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## METHOD AND SYSTEM FOR TRANSIENT SIGNAL DETECTION

## STATEMENT OF GOVERNMENT INTEREST

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefore.

## CROSS-REFERENCE TO RELATED PATENT APPLICATION

This patent application is co-pending with a related patent application entitled SYSTEM AND METHOD FOR CHAOTIC SIGNAL IDENTIFICATION, Ser. No. 08/682,896 (Navy Case No. 74951) having a filing date of 28 June 1996.

## BACKGROUND OF THE INVENTION

(1) Field of the Invention

The present invention relates generally to signal detection, and more particularly to a method and system for detecting transient signals so as to characterize the structure of acoustic signals and to provide rapid detection and classification of transient signals.

(2) Description of the Prior Art

Characterizing the structure of acoustic signals is critical to data integration and evaluation in generating an overall picture of a tactical situation. For example, the acoustic signature of a threat, such as the launch of a torpedo against a friendly vessel, must be quickly distinguished from background noise in order for the vessel to take evasive maneuvers. In littoral environments, where background noise and acoustic signal reverberation are likely to be increased, more robust techniques for information processing are required. In addition to identifying threats, it is necessary to minimize self noise so as to prevent early detection by hostile forces. As defense resources become scarcer, noise quieting efforts must be concentrated in areas having the largest quieting payoffs. As with identifying threats, self noise signals need to be carefully analyzed to identify those portions of the signals which provide the greatest risk of detection. Quieting efforts can then be concentrated on those systems generating detectable signals.

The prior art contains a number of methods and systems which have been used to separate acoustic signals from background noise. U.S. Patent No. 4,894,808 to Pedley et al. provides a method for separating flow noise from an acoustic signal. The level of signal noise caused by fluid flow at a pressure transducer is determined by measuring the electric field, which is proportional to flow rate, induced when fluid flows through a magnetic field. The pressure due to flow is derived by a digital filter which may be adaptive or which may employ a predetermined electric field/flow noise relation. The flow noise is then subtracted from the received signal, the resultant signal then being substantially flow noise free. While reducing flow noise from the received signal, the method does not separate other background noise from the signal. Such other background noise can still prevent the acoustic signal of interest from being detected. U.S. Patent No. 4,144,768 to Andersson et al. provides a system for analyzing a complex acoustic field by resolving the acoustic field into component unit spatial pressure patterns or modes. The system utilizes an acoustic filter having one or more annular cavities surrounding a duct through which the acoustic energy or signal propagates. The filter cavities are dimensioned so as to resonate when the circumferential difference between adjacent nodes of a modal component of the pressure pattern is mathematically related to the velocity of sound within the cavity by a predetermined factor. Gas pressure within the cavities can be varied to control resonance of the cavities, thus allowing measurements of modal amplitude distribution or of transient phenomena of the acoustic energy propagating through the duct. While the system may be helpful in characterizing self noise by measuring flow through a duct, the system does not provide a method for separating background noise from an acoustic signal received at a transducer and analyzing the acoustic signal.

## SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide a method and system for analyzing an acoustic signal which can be used in separating background noise from the signal of interest.

Another object of the present invention is to provide a method and system for analyzing an acoustic signal received at a transducer in a littoral environment.

Still another object of the present invention is to provide a method and system for analyzing an acoustic signal to provide detectable and classifiable features of self noise.

A still further object of the present invention is to provide a method and system for analyzing an acoustic signal through which designs for quieter vessels can be evaluated.

Other objects and advantages of the present invention will become more obvious hereinafter in the specification and drawings.

In accordance with the present invention, a method and system for identifying transient signal features within an acoustic signal is provided. First, a power spectral density (PSD) plot of the signal is obtained and analyzed to determine if it exhibits broadband characteristics. As is known in the art, a PSD is said to be broadband if it exhibits the following features: (1) the power distribution of the signal is spread over a wide range of bandwidth; (2) the appearance of spectral components, i.e., frequency lines in the spectrum, is random, or noise-like; and (3) there are no unique characteristics about the signal which can be determined or revealed from the spectrum. If the PSD exhibits broadband characteristics, then the auto-correlation function is examined to determine if transient behavior exists. If the auto-correlation function exhibits signs of transient behavior, then the state portrait is examined to determine the transformation to noise-like behavior. Processing of an acoustic signal and the quieting of self noise generating equipment can then be concentrated on the portion of the signal prior to the transformation to noise-like behavior.

