Wavelet Analysis / Line Removal

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Outline

➤ Wavelet Analysis Tool
  ➤ Lifting wavelets
  ➤ Daubechie’s wavelets

➤ Line Removal
  ➤ LineFilter class in the DMT

➤ Summary & Plans
Objects:
- WaveletL - family of lifting wavelets
- WaveletD - family of Daubechies wavelets
- WaveletI - integer version of lifting wavelets (maps integers to integers)
- Few constructors are provided (wavelet tree, wavelet binary tree, default)

Methods
- \( t2w(ts, level) \) - decomposition, \( ts \) - input time series, \( level \) - decomposition depth
- \( w2t(ts) \) - reconstruction, \( ts \) - output time series.
- \( getLayer(a, L) \) - extract wavelet coefficients from layer \( L \) into array \( a \).
- \( putLayer(a, L) \) - fill wavelet layer \( L \) with data from array \( a \).
- ..........

ROOT macro-files
- \( WSpectrum(w,"title", pallet) \) - time-frequency plot for wavelet \( w \).
- \( Plot(w, L) \) - plot wavelet coefficients for layer \( L \)
Daubechies Wavelets

- first compactly supported orthogonal wavelets with pre-assigned degree of smoothness.


- Fast Wavelet Transform using cascade algorithm

\[(Hx)_k = \Sigma h_{n-k} x_n, \quad (Gx)_k = \Sigma g_{n-k} x_n; \quad h, g - \text{wavelet filters}\]

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Lifting Wavelet Transform

R.C. Calderbank, I. Daubechies, W. Sweldens, B. L. Yeo. ACHA, V5, N3, pp. 332-369, 199
Wavelet Transforms that Maps Integers to Integers.

- twice faster than Fast Wavelet Transform.
- allows transforms that map integers to integers:

\[ P_1 = \text{int}(P), \ U_1 = \text{int}(U) \] (for lossless compression)

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Wavelet Transform Tree

- Detail coefficients $d_i$ represent data in different frequency bands
  - a. $df = f/2, f/4, f/8, \ldots$ - dyadic basis
  - b. $df = f/n$, $n$ - number of nodes in last layer - linear basis

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white noise + chirp
Wavelet time-frequency plots

- data: white Gaussian noise + linear chirp
- wavelet: db6 (class WaveletD)
- wavelet tree: 10 frequency bands - $df = 1/2, 1/4, 1/8, 1/16, \ldots$
- wavelet binary tree: 64 frequency bands - $df = 1/64$
Wavelet time-frequency plot

- LSC-AS_I_TEMP
  \( \Rightarrow w.t2w(x,8) \) - 256 wavelet layers

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**Combined WT-WBT time-frequency plot**

- **LSC-AS_I_TEMP**
  - `wt.t2w(x,3);` - wavelet tree transform (WT)
  - `w.getLayer(y,0);` - get approximation coefficients
  - `wbt.t2w(y,8);` - wavelet binary tree transform (WBT)

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Transients

- detection
- identification (transient frequency, energy, shape, …..)
- removal

Useful tool for Transient Analysis

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Line Filter

- class to find and remove lines (harmonics with the same fundamental frequency) has been added to DMT.
- construction: \textit{LineFilter}(f, \textit{fid})
  - creates \textit{LineFilter} object to remove harmonic lines with fundamental frequency \( f \) using filter \( \textit{fid} \)
- data
  - linked list \((f, E, a_{n1} : a_{n2})\), where \( E \) - total energy and \( a_{n1} : a_{n2} \) are amplitudes of harmonics \( n1:n2 \)
- methods
  - \textit{setFilter}(w, n1, n2) - set filter, \( w \) - min time interval to remove lines, \( n1:n2 \) - range of harmonics.
  - \( t_{out} = \text{apply}(t_{in}) \) - find and remove specified harmonics. \( t_{in} \) - input time series, \( t_{out} \) - cleaned time series.
  - \textit{findLines}(t_{in}) - find parameters \((f, E, a_{n1} : a_{n2})\) for input \( t_{in} \).
  - currently a quasi-Monochromatic Line Removal algorithm from UF is implemented (\( \textit{fid} = 0,1 \)). Other methods can be added.
- \textit{LineFilter} class can be used to develop Line Monitor (a background process to track selected lines)

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Documentation

- WAT: http://www.phys.ufl.edu/LIGO/wavelet/index.html

Wavelet Analysis Tool - WAT.
- WAT Objects and Methods.
- Start Using WAT.
- Using WAT.
- WAT Description I-III. (PostScript)
- WAT Description IV-VII. (PostScript)
- How To.

Bugs, Pitfalls, Tips and Tricks.
- Building and Installing ROOT and DMT.
- Adding Your Own Classes to ROOT via Shared Libraries.
- Documenting Your Classes via ROOT.
- Quirk in Frame Format.
- Note on Complex Numbers in WAT.
- Building Standalone Programs with WAT.

Software Used by WAT.
- GNU C++ compiler.
- The ROOT System.
- Data monitor Tool Project (DMT).
- Sandbox Library.
- Frame Class Library.
- PFT: Fortran code, C++ code, Benchmark test.

- Line Removal: http://www.phys.ufl.edu/~klimenko

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Summary & Plans

● Summary
  ➢ Wavelet transforms (lifting & Daubechie’s) are available for use in the DMT.
  ➢ Set of ROOT macro files is available to process and plot data
  ➢ LineFilter class to track and remove lines is included into the DMT. Currently the qMLR method is implemented. Other methods (multi-taper, CLR, …) can be added.
  ➢ The LineFilter class can be used to develop the Line Monitor.

● Plans
  ➢ Add family of Gaussian wavelets (example: Mexican hat).
  ➢ Add family of Symmlets (symmetric Daubechies wavelets).
  ➢ Transient analysis with wavelets: Development of statistical algorithms for transients detection, identification and removal. Try wavelet algorithms on the engineering run data.

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