G3000-II) is developed by the Milster Research Group to recover data from relatively large fragments of a CD.
- The signal is then processed using a simple median filter and thresholded to recover the derived electronic signal.



Acquired signal from G3000-II

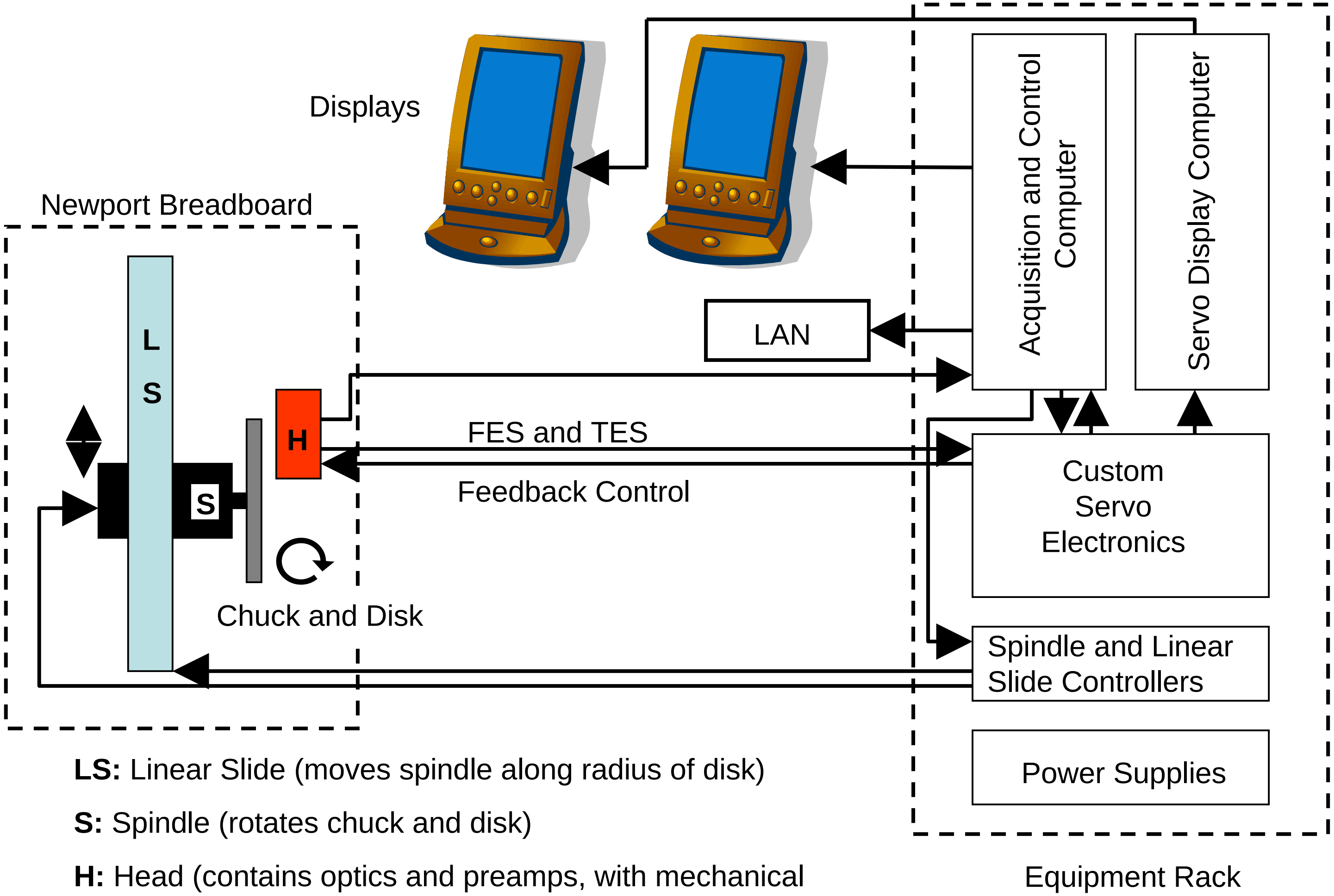


After Thresholding and Median Filtering



Recovered derived electronic signal

G3000 System Layout



LS: Linear Slide (moves spindle along radius of disk)