## BRIEF DESCRIPTION OF THE DRAWINGS

A more complete understanding of the invention and many of the attendant advantages thereto will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in conjunction with the accompanying drawings wherein corresponding reference characters indicate corresponding parts throughout the several views of the drawings and wherein:

FIG. 1 is a block diagram illustrating the steps of the method of the present invention;

FIG. 2 is a power spectral density plot of a representative data set illustrating broadband characteristics;

FIG. 3 is a plot of the auto-correlation function for the representative data set illustrating signs of transient behavior;

FIGS. 4A through 4D are state portraits for selected time segments of the representative data set; and

FIG. 5 depicts a system for implementing the method of the present invention.

## DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. 1, there is shown a block diagram of the method of the present invention used in detecting transient hydroacoustic signals. To identify transient signal features, nontraditional signal processing techniques are applied using the Nonlinear Dynamics Analysis System (NDAS). As described in related patent application, Ser. No. 08/682,896, the NDAS includes a plurality of processing modules each for receiving a digital data stream from an input means, such as an acoustic sensor, and for generating therefrom an output useful in identifying one of a plurality of chaotic processes. The processing section is responsive to processing selection information to select one of the plurality of processing modules to provide the output. The control module generates the input data selection information and the processing selection information in response to inputs provided by an operator. Utilizing the NDAS processing modules, the method of the present invention first receives the signal to be processed at step 10. Step 12 calls the NDAS signal processing module to obtain the power spectral density (PSD) of the signal. The PSD is examined at step 14 to determine if broadband characteristics exist. Broadband characteristics include the power distribution of the signal being spread over a wide range of bandwidth, the random or noise-like appearance of spectral components, i.e., frequency lines in the spectrum and the signal having no unique characteristics which can be determined or revealed from the spectrum. Such broadband characteristics tend to indicate the presence of transient behavior. Without such characteristics, no transient behavior exists, and the method branches to step 16 to exit. If broadband characteristics are present, step 18 calls the NDAS auto-correlation module to perform an auto-correlation operation. The auto-correlation operation yields an auto-correlation function which provides a measure of the dependence or independence of values of the signal data stream at different points in time and thus indicates the time variation and degree of randomness of the input signal data. As with the PSD at step 14, the auto-correlation function is examined at step 20 for signs of transient behavior. Generally, known chaotic systems exhibit large amplitude, slow fluctuations of the auto-correlation function. The launch of weapons, countermeasures and other devices from a submarine, for example, may be characterized as a short duration transient event which converts a considerable amount of potential energy into other forms of energy, including acoustic energy. If the transient component can be considered to be a significant component of the overall signal signature and the transient component has a short time duration, then transient behavior would appear to be present and the method continues to step 22. If no transient behavior is exhibited, then step 20 branches to step 16 to exit. If transient behavior appears to be present, the auto-correlation function is further examined at step 22 to determine a preliminary time-delay parameter. The preliminary time-delay parameter is computed in the standard fashion by taking a time delay equal to one third of the first zero crossing of the auto-correlation function. Having established the likelihood of transient behavior from steps 14 and 20, this preliminary time-delay should produce a well-defined state portrait which would indicate that the sensor signal corresponds to a chaotic attractor. Step 24 calls the NDAS strange attractor generator using the time-delay from step 22 over a time interval encompassing the first zero crossing. Step 26 evaluates the strange attractor provided by step 24 to determine the possible existence of a strange attractor. The criteria used to evaluate the state portrait includes: (1) the existence of attraction points; (2) the density and rate of trajectory evolution in the vicinity of attraction points; (3) location of the center of gravity of the entire strange attractor; and (4) the structure of the strange attractor. Step 26 further assigns and stores a ranking for the strange attractor based on the results of the evaluation. No ranking is stored if the evaluation indicates no strange attractor criteria exist. Step 28 decrements the time-delay criteria. The decremental value chosen would depend on the resolution desired. A typical decremental value would be 0.01 of the value of the zero crossing location. Step 30 checks then checks to see if the decremented time-delay is less than a selected minimum value. Typical minimum values would be in the range of 0.1 of the zero crossing value. If it is not, then step 30 returns to step 24 to generate a new strange attractor based on the decremented time-delay. If the decremented time-delay is less than the selected minimum value, then step 30 branches to step 32, which examines the stored rankings. If no rankings exist, then no strange attractor exists and step 32 branches to step 16 to exit. If at least one ranking exists, step 32 chooses the time-delay corresponding to the best ranking and branches to step 34 which calls the NDAS phase portrait generator. Using the chosen time-delay, step 34 provides phase portraits for selected time intervals over the total duration of the signal being analyzed. Depending on the number of intervals chosen, the phase portraits will show the transformation from periodic behavior to noise-like behavior. Choosing the portion of the signal demonstrating periodic behavior at step 36, the user thus concentrates further signal processing on that portion of the signal where a greater likelihood of separating an acoustic signal from the background noise exists. When noise quieting is the goal, design efforts can be concentrated on the processes associated with the generation of portion of the signal chosen, i.e., those noise generating processes which occur within the same time frame as the periodic behavior.

