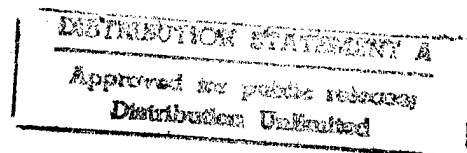


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NOTICE

The above identified patent application is available for licensing. Requests for information should be addressed to:



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DEPARTMENT OF THE NAVY
CODE OCCC3
ARLINGTON VA 22217-5660

19970205 050

DTIC QUALITY INSPECTED 3

2
3 METHOD FOR DATA GAP COMPENSATION

4
5 STATEMENT OF GOVERNMENT INTEREST

6 The invention described herein may be manufactured and used
7 by or for the Government of the United States of America for
8 governmental purposes without the payment of royalties thereon or
9 therefor.

10
11 CROSS REFERENCE TO RELATED PATENT APPLICATION

12 This patent application is co-pending with a related
13 application, which is commonly assigned and is filed on even date
14 to the filing herewith, entitled SYSTEM AND METHOD FOR CHAOTIC
15 SIGNAL IDENTIFICATION, (Navy Case No. 74951), having same filing
16 date.

17
18 BACKGROUND OF THE INVENTION

19 (1) Field of the Invention

20 The present invention generally relates to the field of
21 signal processing, and more particularly to noise discrimination
22 and analysis of discontinuities (missing data) in time series
23 signals.

24 (2) Description of the Prior Art

25 It is well known that time series data signals are sometimes
26 corrupted, resulting in missing or unusable data. By way of

1 example, it is often the case that discontinuities (missing data)
2 are observed in the time series signals measured and recorded by
3 underwater acoustic sensing contact, or target tracking devices,
4 such as naval sonar systems, contact localization motion analysis
5 systems, or the like. These discontinuities in the signal may be
6 caused by electrical interference, i.e., noise, that is
7 internally generated by the measuring device itself, or by noise
8 from the environment being observed. This noise often causes a
9 portion, or portions, of the time series signal to be missing or
10 unusable. In any case, information contained in the time series
11 signal often needs to be preprocessed to compensate for such
12 corruptions, before it can be properly analyzed and subsequently
13 used.

14 Moreover, there is a special need for such compensation
15 preprocessing within the functioning of submarine carried
16 analysis systems for processing passive acoustic contact, or
17 target generated signal values for determination of the presence
18 and nature of chaotic signal components in the signal values.
19 The analysis system disclosed in the above-identified copending
20 application, hereby incorporated by reference in its entirety, is
21 exemplary of such special need. The underlying data to be
22 detected by this system is the presence of a chaotic (and hence
23 nonlinear) component of the signal, such as acoustic energy
24 induced by turbulence associated with underwater vehicle
25 movement, where data sequence measurements are biased by the
26 imperfections of sensory devices. Particular discussion of how

1 the method of this invention would be employed in its functioning
2 is described in a portion of its DESCRIPTION OF THE PREFERRED
3 EMBODIMENT section which provides a detailed description of a
4 data gap compensator (reference number 23, therein) commencing
5 with text "The data gap compensator ..."; and ending with text
6 "... to the processing section 12" and in a portion which
7 summarized the operation of the data gap compensator (23,
8 therein) in conjunction with control module (14, therein)
9 commencing with text "The control module 14 ..." and ending with
10 text "... to the operator step 110."

11 Employing regression methods for data gap compensation is
12 known. Most of the traditional linear regression methods employ
13 a simple model with a moderate model (quadratic, cubic, or at
14 most, fourth-order). It has been widely publicized in the open
15 literature that the performance of projecting missing data via
16 traditional techniques is not optimized. In many real-world
17 applications of data gap compensation with traditional methods
18 there exists many shortfalls such as errors between true and
19 projected curves. One technology area where these problems exist
20 is the processing of noise corrupted time measurements where the
21 underlying data or measurements which are to be processed are
22 nonlinear in nature, corrupted by non-white noise, and biased by
23 the imperfections of sensory devices.