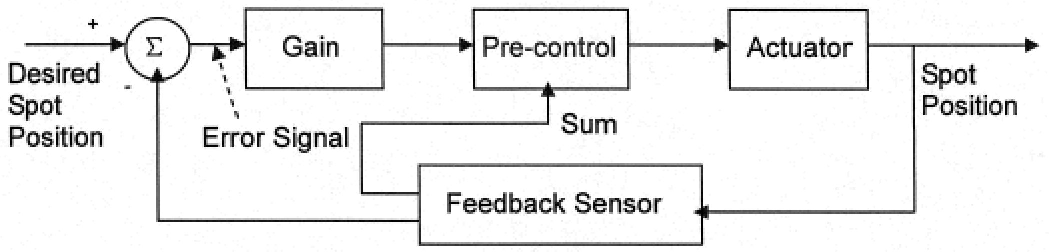
S: Spindle (rotates chuck and disk)

H: Head (contains optics and preamps, with mechanical adjustment fro alignment at fixed location)

Data Recovery From Various Damaged Optical Media

Special Defect Detecting Circuitry

- Regular discs – thickness of 1.2mm with a variance of 100nm.
- Optical disc actuators are capable of handling variance less than 500nm.
- With level IV erasures, sudden depth changes easily go beyond 100um.
- The control circuit places the laser head too far from the disc surface to lock focus again.

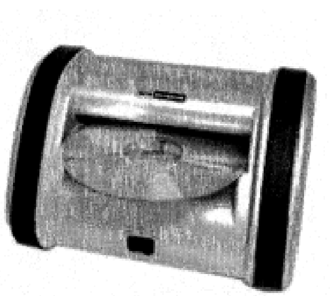


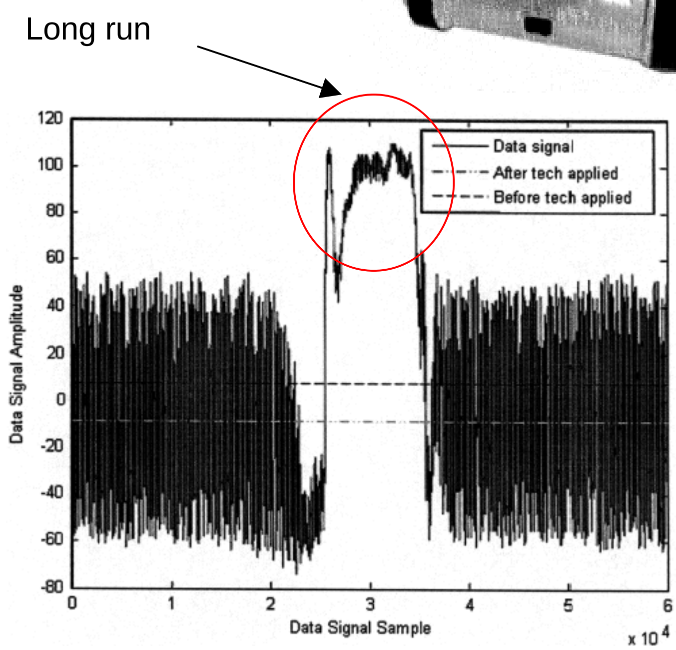
- Pre-control unit decides makes a decision if the error signal fed to the actuator is due to a defect and disables the relocation of the actuator temporarily.

Knurled Disc

Dye side Knurled Disc

- Holes penetrating data recording layer, erases data marks.
- System goes out of focus and enter search mode at the holes.
- Contaminates the run lengths, the longest run goes beyond 5000 samples.
- Threshold level provides an important judgment of the runlengths.
- These high peaks don't represent any data signal.
- Exclusion technique was used to find the threshold – resulted in better histograms.