Referring now to FIGS. 2 through 4, a sample data set is provided to illustrate the use of the method. FIG. 2 shows the results of step 12, a PSD plot of a representative data set. It can be seen that FIG. 2 exhibits broadband characteristics in that the PSD is distributed over a wide range of bandwidth (from 1 to 10,000Hz). Over that range, the energy is distributed almost uniformly, e.g., the magnitude of the PSD over that bandwidth is between 40dB and 50dB. Further, there is no major or distinct frequency line that can be detected from the spectrum and the appearance of the PSD resembles a white noise spectrum. Thus step 18 is called to generate the auto-correlation function shown in FIG. 3. It is noted that the auto-correlation function of FIG. 3 fluctuates about zero, which, from the nonlinear dynamics point of view, is a unique indication of transient behavior. The method then proceeds to step 22 where the initial or preliminary time-delay parameter is chosen as one-third of the first zero crossing. The first zero crossing of FIG. 3 is seen to be 0.2 second, thus the preliminary time-delay parameter is 0.2/3 or 0.0667 second. Upon decrementing the time-delay and storing the rankings at steps 24 through 30, step 32 determines the time-delay corresponding to the highest ranking to be 0.0567 second. FIGS. 4A-4D show the phase portraits generated by step 32 for 0.5 second intervals using the time-delay determined by steps 24-30. It can be seen that FIG. 4A shows periodic and quasi-periodic behavior with only small amplitude noise. FIG. 4B shows the periodic behavior transforming to noise-like behavior, with the remaining oscillations centered on three points. FIG. 4C still exhibits some periodicity, but mostly mean zero Gaussian noise. FIG. 4D has zero mean Gaussian random noise. Thus, at step 34, the first second of the signal duration should be chosen to concentrate further signal processing or noise quieting design efforts.

FIG. 5 shows a system to implement the method of the current invention. Sensor 100 detects the acoustic signal of interest which is communicated to computer 102 via cable 104. Sensor 100 may be any one of many well known sensors which would provide a digital signal to computer 102. Sensor 100 may also be an analog sensor in combination with and analog to digital converter. Cable 104 may be electrical or optical depending on the sensor equipment being used. Computer 102 may be any general use computer capable of accepting and processing acoustic signal inputs. For implementing the method of the current invention, it is anticipated that computer 102 would call and run the NDAS processing modules, although any system configuration capable of calling and executing the NDAS modules may be utilized. Monitor 106 and keyboard 108 provide user interface with the NDAS and the method steps of the current invention. Once the method of the present invention has determined the significant portions of the signal, computer 102 may also be used for further processing of those portions and may direct the sensing characteristics of sensor 100, concentrating on more detectable signals. Additionally, computer 102 may be used for noise quieting design analyses of the source of those significant portions of the signal, leading to design changes in noise generating equipment.

The invention thus described provides a method and system for identifying transient signal features within an acoustic signal. After receiving a signal from a sensor, the signal is analyzed using the NDAS processing modules. First a PSD plot is generated and examined to determine if it exhibits broadband characteristics. If it does, then the auto-correlation function is generated and is examined for signs of transient behavior. If such signs are exhibited, then the state portrait is examined to determine the transformation to noise-like behavior. Processing of an acoustic signal and the quieting of self noise generating equipment can then be concentrated on the portion of the signal prior to the transformation to noise-like behavior. Since signal processing can concentrate on the portion of the signal occurring prior to noise-like behavior, the method and system can better separate background noise from the signal of interest, especially in environments having extensive background noise and reflections, such as littoral environments. By concentrating on transient behavior, the method and system aid in detecting, analyzing and classifying self noise, as well as aiding in noise quieting design.

