Extracting Signals via Blind Deconvolution

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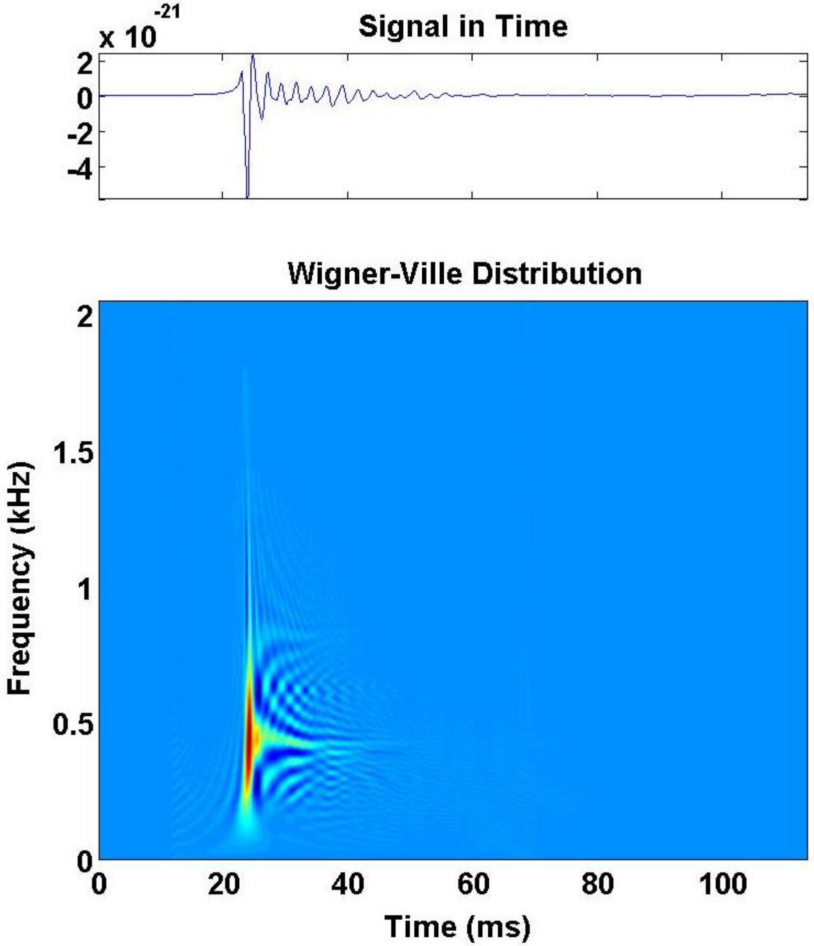
Goal: Core-Collapse Supernovae Signal Extraction

- Want to answer the question: What supernova waveform features can be extracted from a LIGO detection for different S/N?
  - » For example: bounce frequencies, ringdown frequencies
- Need to be able to combine data from multiple IFOs to recover a common signal

Waveform at right from Ott et. al. **astro-ph/0307472**



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Blind Deconvolution Problem Formulation

- In a Single Input Multiple Output (SIMO) system a source signal s(k) is detected by multiple instruments whose output is $x_i(k)$
- The modification of the signal by the instruments can be described by a filter h_{ip} (also called channel) so that:

$$x_i = \sum_{p=0}^{M} h_{ip} s(k - p) + v_i$$

- Blind Deconvolution (also called Blind Equalization) algorithms either find h_{ip} or an inverse filter so that s(k) can be recovered.

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Blind Deconvolution: Challenges

- Nearly all Blind Deconvolution algorithms assume that the source signal is independent and identically distributed. Supernova waveforms are highly colored.
- Many algorithms also assume that the channels are minimum phase (all poles and zeros are inside the unit circle). LIGO IFO impulse responses are not minimum phase
- EVAM – algorithm can handle both colored signals and non-minimum phase channels
  - » Reference – EVAM: An Eigenvector-Based Algorithm for Multichannel Blind Deconvolution of Input Colored Signals by Mehmet Gurelli and Chrysostomos Nikias, IEEE Transactions on Signal Processing, Vol43 No1, Jan 1995.

