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DESIGN OF A SUPERRESOLUTION RADIO
1 RECONNAISSANCE SYSTEM

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3 Abstract

Two approaches for the design of a superresolution radio reconnaissance system are discussed. The system fulfills on-line directions of arrival estimation of a class
4 of received signals, and off-line superresolution analysis of threat targets. It provides also fast scanning and monitoring of a wide frequency band with a backup of received signals in the last 20 seconds.

Key Words

Array signal processing, Avionic, Direction finding

I. Introduction

The design of an advanced radio reconnaissance system is governed by many features including fast scanning and monitoring of a wide frequency band, real time directions of arrival estimation, tracking a large number of threat targets, and relatively high probability of detection of hopping signals.

Although a large number of technical specifications have to be considered in the design, the main two items that strongly affect the attained features are the measurement accuracy, and both the spatial and frequency resolutions. An advanced system based on interferometer/ or correlative interferometer Directions Of Arrival (DOA's) estimation technique can be implemented with excellent features using off-the-shelf PCs and DSP modules. In practice, these systems do not fulfill the specified resolution in the environment of multi-paths, coherent signals, and interference that violates the basic principle of the interferometer techniques.

In the last 15 years, one of the active research topics in the DSP field is the superresolution algorithm for estimating the directions of radioactivity in a practical

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environment. Although a numerous number of algorithms have been developed, the application was very limited to a few years ago. The reason behind this limitation was the computer resources that include the memory size and the CPU speed. The current revolution in the development of the computers and DSP modules makes the implementation of such systems more visible.

This article is introduced to outline two approaches for the design of superresolution radio reconnaissance systems. The paper is planned as follows. In section II, a review to the DOA's estimation techniques is presented. It includes the interferometer and the correlative interferometer techniques, and the most widely applied superresolution techniques. In section III, two design approaches are discussed, and the system resources are determined. Finally conclusions are presented in section IV.

II. DOA's Estimation Techniques

Interferometer and Correlative Interferometer Techniques

The most common configuration of the interferometer systems is a dual base system consisting of three channels digital receiver and a DSP module [1]. Using one channel as a reference for the others, the DOA's of a narrow band signal can be computed from the phase difference between the signal of the other channels and the reference. The main function of the DSP module is performing the FFT algorithm to turn the problem of a wide band signal into a number, depending on the frequency resolution, of narrow band signals. The performance of this system is significantly reduced in the environment of multi-path signals, and Signal- to-Noise (S/N) less than 10dB.

The correlative interferometer system is developed to reduce the estimation error caused by the multi-path reelection. The principle of operation is based on storing the received signal from a source in different known directions in the azimuth as a reference. The estimated direction of an unknown source is the direction of the reference signal that provides maximum correlation with the unknown signal. Obviously, the time required for performing the correlation process slow down the scanning speed of the system. In addition, unfortunately, it does not improve the S/N threshold than the interferometer system.

It is worth notifying that the interferometer and correlative interferometer techniques are suitable for the real time applications using the recent off-the-shelf PCs and DSP modules.

Superresolution Techniques

The application of superresolution techniques requires a system with hardware resources convenient for processing the picked signals by a multi-channel coherent receiver, using a selected superresolution estimator. This process reduces significantly the S/N threshold, and improves the resolution in case of incoherent sources problem. For alleviating the problems that may arise in the environment of coherent sources, two techniques are commonly applied; the focusing [2,3], and the spatial smoothing [4,5] techniques. The former one may improve the estimator performance at low S/N if both the direction and the width of the focusing domain are successfully predicted. In a problem of more than 4 coherent sources, the predication of both is inaccurate, and the focusing process is too long. In this case, the technique of spatial smoothing is the favorable although its resolution is less than that of focusing. However both techniques require a long processing time and can't be employed in a real time system.

III. System Design

Assume that the system has to utilize on-line interferometer and off-line superresolution processes, with the following main features:
1) Scanning and monitoring the radioactivity over a specified frequency band.
2) On-line interferometer directions of arrival estimation of a class of received signals.
3) Off-line superresolution analysis of threat targets.

Let a circular array comprises eight antenna elements is used in the system. The signal picked by each element is processed as a separate channel in multi-channel digital receiver. For maintaining low noise floor, the tuners are plugged in a separate cage, and controlled by means of an RS-232 interface. As shown in Fig.1, two approaches in the design of the data acquisition and processing unit can be considered depending on the bandwidth of the tuners output.