Although the present invention has been described relative to a specific embodiment thereof, it is not so limited. For example, the preliminary time-delay parameter can be determined in a variety of ways, e.g., choosing one quarter of the zero crossing value. The method and system need not be limited to the use of the NDAS. Any method of obtaining the necessary parameters may be used, including traditional mathematical techniques. Further, the system need not be limited to acoustic signals. Analysis of electromagnetic or other signals amenable to the signal processing techniques described herein may also profit by the use of the inventive method and system.

Thus, it will be understood that many additional changes in the details, steps and arrangement of parts, which have been herein described and illustrated in order to explain the nature of the invention, may be made by those skilled in the art within the principle and scope of the invention.

Attorney Docket No. 78041

METHOD AND SYSTEM FOR TRANSIENT SIGNAL DETECTION

## ABSTRACT OF THE DISCLOSURE

A method and system for identifying transient signal features within an acoustic signal first obtains and analyzes a power spectral density (PSD) plot of the signal to determine if it exhibits broadband characteristics. If broadband characteristics are exhibited, then the auto-correlation function is examined for signs of transient behavior. If the auto-correlation function exhibits signs of transient behavior, then the state portrait is examined to determine the transformation to noise-like behavior. Processing of an acoustic signal and the quieting of self noise generating equipment can then be concentrated on the portion of the signal prior to the transformation to noise-like behavior.

