Advances in Signal Processing Technology

for

Electronic Warfare

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ABSTRACT

The denial of effective communications by enemy forces during hostile military operations has been a primary concern for military commanders since the inception of radio communications on the battlefield before World War II. Since then, the electromagnetic environment has been in a constant state of evolution toward more sophisticated jam-resistant and convert forms of modulation. For example, exotic modulation techniques employing spread spectrum (SS) signaling are routinely used by our adversaries to provide their communication links an advantage over US and Allied jammers. More recently, these same spread spectrum modulation techniques are being refined to provide convert, low probability-of-intercept (LPI) features to the unintended interceptor. The thrust of this paper focuses on developments in the theory and algorithms for detection, characterization, and exploitation of advanced waveforms using new mathematical signal processing tools introduced within the past decade. Specifically, quadratic time-frequency signal representations, wavelet transforms, and cyclostationary signal processing are introduced. This overview demonstrates the importance of these advanced techniques in a clear and concise manner. Applications and future research activities are described in this significant area that is gaining much attention in a variety of technical fields.

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INTRODUCTION

In the early days of electronic warfare an operator would tune his radio across the band listening for threat signals, likely in the form of voice modulation spoken in a foreign language. Upon detection, he would simply place his noise jammer at the same carrier frequency with as much power as possible. The operator, using his ears and brain, comprised the signal processor. Today, it is not possible for manual operators to identity threat signals efficiently and effectively because of the proliferation of complex waveforms used for voice, data, radar, navigation, and image transmission.

Modern electronic intercept systems must perform the tasks of detection classification, identification, and exploitation in a complex environment of high noise interference and multiple signals. Some waveforms are intentionally designed to make the detection process nearly impossible. Such signals are referred to as LPI or LPD waveforms, meaning they offer a low probability intercept or low probability-of-detection. After the signals are detected, the task of classification requires sorting into groups having similar characteristics. Parameters such as carrier frequency, modulation type, data rate, and time or angle-of-arrival are just a few of the fundamental features that distinguish one signal from another. Data bases are used to configure these signal parameters into arrays that are compared to existing knowledge or to establish new

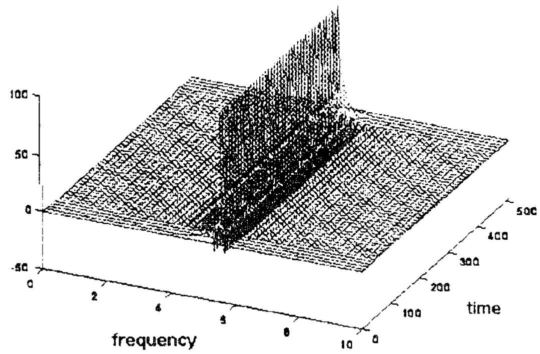

Fig. 1A. Stationary

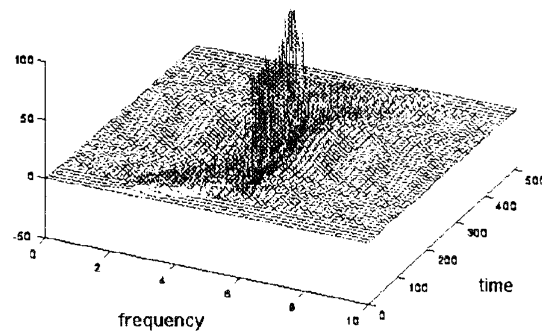

Fig. 1B. Non-Stationary

Fig. 1. Stationary and Non-Stationary Signal

records. The sorting and cataloging of signals leads to the process of identification, a critical step when effective electronic countermeasures are to be initiated and the jamming of ones' own resources is to be avoided. Finally, the problem of effectively and efficiently jamming the signal is met. The electronic attacker must select a strategy that requires the least amount of resources, but yet offer the most effectiveness. Getting feedback regarding the success of your jamming is extremely helpful, but not always possible. A technique called "look-through" allows the jammer to observe his effectiveness on the target. This may be accomplished by stopping to listen periodically or listening through the jamming by using special filters. Overall, electronic attack can be thought of as a game and many of the strategies of game theory can be applied to the overall problem. Each of these initial processes: detection, classification, identification, and exploitation require advanced signal processing techniques. Many of the theoretical signal detection concepts in use today were advanced in the 1920's and 1930's during the early development of radar technology. But, in the last 20 years the development of exotic modulation schemes implemented through advances in digital signal processing gave rise to signals supporting higher information rates, greater channel capacity, and improved noise immunity. These same techniques are now being used to exploit these modern waveforms.