The First Approach

This approach is normally applied in case of using wideband coherent tuners. A typical IF output of off-the-shelf tuners is 10.7MHz with .5MHz bandwidth or 21.4MHz with 10MHz bandwidth. In the data acquisition and processing unit in Fig.1.a, the analog signal from each tuner is converted to a digital form with a specified accuracy, and applied to a digital receiver. The sampling rate of the A/D converter is greater than twice the maximum IF output frequency. The digital receivers are narrow band coherent receivers that perform frequency down conversion, low pass filtering, and decimation of the sampled output. It has a programmable bandwidth that can be centered about a frequency of interest in the IF band. Both the local oscillator and the decimation factor of the digital receiver control the position and bandwidth of selected slice. The outputs of the digital receivers are processed in eight separate DSP units that analyze the frequency spectrum of the selected band, time tag the data, and store the results in mass storage ring buffer. The ring buffer serves as a slave for two external PC hosts. The first PC is an on-line host to display the frequency spectrum, estimate the directions of signal arrival, track threat targets, and trigger an alarm system at specified conditions. In addition, it scans the IF frequency band by sweeping the local oscillator of the digital receiver, as well as the frequency band of the RF tuners. The second PC is an off-line host that may be activated by the user or the trigger system of the on-line host in presence of threat targets. It downloads the stored data of selected targets, and performs superresolution analysis to refine the estimated directions of arrival.

The Second Approach

This approach is based on the band pass sampling criterion, and employs tuners with narrow band outputs. A typical IF frequency is 455KHz with output bandwidth equals 50KHz. A low rate A/D converter followed by a low pass filter is used for each channel before the DSP module as shown in Fig.1.b. The key in this case is that the sampling frequency to the center frequency ratio is equal to an integer plus 0.5 for avoiding the spectrum alliasing. The on-line and off-line hosts perform the same functions as those in the first approach with sweeping only the RF tuner.

The Keys of the Design

The basic rule in the design of a real time system is that the maximum time of analysis of a frequency band must be less than the data collection period. This frequency band is called the real-time bandwidth, and defined as the highest frequency at which the spectrum of a band and some other functions can be calculated and processed without missing any data. This frequency is governed by the processing speed of the DSP processor, and the main technical features of the system; e.g. the frequency resolution, and frequency band scanning speed. The difference between the data collection period and the time of analysis is the available period for changing the system setting, and downloading the data from the ring buffer to the host. If this gap is too small, the design may be complicated for avoiding the contingence of the data flow during some other functions.

In the first design approach, the decimated output rate of the digital receiver equals twice the real-time bandwidth. One important decision is the choice of the data collection period for real-time spectrum analysis. Since the number of samples, due to the FFT processes, equals the number of discrete frequencies that outlines a specified band, the number of samples determines the attained frequency resolution. In addition, the computation efficiency of the FFT algorithm is better as the number of samples increases. This does not mean that there is no upper limit to the number of samples or the period of data collection. As the period of data collection increases, the scanning rate decreases, and the probability of catching burst and hopping signals may become unacceptable. One additional requirement that limits the period length of data collection is that the signal has to be considered stationary during that period for both on-line and off-line directions of arrival estimation. The problem in a statement is: what are the maximum scanning rate and best frequency resolution that can be attained in the real time analysis of an implicitly stationary signals using a specific DSP module?

A typical DSP module, based on TMS320C40, performs real time FFT algorithm for a number of samples N=1024 in 10mSec with 16 bits accuracy. This time is approximately required for performing $N\log_2N$ multiplication operations in the FFT algorithm, assuming that a specific band of frequency has to be scanned at intervals of length equal the real-time bandwidth. Figure 2 illustrates the maximum scanning rate with associated best resolution, required number of samples, and the time of analysis as a function of the real-time bandwidth. It shows that a high scanning rate can be achieved with a poor resolution using a small number of samples, and a very high resolution can be attained with slow scanning on the account of the time of analysis and the length of samples. The problem associated with the fast scanning is that the narrow band signal may be lost in the analysis. During the slow scanning, the received signal may not be stationary during the long period of data collection that affects the accuracy of the DOA's analysis. However, the high resolution that can be attained during the slow scanning comes on the account of the size of storage buffer. During a scanning rate equals 10MHz/s with 16 bits data accuracy, 800 Mbytes is the approximate size of the buffer per channel for storing the received data in 20 second. Obviously the implementation of a system with a huge buffer is a difficult task for both hardware and software designer. Therefore, there should be a scanning rate limit in the system operation for a selected DSP module. Selecting a practical value of scanning rate to be 100KHz/s improves the resolution to 10Hz, and rises the necessary number of samples to 1024. The size of the ring buffer required for each channel is 8Mbytes to store the data in 20 second, and hence the total system requires 64 Mbytes. This size is available using off-the-shelf DSP modules. Therefore, the configuration in Fig.1.a of the first approach may achieve a maximum scanning rate equals 100KHz/s with 10Hz-frequency resolution.