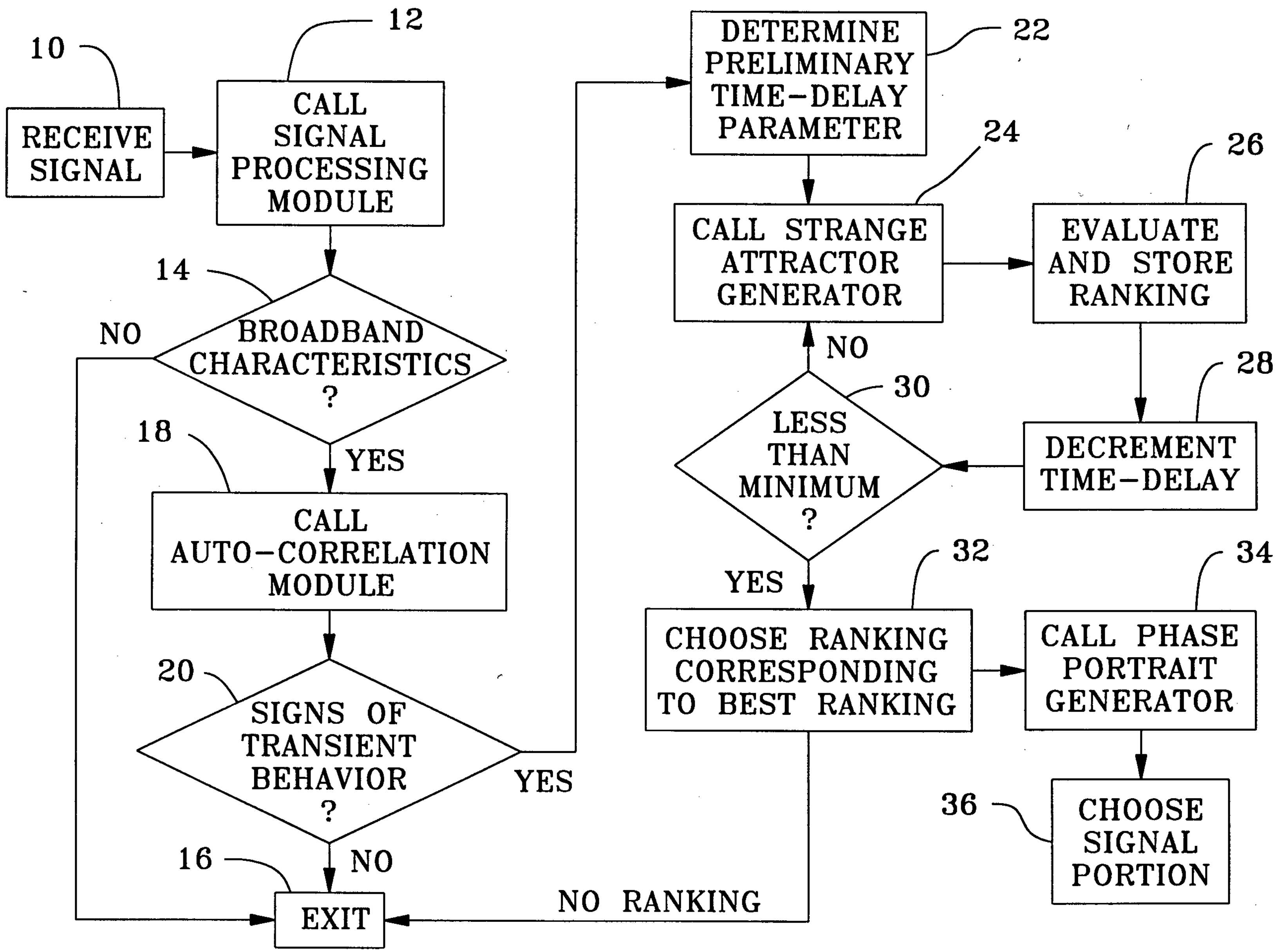
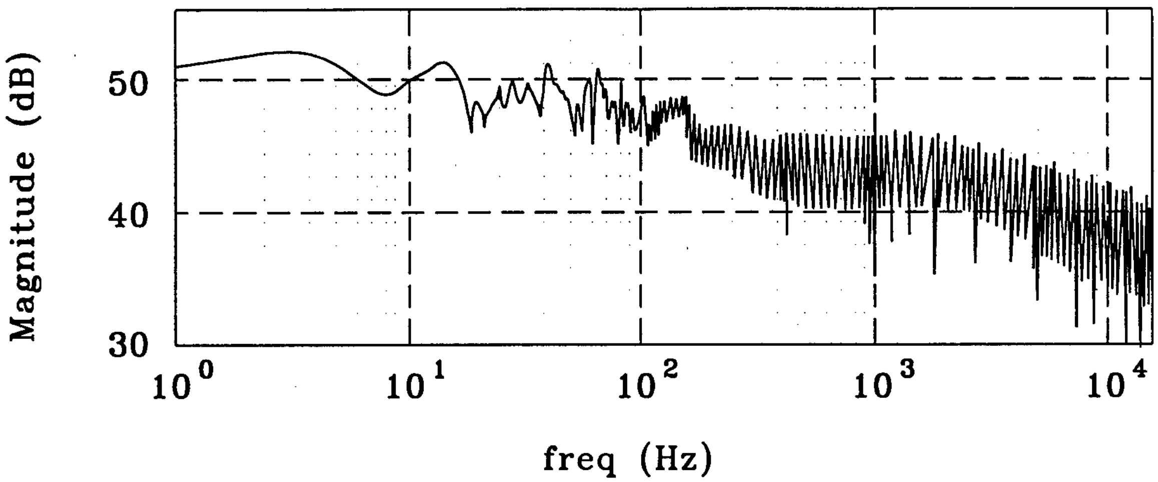
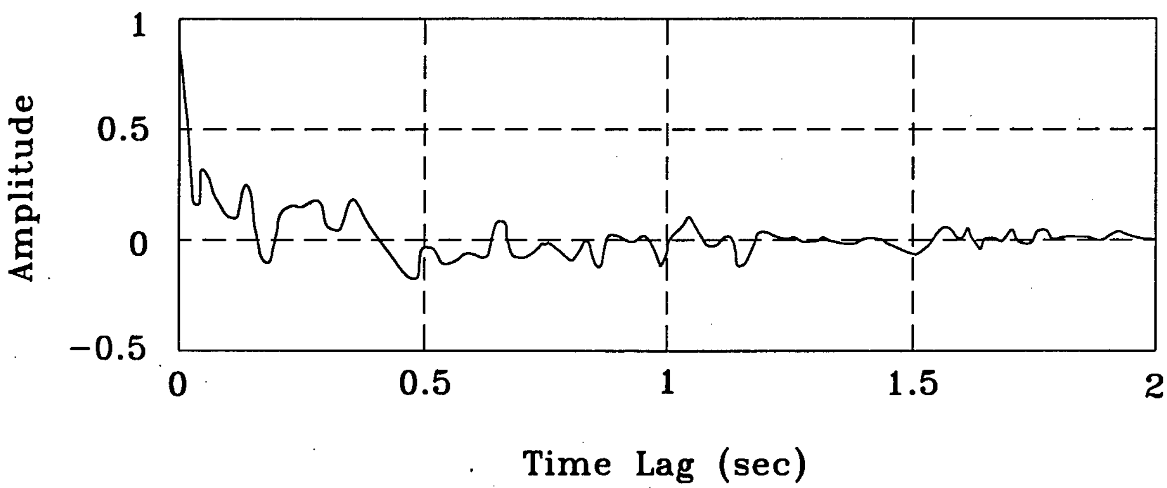