TECHNIQUES

A good understanding of the advances in signal processing technology requires a discussion of the fundamentals of Fourier Analysis. From this basic tool, more complex processes have evolved. Some of the more significant techniques currently being researched for Electronic Warfare applications are described below.

The Fourier Transform

Traditional signal analysis deals with the examination of time and frequency separately through the use of the Fourier Transform. The Fourier Transform and its digital implementation, the FFT (Fast Fourier Transform), allow the decomposition of a signal into individual frequency components and their amplitudes. However, the major drawback of these tools is that time and frequency information cannot be combined to tell how frequency content is changing in time. For example, if you look at the light coming from the sun above the earth's atmosphere, it is steady state and its frequency content is the same over millions of years. If we look at the sun's light at the surface of the Earth, the frequency content changes dramatically during sunrise and sunset. We refer to the first case as a stationary event and the second a nonstationary event. A stationary signal is independent of time, whereas, a non-stationary signal changes over time. Figure 1 illustrates stationary and non-stationary signals through the use of the Short-Time Fourier Transform (STFT). The STFT is also known by the names "Windowed Fourier transform" and "spectrogram." Almost all digital signal processing systems use the STFT since the environment is typically sampled over some time-interval, processed (i.e., FFT), and then output to its intended function. This process is continually repeated. But what is important to realize is that a only a portion of the RF environment is analyzed during a small time segment.

The STFT was the first tool devised for analyzing a signal in both time and frequency simultaneously. The basic idea is to Fourier analyze a small part of the signal around the time of interest to determine the frequencies at that time. Since the time interval is short compared to the whole signal, the process is called taking the short-time Fourier transform. In implementing the STFT, researchers began to experiment with the window. How large should the time interval be? What if we shape the window to give more weight to the central points and less weight to the end points? Different windows will produce different short-time distributions. Unfortunately the estimates of the properties of the signal are window dependent making interpretation of the results difficult.

Time-Frequency Distributions

The motivation for the study of time-frequency distributions is to improve upon the STFT. The basic concept is to devise a joint function of time and frequency