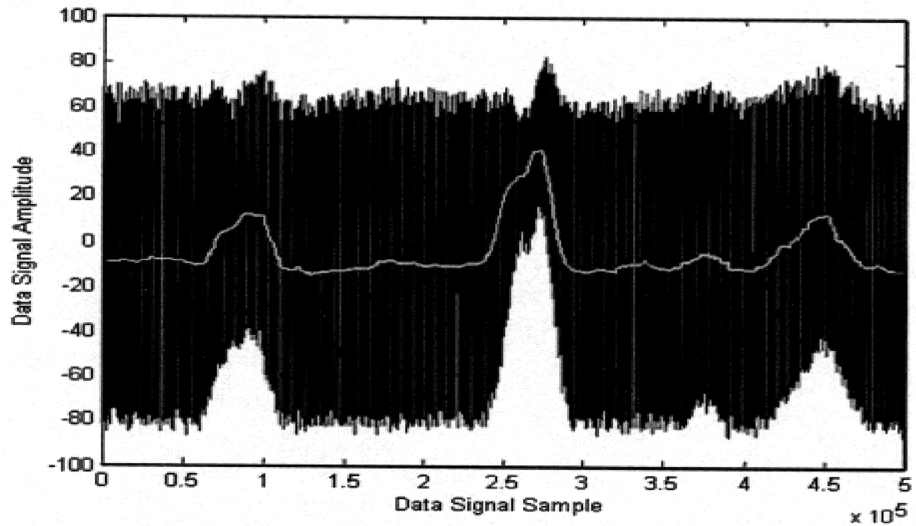




Knurled Disc

Substrate-side Knurled Disc

- No change on the data marks but deceives the system by creating light distraction through the holes on the data marks.
- Dynamic threshold adjustment algorithm is developed.
- The threshold follows the rise an fall of the envelope.
- Improvements were seen in the histogram and hence the probability of data recovery.
- Another promising mechanical recovery technique explored is improving the substrate topology by filling knurled holes with epoxy.



Statistics From Dye-Side Knurled Disc

- Knurled frames occur 24.59 times out of 363.79 average total frames.
- Total number of errant frames is 44.01.
- Knurling effect is 10.1.
- Overall bad frame percentage is 13.064%

STATISTICS FOR DYE-SIDE KNURLING EFFECTS BASED ON RADIUS

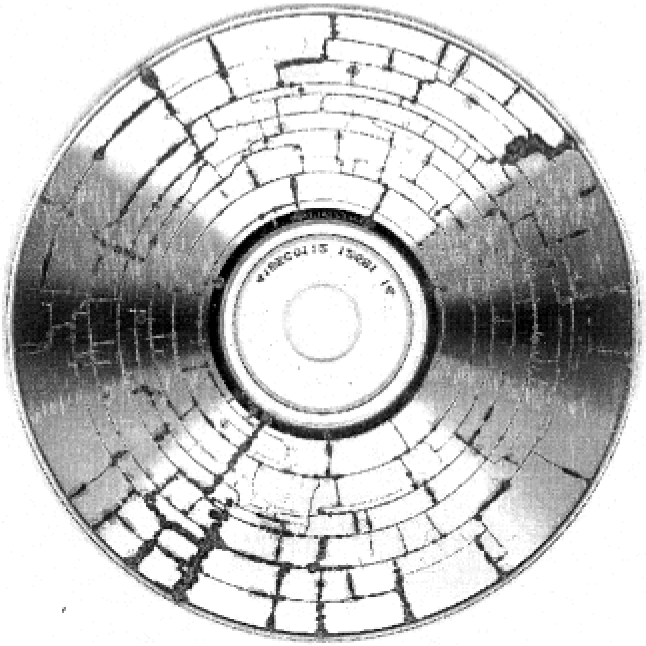
Radius Range (mm)	Bad frames Percentage	Standard deviation	Overall # frames	Total Bad # frames	Knurl affected # frames
35.37~35.55	13.064%	1.839%	363.95	47.55	33.14
40.47~41.57	13.092%	6.062%	363.82	47.36	25.41
44.5~45.7	10.214%	3.106%	363.70	37.15	19.07

Microwaved Disc

- CD-R gets cracked, major cracks follow dye pre-grooves and are concentric.
- Minor cracks connect these concentric cracks in radial direction.
- Data marks are burned and reflectivity at these regions drops dramatically.
- Low reflectivity happens once in a while and blinds the system.