EVAM: Algorithm Overview (2 channel case)

- Choose initial filter lengths N_0
- Calculate ($2N_0$ x $2N_0$) sample correlation matrix R_x

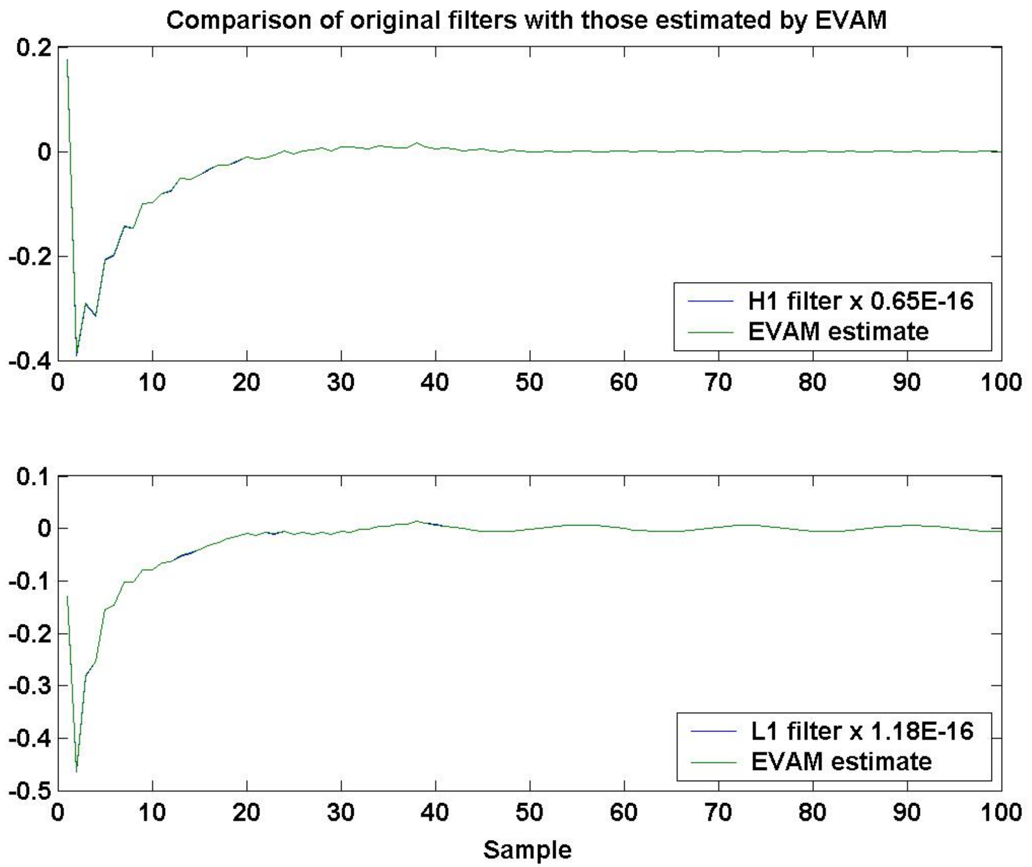
$$\underline{X}(k) = [x_1(k), x_1(k-1), \ldots, x_1(k-N_0), x_2(k), x_2(k-1), \ldots, x_2(k-N_0)]^T$$

$$* A_x = [\underline{X}(\tau), \underline{X}(\tau-1), \ldots, \underline{X}(1)]^T \quad R_x = A_x^T A_x$$ ***eqn incorrect in paper**

- Find the eigenvectors corresponding to the K_0 smallest eigenvalues of R_x and new filter lengths $N_1 = N_0 - (K_0+1)$
- Calculate ($2N_1$ x $2N_1$) matrix M^TM where M is similar in form to A, using the eigenvectors found in the previous step in the place of x(k)
- The eigenvector of M^TM corresponding to the smallest eigenvalue is equal to the channel filters
- Filter data with the inverse of the channel filters in the frequency domain to recover the original signal

