An Investigation of Nonlinear Adaptive Space-Time Processing for the Real-Time Detection of Extraterrestrial Transients

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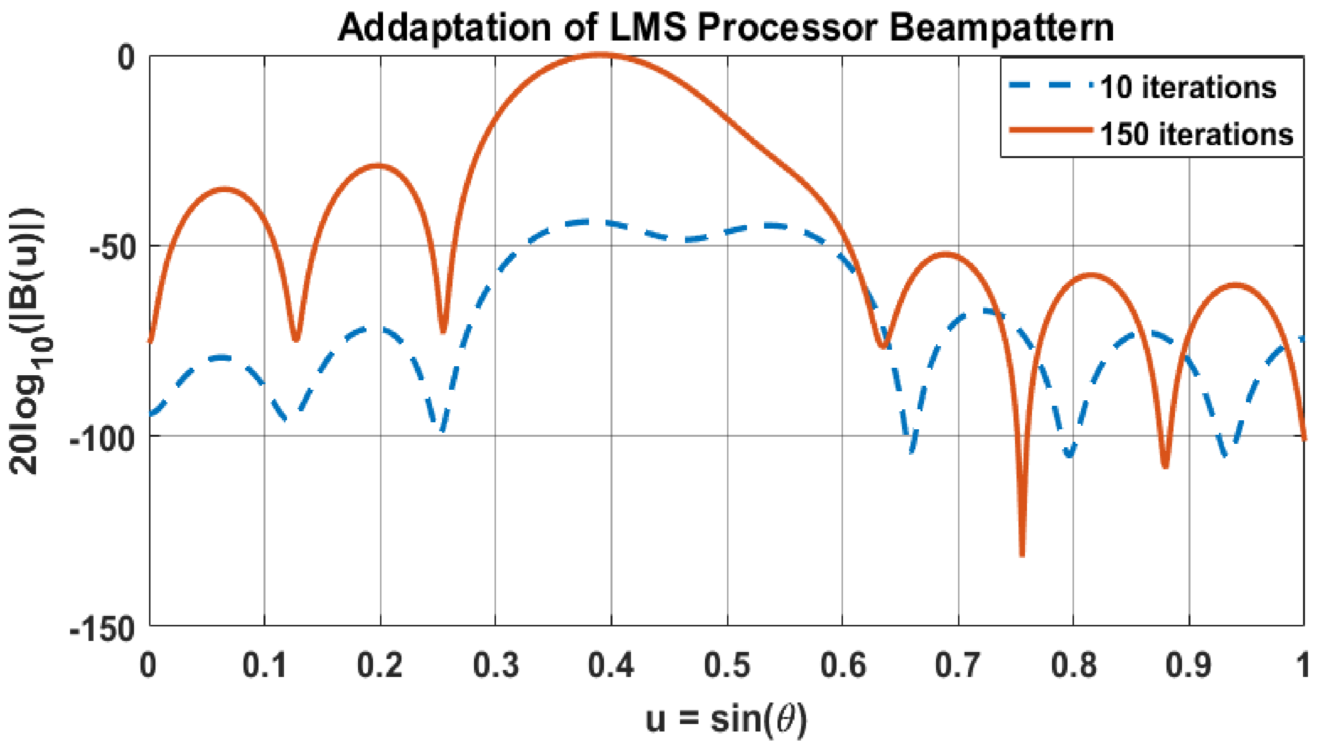
Introduction:

- Observations in radio astronomy can be broadly separated into to classes, imaging of steady radio sources and the detection and analysis of radio transients. In both cases, system sensitivity is a critical issue.
- Transient detection often involves feature extraction, parametric searches and machine learning algorithms which are computationally complex and difficult to parallelize.
- Since some extraterrestrial transients display nonlinear behavior, it may be advantageous to employ an augmented LMS filter to the transient detection problem, as the filter is highly parallelizable.