STATISTICS FOR MICROWAVING EFFECTS BASED ON RADIUS

Radius (mm)	Fraction of the rotation	Bad frames Percentage	Overall # frames	Total Bad # frames	Microwave affected # frames
35.7	0.59-0.87	7.67	365	28	25
35.7	0.64-0.91	12.64	364	46	44
35.7	0.7-0.97	35.34	365	129	57
35.7	0.73-1	22.53	364	82	62



Sanded Disc

- Discs sanded on the substrate cause large scattering losses and much distortion in the laser beam
- Since data marks are erased, reading or even observing the marks under microscope is impossible
- Mechanical technique of covering the substrate with epoxy gave some encouraging results
- The erroneous rate of 6 bad frames out of total 124 frames i.e, 4.8% error rate
- This statistic is close to undisturbed disc.

Introduction To Wavelets

- Wavelets are used to preprocess and filter the noise components before conversion of the derived analog signal into digital signal.
- “The wavelet transform is a tool that cuts up data, functions or operators into different frequency components and then studies each component with a resolution matched to its scale (frequency)”
- Wavelet transforms provide a way to analyze signals in the frequency-time plot and with a resolution matched to the frequency
  - Higher frequency components => Lower frequency resolution

    Good time resolution
  - Lower frequency components => Higher frequency resolution

    Bad time resolution
- Discrete wavelet transform provides a means of computationally efficient frequency-time analysis.

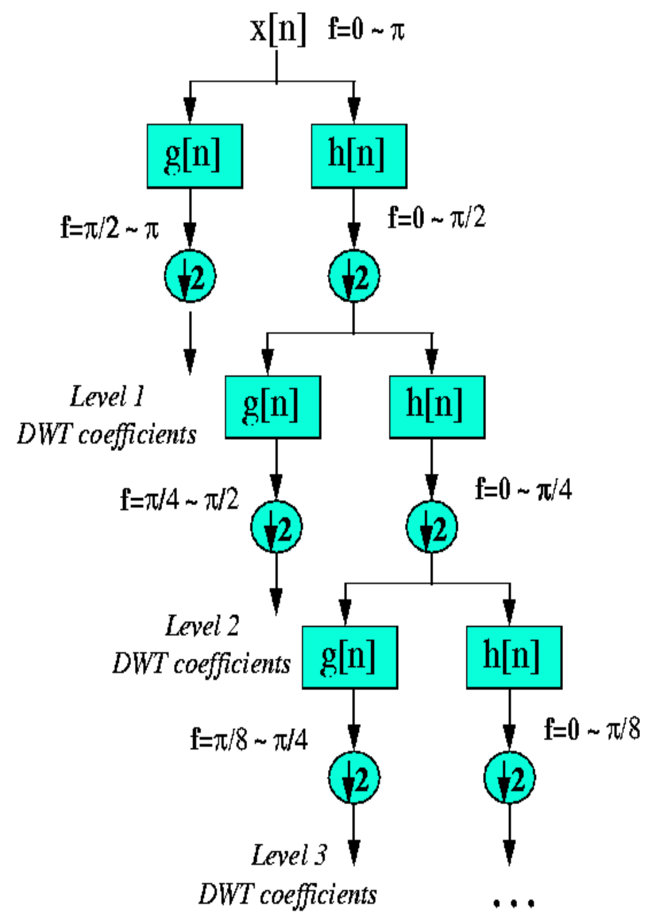
Introduction To Wavelets

- The signal is passed through a bank of low-pass and high-pass filters.
- At each stage, frequency band reduces by 2.
- Nyquist rule – every other sample is redundant and hence the signal is sub-sampled by 2 after each filtering stage.
- The Low pass and high pass filters are quadrature mirror filters – ensures easy reconstruction since half band filters form orthonormal bases
- Quadrature mirror filter relation

