Atomic Representation of Glitches - Preliminary Results

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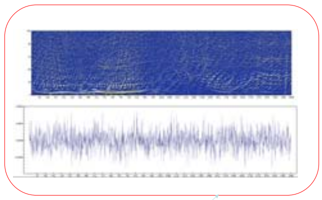
Abstract - Glitches are transients of environmental or instrumental origin appearing in the data channel of existing large baseline interferometer based gravitational wave detectors. Their presence limits severely the performance of gravitational wave detection/estimation algorithms based on the customary Gaussian noise assumption, and requires adopting ad-hoc data laundering techniques. Modeling glitches is in important issue both for simulating the instruments' noise background and for designing gravitational wave detection algorithms with improved performance. We believe that glitches can be modeled as superpositions of very simple time-frequency atoms, and discuss the use of a Matching-Pursuit algorithm to decompose glitches into Sine-Gaussian and Ring-Down components. The method has been tested on the data-channel glitch database maintained by P. Saulson and co-Workers [1]. Preliminary results appear encouraging, and suggest that only a few atoms may be needed to represent most of the observed glitches.



Rationale

This study is based on the hypothesis that glitches can be conveniently modeled by combining a suitable number of time-frequency atoms (waveforms with compact time-frequency support), extracted from a limited set (dictionary) of shapes. Indeed, typical glitches were found to occur many times within each data record, and across the whole database. From a physical viewpoint, this suggests a model where wide-band (impulsive) random excitations hit the interferometer at some susceptible entry points (many have been actually identified [2]) reaching the data channel through specific narrow-band linear transfer functions. The shape of observed glitches depends thus primarily on the nature of these transfer functions, resulting into simple recurrent waveforms. The input disturbances may be modeled as random Dirac-delta spike trains, distributed as Cox (adiabatically non-stationary Poisson) processes.

The result is a model for the glitch noise component in the data channel of the Middleton class, introduced in [3].

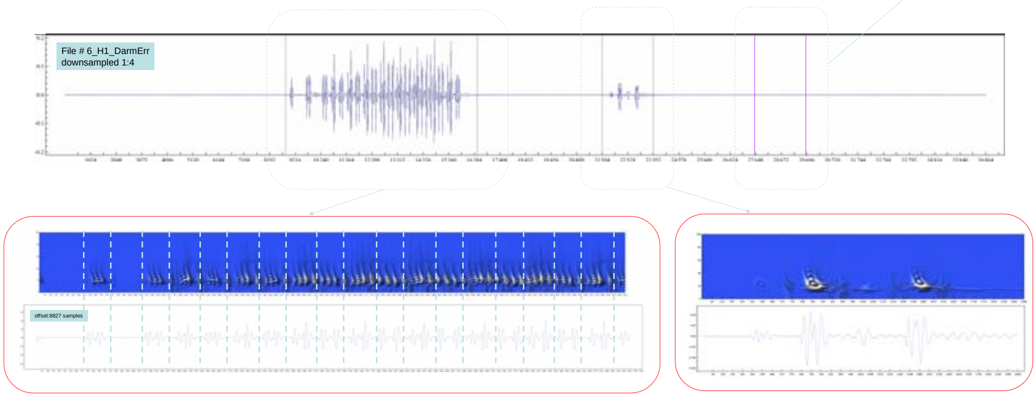


Fig. 1 - File # 6 in [1] , downsampled 1:4 ($f_s = 4096$ Hz). The insets show the two glitchy subsets in the original time series, as well as a "quiet" (Gaussian) subset. Two main "recurrent" transient waveforms are identified upon inspection of the time series. The blue background pictures display the relief maps of the corresponding Discrete Pseudo Wigner-Ville (DPWV) time-frequency transform of the data. Elementary ("atomic") constituents, with essentially compact time-frequency support are clearly visible, together with interference (striped) artifacts.

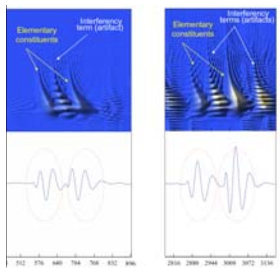


Fig. 2 - Close-ups of main "recurrent" waveforms in file #6. DPWV time-frequency images (top) reveal atomic constituents and interference terms.

Implementation. Matching Pursuit

We used a dictionary of (complex) Sine-Gaussian (Gabor) functions. These are minimum spread $(\Delta t \cdot \Delta f = (4\pi)^{-1})$ atoms, depending on 5 parameters only (amplitude, initial phase, location in time, location in frequency, and time spread). In order to decompose glitches into time-frequency atoms we implemented a modified Matching Pursuit (MP) algorithm [4]. MP was originally designed to decompose very complicated (e.g., musical) signals into thousands of time-frequency atoms. Hopefully, MP should be effective in decomposing much simpler signal into a much smaller number of atoms. Our preliminary findings suggest that this approach is generally successful, although special care is required in several stages of the algorithm, compared to standard implementations. The MP flow diagram is sketched below.

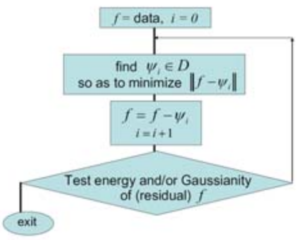


Fig. 3 – MP algorithm flow-diagram

Performance

We run successfully several tests on simulated atomic clusters embedded in Gaussian noise, which were reconstructed satisfactorily. The MP algorithm succeeded in disentangling overlapping atoms at sufficiently large (>10) glitch signal-to-noise ratios. The algorithm was then applied to the LIGO DARM_ERR channel glitch collection in [1]. See [5] as regards the selection criteria used to compile this database. For most glitches in the database, even a single atom may capture most (70-105%) of the glitch energy. In general only a few atoms were needed to obtain a strong approximation to the original signal. See Figure 3 for an example.

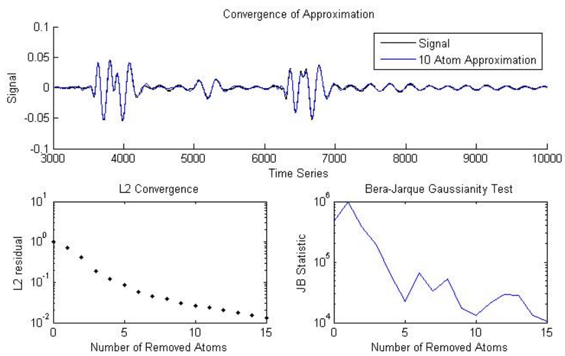


Fig. 3 Glitch train & its Sine-Gaussian Approximant, L^2 Residual vs # of Atoms, and Bera-Jarque gaussianity test

Ongoing Work

We are now working toward: i) Obtaining atomic parameter distributions from atom-based representations of glitch databases, ii) considering alternative and/or additional dictionaries. In particular, we plan to explore the possible use of generic Ring-Down waveforms, and using (robust versions of) Prony algorithm [6] to identify them.

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References

[1] Glitch database maintained by P. Saulson and Co-workers available at http://www.phy.syr.edu/research/relativity/ligo/restricted/glitch_catalog/ (LIGO password req-uired).
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