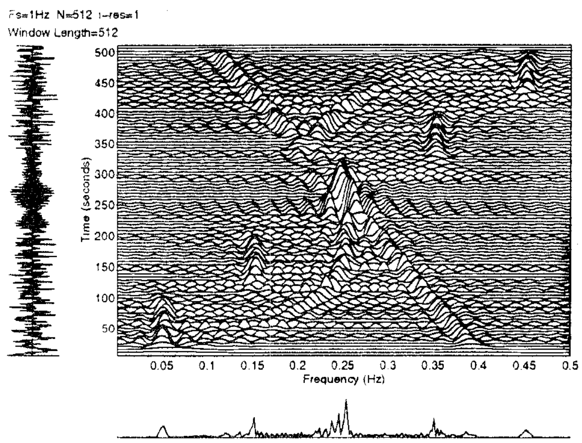

Fig. 2. Time-Freqeuncy Distribution for Multiple Signals

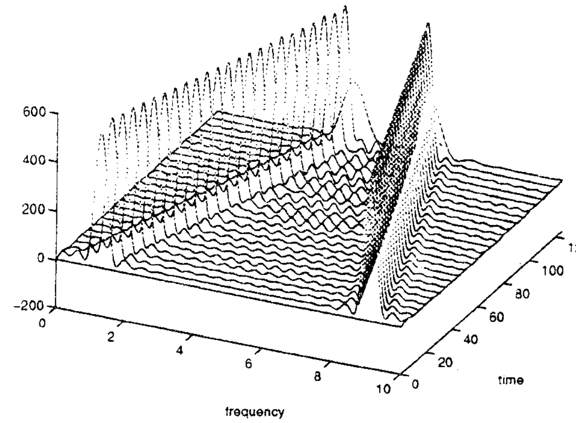

Fig. 3A. STFT

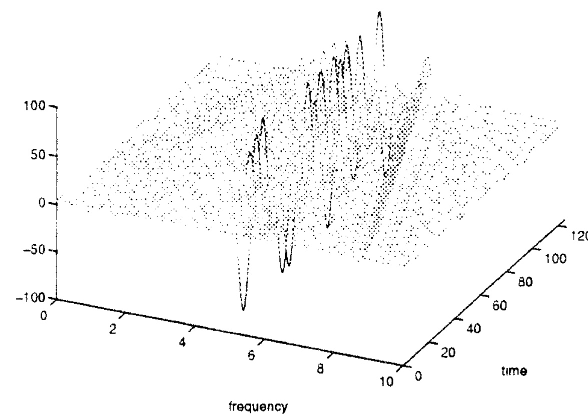

Fig. 3B. Wigner-Ville

Fig. 3. Cross-Terms Produced from Wigner-Ville Distribution

that will describe the energy of the signal accurately in both time and frequency. The word "distribution" may be puzzling to some. One should think of it as a 3D surface plot of how the energy is "distributed" in the time frequency cells. For example, in Figure 2, the time-frequency distribution for several signals is shown. Present in this plot is a linear chirp moving down in frequency, a frequency hopping signal increasing in frequency, and a frequency varying signal having non-linear properties. A time-plot of the sum of these three waveforms is toward the left running up the page. The power spectral density is shown below the main figure. The nature of these signals is not obvious from either the time-plot or the power spectral density. That time-frequency distribution clearly provides a clearer representation of the characteristics of these signals. The time-frequency distribution tells not only what frequencies exist, but at what time each existed making multiple signals much easier to separate and identify. In other words, the power spectrum density tells us the frequencies that existed for the whole duration of the signal. The time-frequency distribution allows us to determine the frequencies at a particular time.

What exactly is wrong with the STFT you might ask? The STFT is easily understandable and it gives a good time-frequency representation for many signals. However, it can be shown mathematically that the STFT does not satisfy what are called "marginal energies." Hence, something is being added or subtracted from the representation. If the joint density of the time-frequency distribution satisfies the individual intensities in time and frequency, "marginal energies" are satisfied. But, for the STFT this condition is not satisfied. To do so would require an arbitrarily small window in both time and frequency. This is contradictory. A small window in time results in a wide frequency window. The concept known as the Uncertainty Principle states that good time and frequency resolution cannot be simultaneously achieved. One must be sacrificed at the expense of the other.

To satisfy the marginal conditions, other distributions such as the Wigner Distribution (WD) have been developed. The WD is a quadratic (non-linear) distribution that will produce interference terms, also called cross-terms, when multiple signals are analyzed. Although the WD provides improved time and frequency resolution, the presence of the cross-terms is a disadvantage. A variant of the WD, called the Wigner-Ville Distribution (WVD) incorporates smoothing to decrease the effect of cross-terms by using independent windows in time and frequency. The WVD) is also a quadratic distribution but through the choice of the length of the time and frequency windows, reduced cross-term suppression is obtainable. Figure 3 illustrates the generation of cross-terms from two chirp signals through the use of the WVD. Other distributions have been developed both to minimize the effects of cross-terms and because they are simpler to implement in software. The main stumbling block in attempting to use the wide variety of time-frequency analysis methods available is the fact that their behavior is dramatically different from one problem to the next and each has peculiar properties. It is