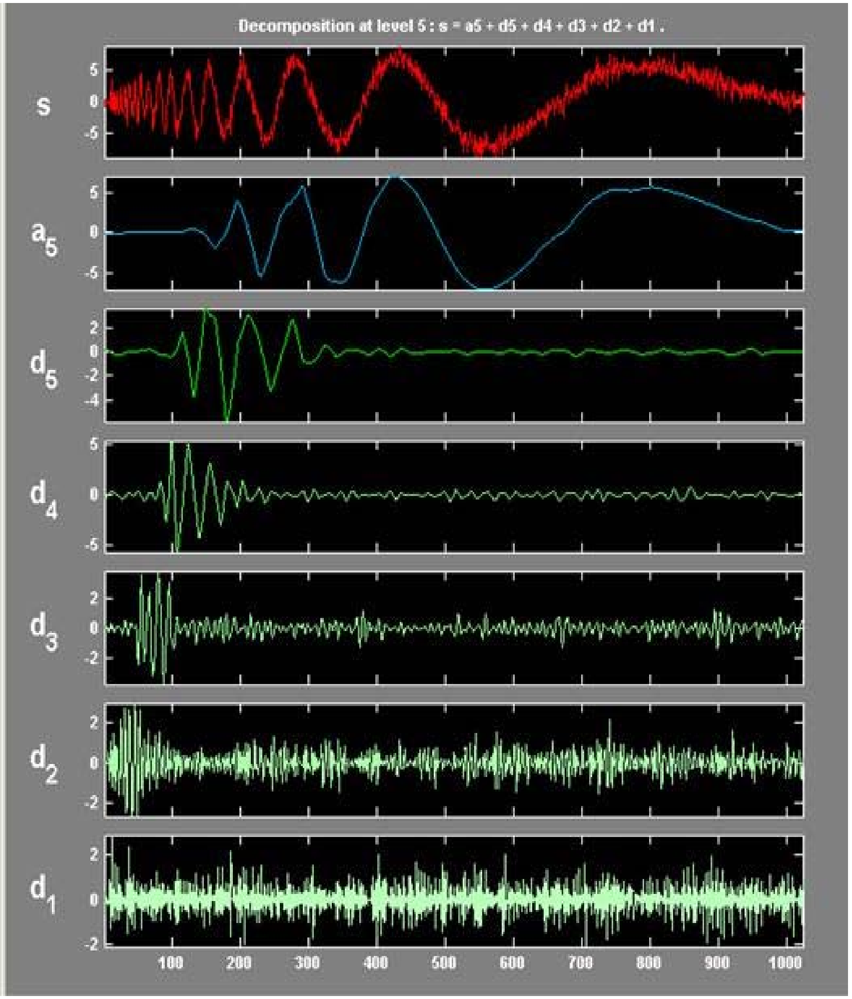
  $g[L-1-n] = (-1)^n.h[n]$

  g[n] - impulse response of high pass

  h[n] - impulse response of low pass



Introduction To Wavelets

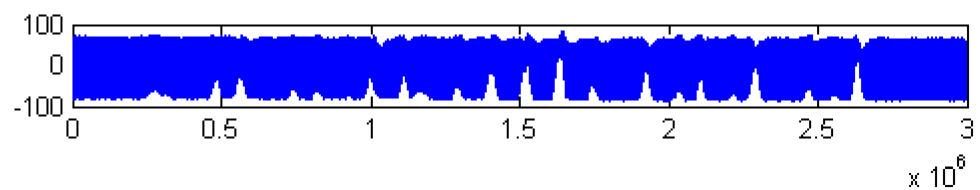


- Figure shows the decomposition of the given signal s into lowest-highest band of frequencies as a function of time.
- Optimal level of decomposition is chosen to observe the signal.
- Constituents causing error are identified and the reconstruction is performed by altering the same.
- Reconstruction is done by traversing the tree in the reverse direction – up sampling followed by filtering.

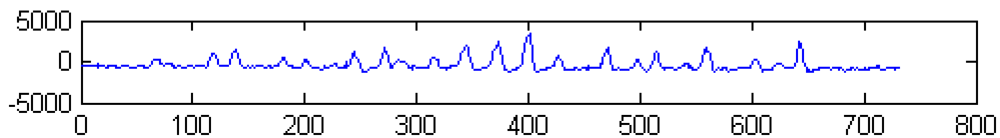
Wavelet Processing

Motivation

- The original dynamic thresholding method that was developed for recovering data from knurled discs takes longer time and buffer space.
- The adaptive algorithm is not able to keep in pace with the abrupt changes in the envelop of the signal.
- Wavelet coefficients that follow the envelop of the signal is used to correct the signal.
- This way the system gets the information directly from the signal and no need for it to adaptively learn it from the signal.