1 As a consequence, there has been a long felt need for a
2 method of filling data gaps in time series data signals that are
3 generated by such underwater acoustic sensing or contact tracking
4 devices.

5 6 SUMMARY OF THE INVENTION

7 It is, therefore, an object of the invention to provide a
8 method for filling in at least one missing interval of data
9 within quantized time-dependent data signals with all the
10 aforementioned needs substantially met.

11 Another object of the invention is the provision of a method
12 for compensating for the discontinuity caused by missing
13 intervals of data within a quantized time-dependent data signal,
14 and which is of special utility in the performance of such
15 functions in a submarine carried analysis system for processing
16 passive undersea acoustic contact, or target transmitted signals
17 for determination of the presence and the nature of chaotic
18 signal components.

19 Still another object of the invention is the provision of
20 such a method of data gap compensation which is of special
21 utility in processing noise corrupted time measurements where the
22 underlying data or measurements are non-linear in nature,
23 corrupted by non-white noise, and biased by the imperfections of
24 sensory devices.

25 Yet another object of the invention is the provision of such
26 a method of data gap compensation which as one of its performance

1 features includes inherent flexibility of mode of operation to
2 select the appropriate gap spanning parametric equation for a
3 curve both as to selection of a specific curve and to curve
4 fitting.

5 Yet another object of the invention is the provision of a
6 method for filling in at least one missing interval of data
7 within a quantized time-dependent data signal that enhances the
8 continuity of that data signal's structure, thereby reducing
9 statistical biases in subsequent signal processing.

10 Yet another object of the invention is to provide a method
11 for filling in at least one missing interval of data within a
12 quantized time-dependent data signal that is easily adapted for
13 implementation with either standard electronic components or via
14 software means.

15 With the above and other objects in view, as will
16 hereinafter appear, a feature of the present invention is the
17 provision of a novel recursive projection regression method for
18 filling in at least one missing interval of data within a
19 quantized time-dependent signal. One preferred embodiment of the
20 present method employed in the processing of acoustic passive
21 undersea warfare contact, or target transmitted signals comprises
22 the following steps:

23 (1) providing means for measuring a quantized time-
24 dependent signal;

1 (2) filtering that quantized time-dependent signal to
2 remove all high frequency components above a certain threshold
3 frequency;

4 (3) providing means for retrievably storing data
5 representing the filtered quantized time-dependent signal wherein
6 that data comprises a time-series of data points;

7 (4) retrieving the time-series of data points from the
8 storage means;

9 (5) determining the number of missing intervals within the
10 time-series of data points;

11 (6) forming a data window comprising at least a selected
12 portion of the time-series of data points immediately preceding a
13 first missing data interval empirically determined from a data
14 base of actual signal values gathered in sea tests involving
15 contact localization motion analysis scenarios between a sensor
16 carrying submarine and a contact submarine generating a passive
17 acoustic signal in environments of various levels of acoustic
18 propagation noises;

19 (7) fitting a first order regression curve to that portion
20 of the time-series of data points within the window;

21 (8) fitting a second order regression curve to the same
22 portion of the time-series of data points within the same window;

23 (9) computing a plurality of residual values for the first
24 and the second regression curves;

25 (10) computing a root-mean-square value for the plurality
26 of residual values for the first order regression curve and for

1 the plurality of residual values for the second order regression
2 curve;

3 (11) determining the smallest root-mean-square value for the
4 plurality of residual values for the first order regression curve
5 and for the plurality of residual values for the second order
6 regression curve;

7 (12) comparing the smallest root-mean-square values of the
8 first order and the second order regression curves;

9 (13) selecting a regression curve that provides the
10 smallest root-mean-square values; and

11 (14) storing and recording the selected regression curve as
12 synthesized values for compensation of the discontinuity caused
13 by an interval or intervals of missing data.

14 15 BRIEF DESCRIPTION OF THE DRAWINGS

16 Reference is made to the accompanying drawings in which are
17 shown illustrated embodiments of the invention, from which its
18 novel features and advantages will be apparent.