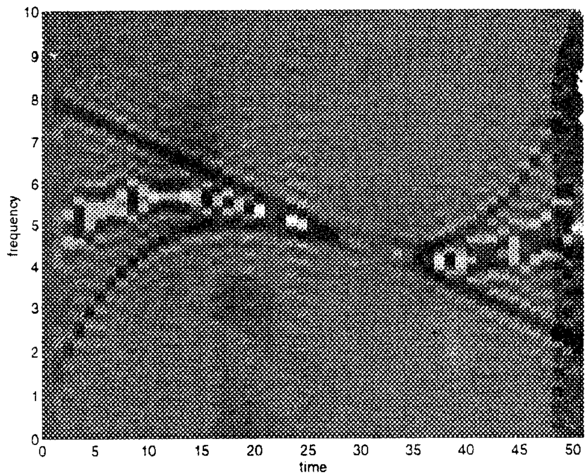

Fig. 4A. Wigner-Ville

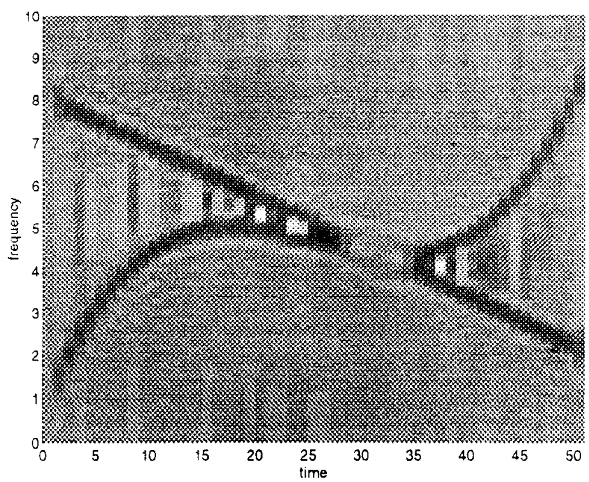

Fig. 4B. Choi-Williams

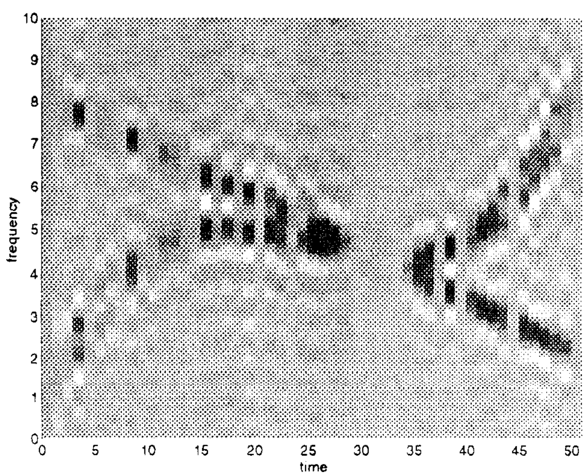

Fig. 4C. Rihaczek-Margenau

Fig. 4. Differences in Various Quadratic Distributions

important to recognize that even though a distribution may not behave properly in all respects or interpretations, it may still be useful if a particular property is to be exploited. This point is emphasized in Figure 4 using topdown plots of the Wigner-Ville, Choi-Williams, and the Rihaczek-Margenau distributions on identically the same signal environment. Although, each distribution is different in appearance, they are equivalent in the sense that each can be obtained from the other and they each contain the same amount of information. They are very different, but nonetheless each has been used successfully for particular applications. These are just three possibilities out of a large number of choices, all with different behavior. There has been considerable controversy in the past few years regarding the choice of a quadratic time-frequency distribution for the analysis of non-stationary signals. The numerous distributions which have been proposed may be interpreted as smoothed versions of the WD, with the type of smoothing determining the amount of attenuation of interference terms, loss of time-frequency resolution, and mathematical properties. Here again, the choice of the best distribution depends on the nature of the signals to be analyzed and on additional issues such as the mathematical properties required and limitations in computation and storage. A successful application of time-frequency distributions presupposes some degree of expertise on the part of the user. It is seldom possible to view time-frequency analysis as a "black box" where the signal is input and some clear and meaningful result is automatically obtained as the output. Some prior knowledge about the signal must generally be known in order to select the most suitable distribution and adapt the parameters to the signal, [1, 2] are outstanding sources for a description of many or the more common time-frequency distributions.

Wavelets

The Wavelet Transform (WT) is of interest for the analysis of non-stationary signals, because it provides still another alternative to the STFT and many of the quadratic time-frequency distributions. The basic difference is in contrast to the STFT, which uses a fixed signal analysis window. The WT uses short windows at high frequencies and long windows at low frequencies. This helps to diffuse the effect of the Uncertainty Principle by providing good time resolution at high frequencies and good frequency resolution at low frequencies. Unlike many of the quadratic functions such as the Wigner-Ville and ChoiWilliams distributions, the WT is a linear transformation therefore extraneous cross-terms are not generated. There is one other major difference between the STFT and the WT. The STFT uses sines and cosines as an orthogonal basis set to which the signal of interest is effectively correlated against. The WT uses special "wavelets" which usually comprise an orthogonal basis set. The WT then computes coefficients, which represents a measure of the similarities, or correlation, of the signal with respect to the set of wavelets. In other words, the WT of a signal corresponds to its decomposition with respect to a family of functions obtained by dilation's (or contractions) and translations (moving window) of an analyzing wavelet. A filter bank concept is often used to describe the WT. The WT can be interpreted as the result of filtering the signal with a set of bandpass filters each with a different center frequency f. In the STFT case, the bandpass filter's bandwidth is independent of the center frequency. In contrast, the bandwidth of the WT is proportional to f or equivalently, the filter's quality factor Q (Q = f / bandwidth) is independent of f. In other words, the WT can be viewed as a "constant-Q" analysis.