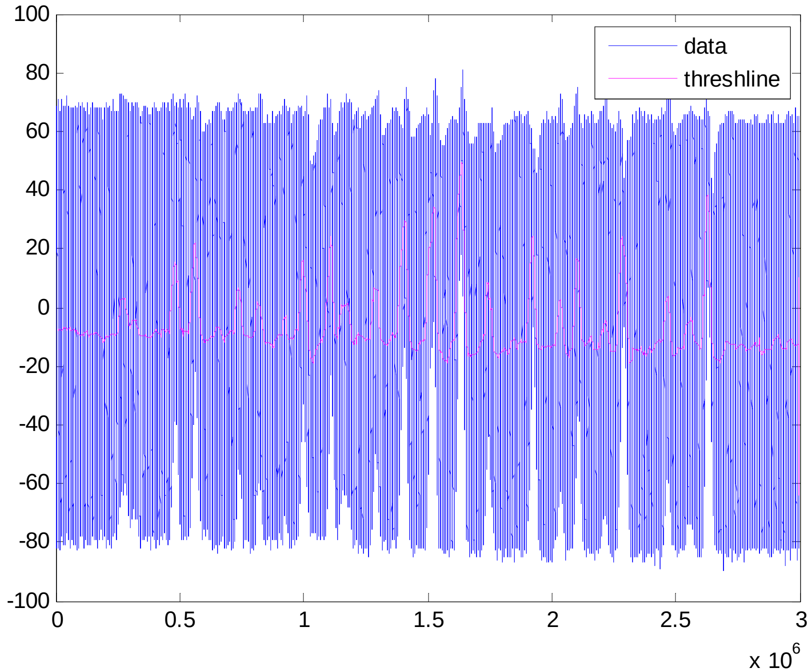
Data signal



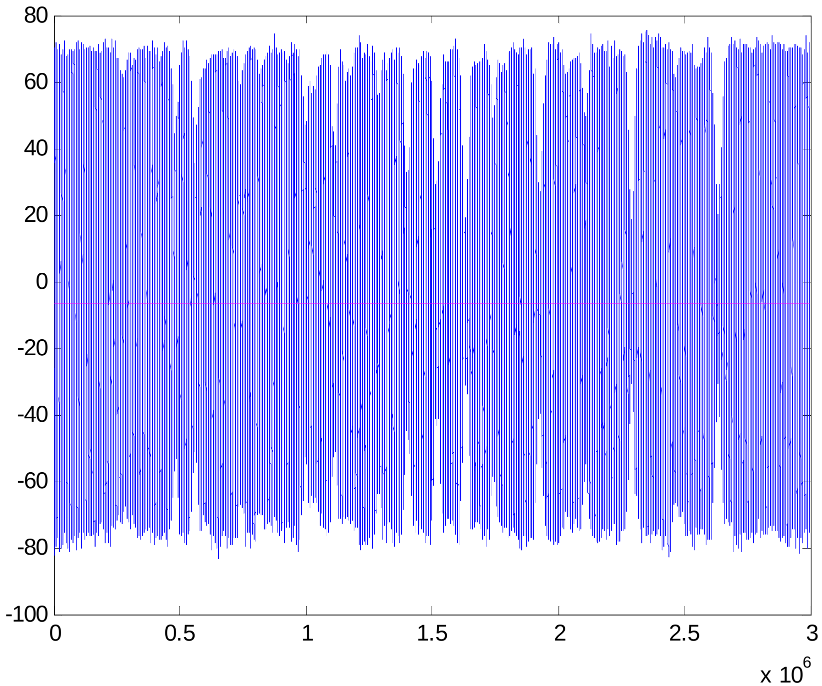
Wavelet coefficient containing envelop information

Wavelet Processing

- Reconstruction is done by substituting these coefficients with a constant value



Data affected by Substrate-side Knurling with dynamic threshold



After Wavelet processing, the signal becomes symmetrical about the fixed threshold

Wavelet Processing Results

- It was observed that the number of errant frames reduced by a factor of 2 after processing with wavelets
- Number of runs that are longer than usual, greatly reduced
- Wavelet de-noising completely removes the shorter than usual runs.