In the second approach described in Fig.1.b, the fixed 50KHz IF BW achieves a high scanning rate with poor resolution. In addition, the required ring buffer in this system is huge enough to be implemented in a practical system. Therefore, the configuration in Fig.1.b is discarded, while that in Fig.1.a is currently receiving the attention.

IV. Conclusions

The design of a superresolution radio reconnaissance system becomes more visible using the recent developed PCs and DSP modules. A typical scanning rate equal 100KHz/s with 10Hz-frequency resolution can be achieved using a DSP module based on the TMS320C40 processor. Faster scanning rate and better resolution are also available with a more expensive DSP module based on the TMS320C80 processor with 128Mbytes-ring buffer. The refinement of the estimated directions of arrival in different environments may requires more than one superresolution estimators for avoiding the limitation of each. However, with the continuous development of new estimators, the system can be simply upgraded with powerful one.

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Fig.1.a

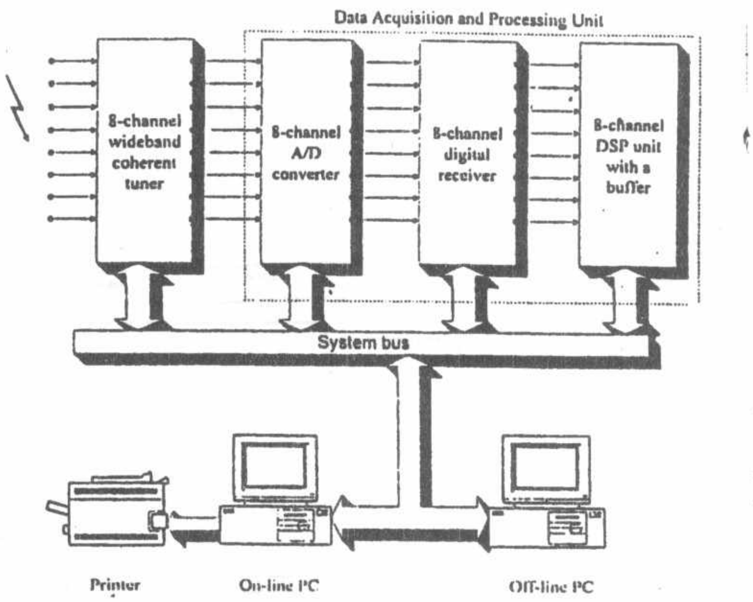

Fig.1.b

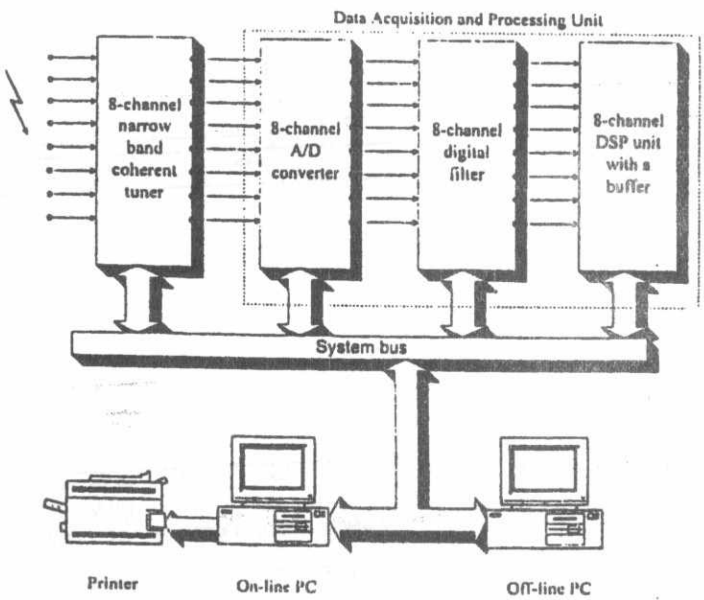

Fig.1 The block diagrams of the first and second design approaches

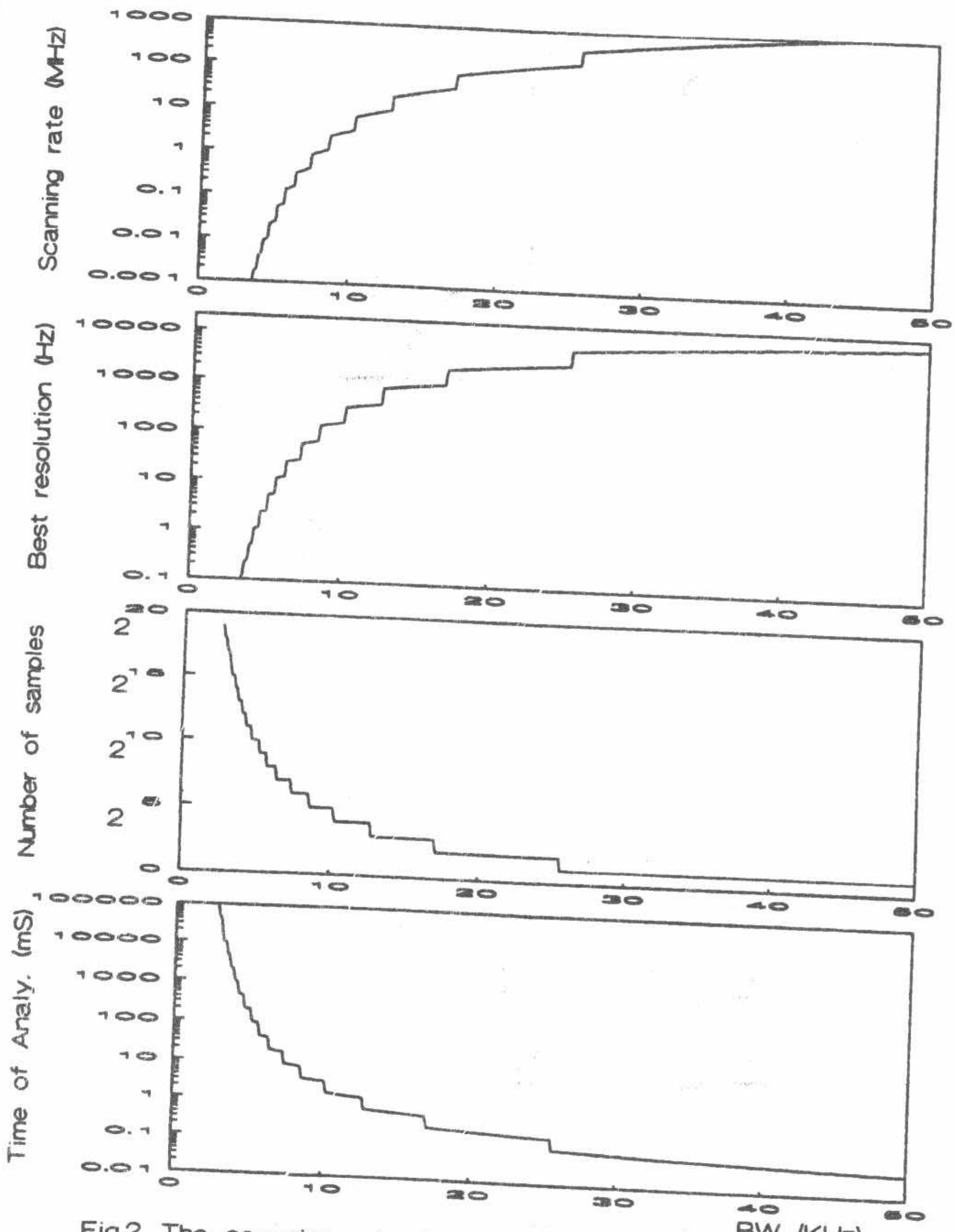

Fig.2 The scanning rate, best resolution, number of samples, and time of analysis versus the real time bandwidth