Another interpretation of the WT is associated with multiresolution analysis, where the decomposition, with respect to an orthogonal basis set, is performed by an iterative scheme based on high pass and low pass filtering followed by downsampling. The signal is then decomposed into a discrete set of orthogonal details from which the signal can be exactly reconstructed. This offers the potential for signal and data compression. Still another interpretation suggests that the bank of filters represents a set of "matched" filters whose outputs represent the degree or correlation to a signal feature of interest. It is important to note that, within certain technical constraints, the "mother wavelet" may be chosen arbitrarily. This means that an analyzing wavelet with properties especially suited to the analysis of some particular class of signals, such as spread spectrum waveforms, may be chosen to support a given application.

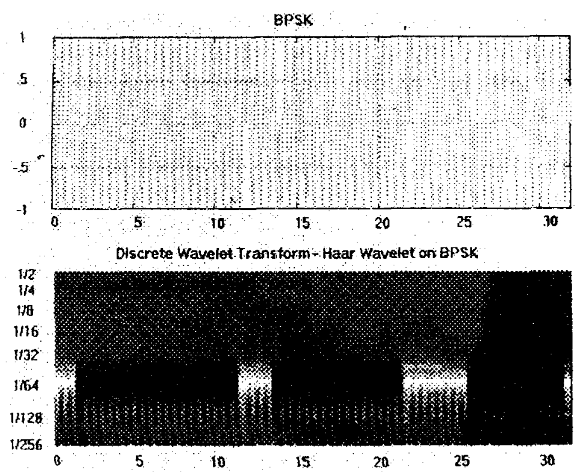

Fig. 5. Signal Analysis with a Haar Wavelet on a BPSK Signal

Figure 5 illustrates the use of a Fast Wavelet Transform (FWT) on a BPSK modulated signal. More signal detail is visible at the lower end of the vertical axis. The actual BPSK keying can be clearly extracted at the 1/64 scale and the carrier can be extracted 1/128 scale.

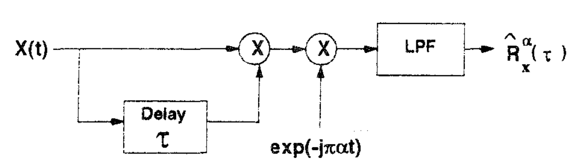

Fig. 6A. Time Domain Implementation of 2nd Order Cyclostationary Process

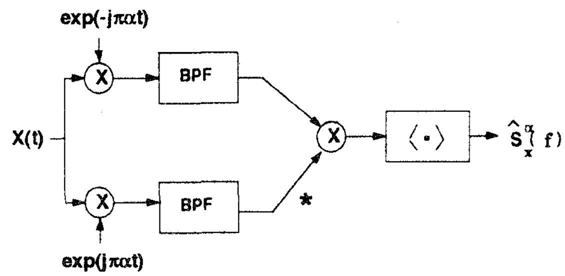

Fig. 6B. Frequency Domain Implementation of 2nd Order Cyclostationary Process

Cyclostationarity

Cyclostationarity is a statistical property exhibited by essentially all digital signals and some naturally occurring waveforms. As before, a stationary signal is one whose statistics do not vary with time. Therefore, a stationary signal can be sampled at periodic intervals without being concerned that the signal may he changing over time. A cyclostationary signal is periodically stationary. That is by delaying the signal by some amount, the statistics do not vary with respect to the signal before the delay. By processing signals as cyclostationary, we can take advantage of the periodic features of a waveform. These preiodicitites arise from modulating, sampling, keying, scanning, coding, multiplexing, and other similar operations, or from naturally occurring periodic events or the motion in rotating machinery.

In the same way that the power spectral density (PSD) function fully characterized the second-order statistical behavior in the frequency domain of a stationary random signal, the spectral correlation density (SCD) function fully characterizes the second-order statistical behavior in the frequency domain of a cyclostationary signal. That is, unlike stationary signals, such as thermal noise, some spectral components in cyclostationary signals will correlate with each other. There are two intuitive ways to view the concept of cyclostationary signal processing: in the time domain and in the frequency domain. In the time domain, consider a simple delay-and-multiply operation as shown in Figure 6A. If the signal contains a periodic component, and if the delay is chosen properly, a strong sinusoid will be present at the output. The computation of the SCD consists of performing this operation over a wide range of delays. Taking the Fourier Transform of each of these outputs will produce the SCD. In the frequency domain, Figure 6B, consider up-shifting the frequency spectrum of interest by some small amount then down-shifting the spectrum by the same amount and the