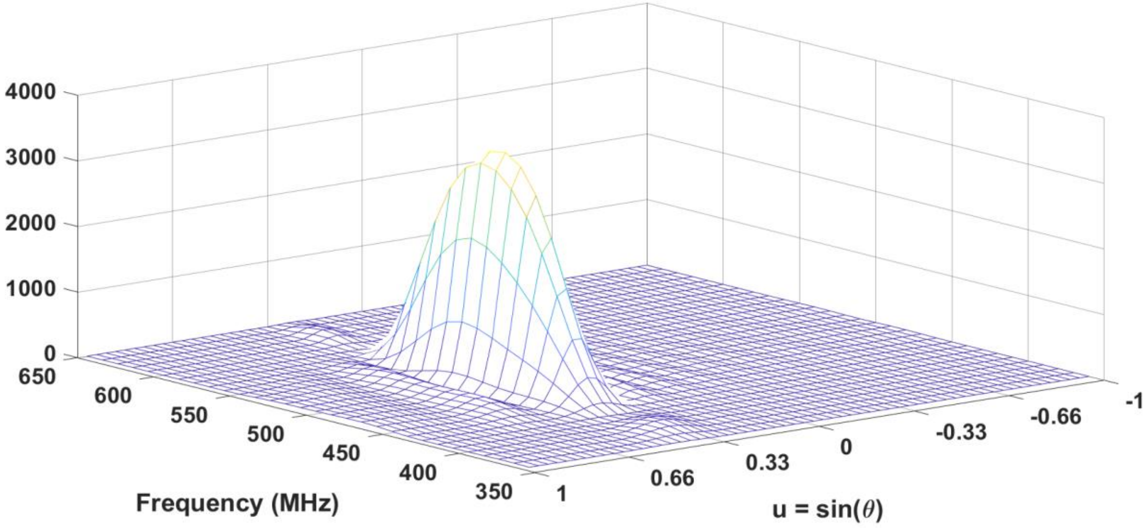
The LMS Adaptive Processor:

- The statistically optimal linear filter in the case of a process with known second order statistics is the Wiener filter.
- The LMS processor is an adaptive Weiner filter which is capable of optimal filtering of unknown signals, so long as a reference signal of similar nature is provided.
- When applied to sensor arrays, the result is a statistically optimal beam pattern which may null out interference, Fig. 1.
- The weight update vector in the weight update equation, Eq. (5), is a linear projection of the input signal onto the error signal. The application of the filter itself is a simple linear projection and adaptive filter is thus highly parallelizable in its implementation.



Extension of the LMS Adaptive Array:

- The standard linear adaptive array is extended to the wideband and nonlinear case. Both extensions preserve the linear updatability and parallelizable implementation of the system.
- The extension to the wideband array is achieved by applying a tapped delay line at each sensor element, instead of a single weight. This provides the adaptive processor with degrees of freedom in both time and space, Fig. 2.
- The response of a general nonlinear system can be expressed in terms of higher dimension convolutions, using the Volterra series expansion. Applying a Volterra filter to the array instead of a linear projection and using the LMS algorithm produces a nonlinear adaptive filter.



Higher-Order Spectral Analysis:

- Just as linear stationary processes may be characterized by their power spectrum, nonlinear stationary processes may be characterized by their higher-order spectra.
- The components of the higher-order spectra indicate increasing orders of phase coupling in the signal under analysis. For example, non-zero components in the spectrum indicate quadratic phase coupling.
- By analyzing transient signals of interest, such as pulsar bursts and FRBs, it may be possible to find similarities in their higher-order spectra. These similarities may be used to provide a reference signal for a nonlinear and wideband LMS sensor array system.

Optimal Space Time Filtering for Nonlinear Signals With Known Parameters:

- A random signal with a bispectrum centered around a known point is simulated and applied at the input of a simulated nonlinear and wideband LMS adaptive array system. The system uses the coupled component representing the center of the bispectrum as a reference.
- An additive white Gaussian noise signal is applied to the simulated array with a different baring to the desired signal.
- It is found that the simulated array can separate the desired signal from the noise signal despite an overlap in their power spectrum.

Conclusion:

- Simulations show that the TDL non-linear LMS processor is capable of detecting a desired signal with known non-linear properties while suppressing linear interference sources.
- The ability of the system to deal with nonlinear interference is still to be tested. It may also be possible that the system may be capable of adaptively implementing a coherent dedispersion filter.
- The practical implementation of such a system may result in improvements in real time detection, as the filter is highly parallelizable in its implementation.