EVAM: Simplified Example

- Calculate impulse response of H1 and L1 for GPS time 729337313 (S2) using inverse calibration function calibsimfd.m (part of the GravEn package)
- Restrict impulse responses and supernova waveform (Ott et. al. s15A1000B0.1) to 256-1024Hz band
- Filter supernova waveform with first 100 samples of H1 and L1 impulse responses
- EVAM recovers supernova waveform (cross correlation between EVAM output and supernova signal = 1)



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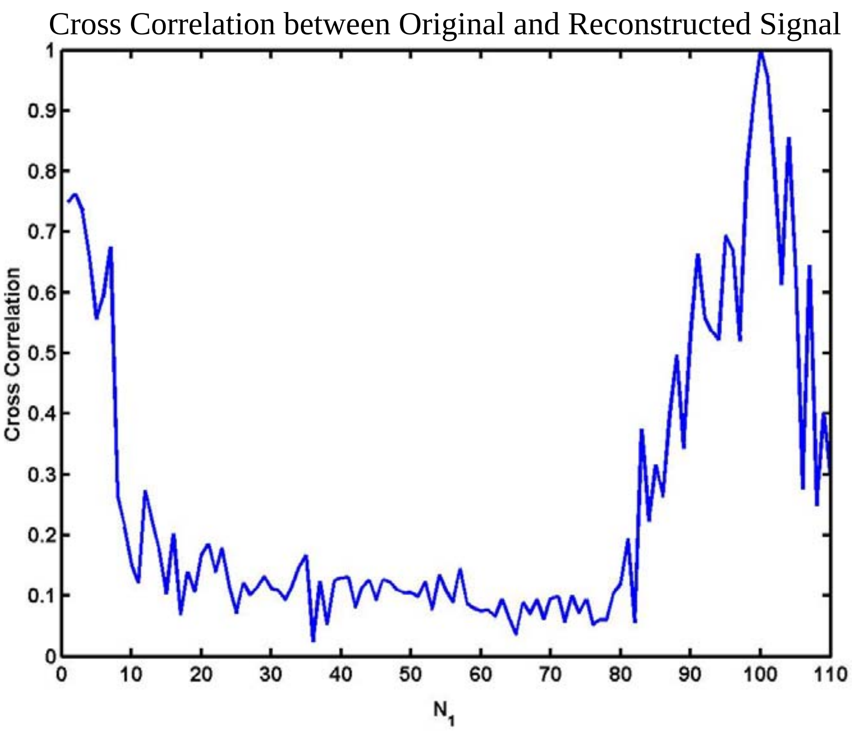
EVAM: Drawbacks

- K_0, the number of smallest eigenvalues of R_x must be chosen so that the length N_1 of the estimated filters is exactly equal to the channel lengths.
  - » Quote from paper – “The selection criteria for these parameters are still under investigation”
  - » May be able to use some information theoretic criterion – to be investigated
- Performance of algorithm not robust to small changes in parameters.
- Possible improvement – use decision feedback equalizer proposed by Skowratananot, Lambotharan and Chambers to recover signals. Adds robustness against similar channels and overestimation of channel lengths



Conclusions & Future Research

- Blind Deconvolution could be a powerful method for pulling signals out of data. So far EVAM is the only method investigated that works for colored signals
- EVAM is very sensitive to a number of parameters and it is not clear how best to select them. More work needed.
- EVAM has not yet successfully reconstructed signals for more realistic situations. (Hardware injections, for example) Due to non-optimum parameter choices?
- Possible Improvements to EVAM – Decision Feedback Equaliser to reconstruct signals.
- Is there a better algorithm than EVAM? For example: Iterative Quadratic Maximum Likelihood (IQML) proposed by Bresler and Macovski
- Suggestions welcome!