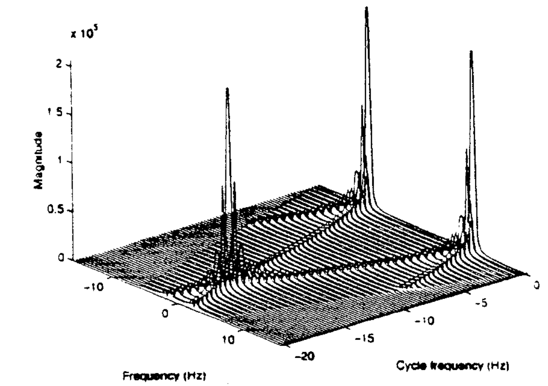

Fig. 7A. 3-D View

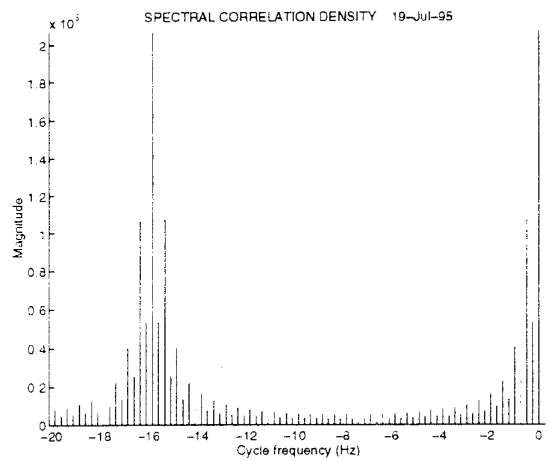

Fig. 7B. End View

Fig. 7. Spectral Correlation Density

computer correlation of the two spectrums. If there is correlation between shifted spectral components, spectral lines will be generated. Repeating this process over a range of frequency shifts will also produce the SCD. Figure 7 illustrates a typical SCD for a BPSK signal showing both the carrier frequency (16 Hz) and data rate (0.5 Hz). The end view plot helps read these rates. The cycle frequency equates to the amount of frequency shift in the frequency domain interpretation of the SA.

APPLICATIONS

Much work is underway to develop more advanced signal processing techniques which will more effectively and efficiently exploit modern digital communication and radar signals. These techniques are directed at improving the tasks of detection, classification, and identification. The traditional STFT has been applied to signal processing problems in many different areas including electronic warfare. Some of the major applications for the STFT include time-varying signal analysis, system identification and spectral estimation, signal detection and parameter estimation, speaker identification, speech coding, estimation of the group delay or the instantaneous frequency of a signal, and complex demodulation. Besides processing received signals, these same STFT algorithms are used to synthesize signals using inverse transform techniques. Some applications of STFT synthesis techniques are time-varying filtering, non-linear noise removal, room dereverberation, time-scale modification, dynamic range and bandwidth compression, and waveform design.

While many conventional statistical signal processing methods treat random signals as stationary, cyclostationary techniques take advantage of periodicities associated with signals. Cyclostationary signal processing has been shown to be very useful for signal processing tasks such as the separation of spectrally overlapping signals and reliable extraction of information from spectrally overlapping signals. For example, information such as emitter location, modulation type, and carrier and clock frequencies can more easily be removed in congested RF environments through cyclostationary signal processing. The presence of signals buried in noise and/or severely masked by interference can also be more easily detected by exploiting the spectral redundancy associated with cyclostationarity. Estimating parameters such as the time difference-of-arrival at two reception platforms or the direction of arrival at a reception array on a single platform is improved over conventional systems that ignore cyclostationarity.

Time-frequency representations are powerful tools for the analysis and processing of non-stationary signals for which separate Time-domain and frequency-domain analysis are not adequate. Researchers have applied the Wigner Distribution for signal detection, spectrum and instantaneous frequency estimation, and pattern recognition. Synthesis techniques have been used to perform time-varying filtering, multi-component signal separation, and window and filter design. A quadratic time-frequency representation known as the ambiguity surface has been used extensively in radar and communications. In the radar case, an estimation of the distance and velocity of a moving target is made, where the distance and velocity correspond to the "range" and "Doppler shift" parameters. The cross-ambiguity surface provides pertinent information about the performance of the maximum-likelihood estimator, thus aiding in the design of the transmitted signal. Synthesis techniques can also be used for isolating a desired component of a multicomponent signal, provided the signal term of interest does not overlap significantly with other signal terms.