Radius	Bad frame %	Standard deviation	Overall number of frames	Total number of bad frames	Knurl affected frames
35.37~35.55	18.596	2.6875	369	68.67	1.33
44.5~44.7	19.66	1.3625	493.33	65.33	4.67
51~51.2	77.476	2.643	847.67	657	324.33

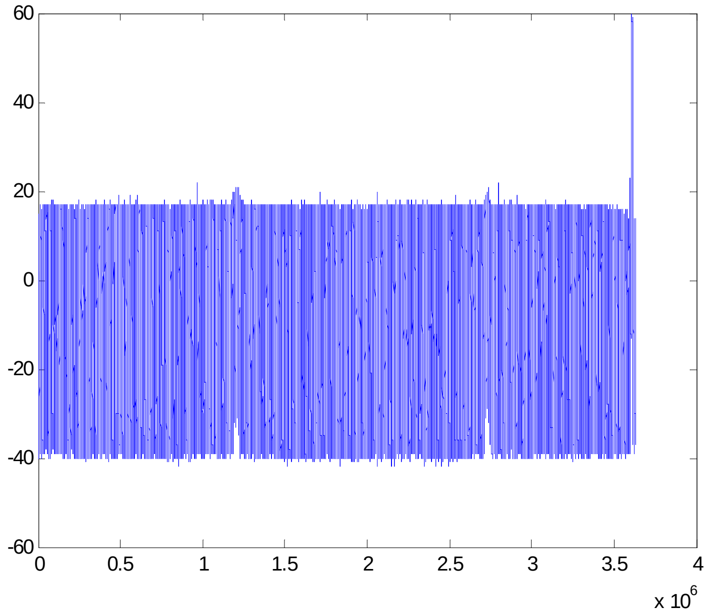
STATISTICS OF A SUBSTRATE KNURLED DISC BEFORE WAVELET PROCESSING

STATISTICS OF A SUBSTRATE KNURLED DISC AFTER WAVELET PROCESSING

Radius	Bad frame %	Standard deviation	Overall number of frames	Total bad frames	Knurl affected frames
35.37~35.55	7.866	1.8943	368.33	29	0
44.5~44.7	7.986	0.248	492.33	31.33	0
51~51.2	47.28	1.7635	732	346	125.33

De-noising Results

- A disc provided to us from one of our sponsors contained bitmap images of less than 3MB. The CD was broken into three parts with scratches caused due to the break. Results compared here are from the half disc and before ECC.



Data with scratches

After Wavelet Denoising

Recovered Bitmap file

De-Noising Results

Bitmap file recovered without
wavelet preprocessing

Bitmap file recovered with
wavelet preprocessing

Conclusions

- Microscope data recovery is possible on small segments (< 25 mm), but the process is slow and *acquisition limited*.
- Spin-stand data acquisition is fast (50,000X faster than current microscope recovery).
- Methods of media damage have been studied.
- Special defect detecting circuit made it possible to read data from knurled discs with sudden depth changes of greater than 100um.
- Long run exclusion technique and dynamic threshold algorithms have given better results.
- Mechanical technique of using epoxy coating gave better results with substrate- side knurled and sanded discs.
- Use of Wavelet analysis in dynamic range adjustment and de-noising have been effectively implemented.
- Performance of the system has been greatly improved

Acknowledgements

The presented work contains the Master's thesis work made by three Graduate students of Electrical and Computer Engineering Department at University of Arizona

- Sashi Kasanavesi, "Data Retireval From Broken CDs Using Microscope Images", 2004
- Kristi Li, "Data Recovery From Various Damaged Optical Media",2005
- Swetha Kannan, "Data Retrieval From Damaged Optical Media Using Wavelet Analysis", 2006