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Title: Broadband Time-Frequency Analysis Using a Multicomputer

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Areas: Algorithm Mapping to High Performance Architectures
Embedded Computing for Global Sensors and Information Dominance

Time-frequency analysis techniques are used to produce a plot of a signal's power spectrum as a function of time. The most well-known time-frequency representation is the spectrogram. Although relatively simple to compute, it suffers from having a significant limitation in that it cannot offer good time or frequency resolution simultaneously. To overcome this weakness, many other representations have been developed that provide combined high resolution over time and frequency. The Wigner-Ville distribution, the scalogram, and the discrete Gabor transform are among the most well-known of these methods. Due to specific shortcomings with regard to these distributions for multi-component signals, and for certain mathematical concerns such as shift invariance and time and frequency marginal conditions, several classes of representations have been developed which effectively address specific signal types. Examples of these categories are Cohen's class, the affine class, and the signal adaptive expansions based upon the Matching Pursuit method. The goals of any of these specific methods are to minimize cross-term interference, provide good time and frequency resolution, and provide a good model for the signal of interest.

In the past, time-frequency analysis techniques have seen limited use on high-sample rate data streams. Although these methods are effective at capturing the evolution of the instantaneous frequency of non-stationary, transient and time-varying signals, the associated computational complexity has been high. As such, the application of such methods has been limited to analysis of relatively low-frequency phenomena. Examples of the types of applications generally include acoustic signals, underwater mammalian and other biological signal analysis, electro encephalograph (EEG) potentials, sonar and underwater acoustics, seismic monitoring, and fault detection and analysis of rotating machinery.

By porting these time-frequency algorithms onto a multicomputer, it becomes possible to accommodate wide-band, high-sample rate data streams. The benefit is that highly dynamic and transient phenomena within the radio spectrum can be detected, measured and identified. Several types of applications now become amenable to detailed time-frequency analysis. Examples might be spectrum compliance monitoring, modeling of time-varying channels for multiple access spread spectrum, detection of exotic waveforms buried in noise, transient signal detection, classification of signal modulation types, improved source direction of arrival (DOA) estimation performance through spatial time-frequency analysis, and interference and jammer excision.

A multicomputer-based solution is an ideal fit to handle the large processing requirement associated with high-sample rates and high-computational complexity. The processing load can be distributed across multiple compute nodes and the data sets can be constructed to ensure efficient movement of data among the nodes. The system can be easily scaled and reconfigured to serve changing analysis requirements.

Mercury has developed a demonstration multicomputer system implementing a selection of these high-performance time-frequency analysis algorithms running in real time. The system is based on PowerPC® G4 processor with AltiVec™ technology interconnected by the RACE++® high-bandwidth switch fabric architecture. A set of powerful software tools has been utilized to implement several of these algorithms. Using MATLAB® as a starting point, the total development time to port these algorithms onto the multicomputer was quite reasonable. The demonstration, rather than including a short snippet of an interesting signal as seen in most of the literature, processes longer duration waveforms from actual radio equipment.