Wavelet theory provides a unified framework for a variety of signal processing applications. For example, wide use is found in multiresolution signal processing and speech and image compression and enhancement. While conceptually, the WT is a classical constant-Q analysis concept, applied mathematicians have recently recognized the many different views and applications stem from a single theory. Still another alternative to the STFT, the main application of the WT in signal processing will be in non-stationary signal analysis. The zooming property of wavelet analysis allows a very good representation of discontinuities in the signal. For example, as applied to image processing, the WT is very good at detecting and enhancing edges. This property is useful for pulsed radar signals, detecting the frequency transitions of frequency hopping radios, or any abrupt transitions characteristic of the signal-of interest. Perhaps the biggest potential use for wavelet analysis is in signal compression, thus allowing increased bandwidth efficiency.

FUTURE RESEARCH ACTIVITIES

As military communication, radar, and navigation systems become more complex, frequency employing sophisticated anti-jam (AJ) or LPI signaling schemes to provide robustness or covertness, the performance limitations of the traditional radiometric energy detector becomes significant. Feature extraction techniques become increasingly more difficult as the covert communicator attempts to suppress and conceal his features. Electronic countermeasures become more difficult and less effective as AJ techniques are implemented. Classical radiometric methods for energy detection are highly susceptible to unknown and changing noise level and interference activity. For example, spread spectrum modulation techniques make it difficult for the radiometer detectors to function because the signal is spread in bandwidth to obtain some processing gain in the presence of interference. Spread spectrum may also employ spectral overlapping techniques such as code-division multiple access (CDMA) which will confuse the radiometer since multiple, similar looking signals, share a common bandwidth. New signal detection and features extraction systems are needed to effectively exploit these new waveforms in today's complex signal environment. Developing new signal countermeasure techniques and assessing the performance of these techniques against a candidate AJ/LPI waveform designs requires new theoretical based approaches and computational tools and techniques.

Time-series data analysis is presently performed either with costly and complex instrumentation or through computer analysis. Computer algorithms have been developed which analyze and graphically display the results of the data for user interpretation. However, new transforms are currently being developed that provide improved graphical representations of time varying data beyond that of conventional FFTs. Pattern recognition techniques will be merged with artificial intelligence technology and neural networks to develop automated analysis and interpretation of signal data in real-time. By establishing a database of signatures signals will ultimately be automatically recognized and an optimal jamming strategy generated.

Spectral correlation analysis instruments or cyclostationary algorithms will become standard equipment in communications laboratories and production facilities with either commercial or educational missions. Analysis systems could be designed for quality control monitoring, testing, system design, performance evaluation, teaching, and research and development. Fault Testing and prediction are possible through the analysis of time-series vibration data of rotating mechanical systems such as engines. Higher-order cyclostationary moments and cumulants are being researched to find new techniques and algorithms for signal detection, characterization, and exploitation against LPI waveforms or against signals in difficult environments.

Considerable theoretical development has taken place regarding advanced signal processing techniques in the last 15 years. Computer models and simulations have shown the advantages of these techniques. Recently, algorithms have been developed which speed the data processing of these potential techniques to realizable goals. Hardware is being developed and integrated into current military systems using many of these, or related, techniques. Industry needs to be made aware of the possibilities that advanced signal processing techniques offers, for example, new signal processing techniques are currently being developed which exploit the periodic nature of naturally occurring signals. Periodic, cyclic, or rhythmic phenomena arise naturally in many areas of disciplines. Some of the fields where periodic, time-series, data are analyzed include medicine, biology, meteorology, climatology, hydrology, oceanology, and economics. The techniques that are being researched for the detection characterization, and identification of LPI waveforms show great promise in these other scientific and commercial fields. Quadratic time-frequency distributions have served as useful analysis tools in fields as diverse as quantum mechanics, optics, acoustics, bioengineering, image processing, and oceanography. These techniques have been used to analyze speech, seismic data, and mechanical vibrations. An excellent example is use of these techniques for recognizing cardiac patterns in the fields of medicine and biology. Wavelets and time-frequency distribution are being used for the detection of electroencephalogram (EEG) spikes, ventricular fibrulation in electrocardiograph (ECG) patterns, and a variety of other biomedical related waveforms. Research efforts have been made and continue to make important groundwork contribution to EW programs, but also continue to provide research benefits to other applications.