10
RECEIVE SIGNAL
12
CALL SIGNAL PROCESSING MODULE
14
BROADBAND CHARACTERISTICS ?
NO
YES
18
CALL AUTO-CORRELATION MODULE
20
SIGNS OF TRANSIENT BEHAVIOR ?
YES
NO
16
EXIT
22
DETERMINE PRELIMINARY TIME-DELAY PARAMETER
24
CALL STRANGE ATTRACTOR GENERATOR
26
EVALUATE AND STORE RANKING
28
DECREMENT TIME-DELAY
30
LESS THAN MINIMUM ?
NO
YES
32
CHOOSE RANKING CORRESPONDING TO BEST RANKING
NO RANKING
34
CALL PHASE PORTRAIT GENERATOR
36
CHOOSE SIGNAL PORTION

FIG. 1



Magnitude (dB)
50
40
30
$10^0$
$10^1$
$10^2$
$10^3$
$10^4$
freq (Hz)


FIG. 2



Amplitude
1
0.5
0
−0.5
0
0.5
1
1.5
2
Time Lag (sec)


FIG. 3

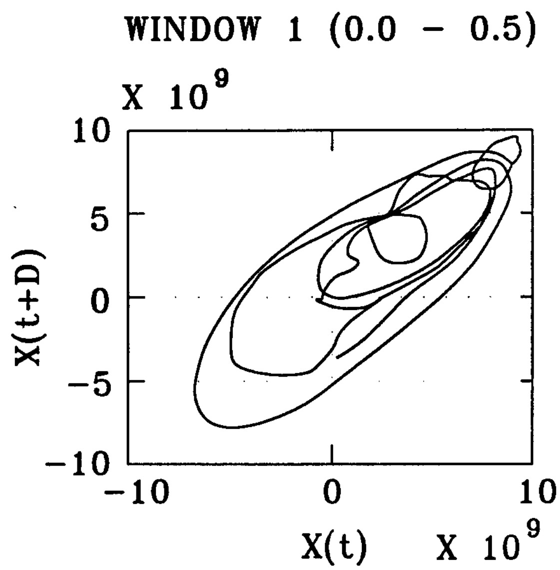



FIG. 4A

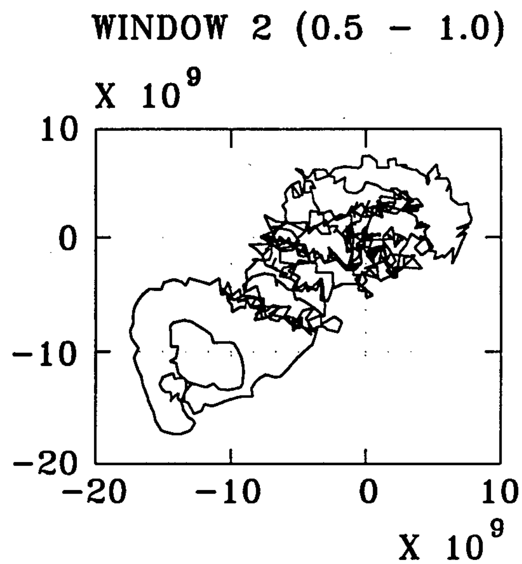



FIG. 4B

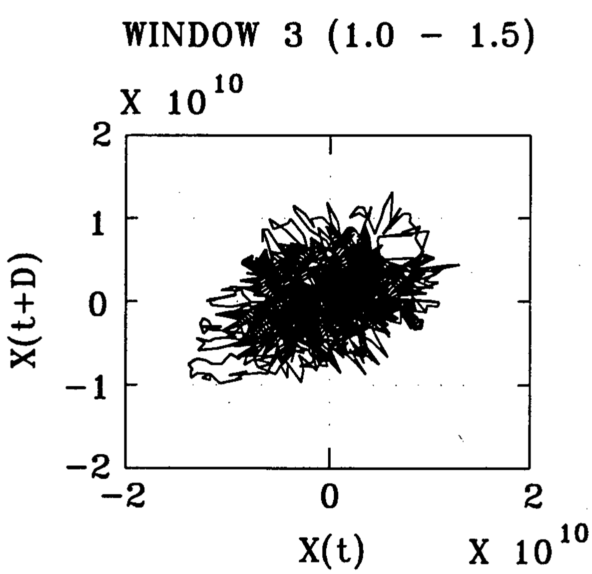



FIG. 4C

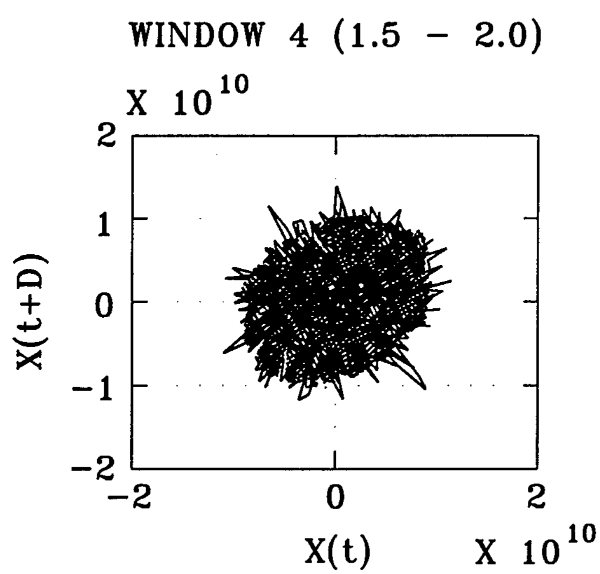



FIG. 4D

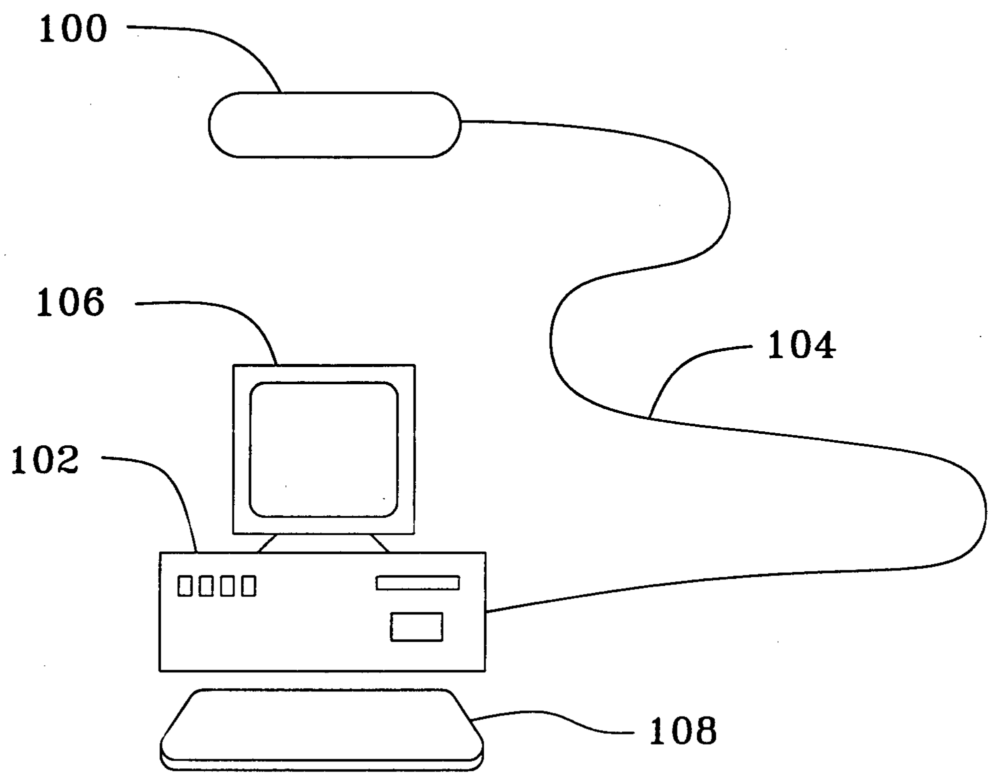



FIG. 5