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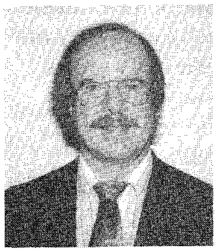

Since January 1991, **James P. Stephens** has been employed as an electronics engineering with Wright Laboratory, Avionics Directorate, RF Technology Division, Electronic Combat Branch, at Wright-Patterson Air Force Base, Ohio. He is responsible for the planning and execution of research projects which will exploit the theory of communications jamming concepts applicable to future Air Force needs and objectives. His research activities involve both in-house and contractual efforts in communications countermeasures toward the development and evaluation of concepts, systems, and supporting technologies with emphasis on spread spectrum and digital signal processing techniques. Mr. Stephens was previously assigned to Foreign Technology Division, Directorate of Technology and Threat, as an electronics engineering analyst from 1982 to 1991. He was also employed by the Federal Communication Commission from 1969 to 1982. Mr. Stephens received an MSEE from the Air Force Institute of Technology in 1990 and a BSEE from West Virginia Institute of Technology in 1969.

More About the Cover:

RADARSAT-1

Canada's First Earth Observation Satellite: First Synthetic Aperture Radar (SAR) Image

The first RADARSAT image was acquired under conditions of darkness, overcast skies, rain, and strong wind, at 5:41 p.m. local time on the evening of November 28, 1995. The satellite was in the ascending, east-looking pass of its 348th orbit and its imaging mode was a Standard 1 beam, with an incidence angle of 23 degrees. The image shows a portion of Cape Breton Island, Nova Scotia, Canada, and is centered at latitude N 46° 27′ 05″ and longitude W 060° 18′ 50″. It covers an area of 132 km × 156 km with a spatial resolution of about 25 m, and was obtained from an altitude of close to 800 km.

Cultural Features: Appearing as bright spots, buildings, power lines, harbour structures, railways, and much of the city of Sydney, including the three wharves in Sydney Harbour, are evident. Local roads and runways at Sydney Airport are readily identified. These are indicative of RADARSAT's utility in land use mapping and urban mapping.

Coastal Delineation: Shorelines and coastal features, which are often obscured by fog or clouds, are clearly visible. The steep cliff of Cape Smokey, the coastal inlet of Ingonish Harbour and its barrier beaches along the northeastern shore of Nova Scotia are evident. Middle Head peninsula, which divides North and South Ingonish Bays, is also seen. RADARSAT's coastal monitoring capability is not only important to Canada but also to many other parts of the world, especially the predominantly cloud covered tropics. The identification of coastal features is also useful in environmental monitoring programs.

Surface Landforms: This image reveals the linear features of the drumlin fields (elongated hills shaped by glaciers) in the Island's Mira region. The prominent Aspy Fault and other major faults and boundaries between rock types are easily identified. These illustrate RADARSAT's sensitivity to surface topography and landforms, making RADARSAT a valuable tool for detecting surface mineral deposits and geological features.

Ship Detection and Monitoring: Ship detection and surveillance of activities in shipping lanes highlight another RADARSAT capability. In this image, the ship Portland Carrier and its V-shaped wake can be seen. The shape of its wake indicates that the ship was inbound towards Sydney Harbour.

Ocean Surface: The bright patches show RADARSAT's sensitivity to wind effects on the ocean surface, especially where the water is exposed to the full force of the winds. The mapping of currents, sea state, and many other ocean features for weather forecasting, ship routing and fisheries resource management is possible.

Forestry: West of Ingonish, south of the Cheticamp reservoir (white), it is possible to see the forested areas (darker) damaged by the spruce budworm outbreaks of the 1970s and 1980s.

The purpose of the RADARSAT program of the Canadian Space Agency is to provide radar imagery on an operational basis to commercial, government and scientific users worldwide. RADARSAT's onboard tape recorder and RSI's international network of distributors and ground stations ensure that users around the world will have access to high-quality images of the Earth, regardless of weather and light conditions. RADARSAT-1, funded by the Federal and Provincial Governments, was built by the prime contractor Spar Aerospace Ltd. The satellite launch on 4 November 1995 was supplied by the United States in return for radar imagery for use by NASA (National Aeronautics and Space Administration), NOAA (National Oceanic and Atmospheric Administration) and other US Government agencies.

For more information, contact: Canadian Space Agency, Communications Branch, 6767, route de l'Aéroport, Saint-Hubert, Québec J3Y 8Y9; Telephone (514) 926-4351, Fax (514) 926-4352, WWW Site http://radarsat.space.gc.ca/, Site RADARSAT sur WWW http://radarsat.espace.gc.ca.