19 In the drawings:

20 FIG. 1 is a general block chart describing the recursive
21 projection regression method of the present invention;

22 FIG. 2 is a simple block diagram illustrating model
23 selection;

24 FIG. 3 is a flow chart of the steps associated with a
25 polynomial model fit according to the present invention;

1 FIG. 4 is a flow chart of the steps associated with a
2 Discrete Fourier Transform model fit according to the present
3 invention;

4 FIG. 5 is a graph of a quantized time-dependent data signal
5 having a plurality of missing intervals of data; and

6 FIG. 6 is a graph similar to that shown in FIG. 5, with the
7 missing intervals of data filled by the method of the present
8 invention.

9 10 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

11 Referring first to FIGS. 1 and 2, block diagrams are
12 provided that generally summarize the recursive projection
13 regression method of the present invention. The method of the
14 present invention generally comprises a module which measures and
15 stores a quantized time-dependent data signal, such as is
16 provided by an underwater acoustic sensing device. For example,
17 naval sonar systems or contact localization motion analysis units
18 associated with sonars (not shown) often produce quantized time-
19 dependent data relating to the observation and tracking of
20 various objects located on or below the surface of a body of
21 water. This quantized time-dependent data signal is then passed
22 to the present invention, which generally comprises a measuring
23 and storing module 20, a data gap deletion module 40, a data gap
24 compensation module 60, and a record and store solution module
25 80, where it is analyzed to determine the number and location of
26 any intervals of missing data, i.e., gaps in the time series data

1 signal caused by noise in the sensing equipment or the local
2 environment, and so as to fill-in any of the intervals of missing
3 data that are detected. The quantized time-dependent data signal
4 may also be modified by a low pass filter of a type well known in
5 the art (FIGS. 3 and 4), to remove any undesirable high frequency
6 noise components within the signal.

7 Data gap compensation module 60 provides a plurality of
8 mathematical models (shown generally at 90 in FIG. 2) that are
9 individually tested to derive an optimum regression curve for
10 that model, relative to a portion of the signal data immediately
11 preceding each previously identified data gap. It will be
12 understood that an optimum regression curve, in the context of
13 the present invention, is that regression curve for which a
14 mathematical convergence of the model is achieved (shown
15 generally at 100 in FIG. 2). In a preferred embodiment,
16 "convergence" of the model is determined by application of a
17 smallest root-mean-square analysis to each of the plurality of
18 models tested. Once a model possessing the smallest root-mean-
19 square value is derived from among the plurality of models
20 tested, that optimum model is then selected (shown generally at
21 110 in FIG. 2), recorded, and stored via record and store
22 solution module 80 (see FIG. 1) module, for use in filling the
23 data gap (shown generally at 120 in FIG. 2). This process is
24 then repeated for each subsequent data gap until all of the
25 identified data gaps are filled.

1 In connection with the present invention, various
2 mathematical models may be used to derive an appropriate
3 regression curve for fitting to the quantized time-dependent data
4 signal. In one preferred embodiment, a class of generalized
5 "Maximum Likelihood Estimation" (MLE) functions are employed. It
6 will be understood that MLE functions of this type have been
7 found to be useful in modeling data structures that conform to a
8 statistical linear model, and are well known to those skilled in
9 the art. Details of this type of "general linear model" may be
10 found in *Introduction to Statistical Theory* by P.G. Hoel, et al.,
11 Boston, Houghton Mifflin Company, 1971, and more particularly to
12 its chapter 4 (Linear Models - Estimation), pages 112-133, and
13 its chapter 5 (Linear Models-Test), pages 140-157, which text
14 portions are hereby incorporated herein by reference.

15 In this embodiment of the present invention, a "general
16 linear regression model" is preferably derived from a
17 multivariate generalized jointly distributed MLE function, such
18 as:

$$E(Y_i) = \beta_1 X_{1i} + \beta_2 X_{2i} + \dots + \beta_k X_{ki} \quad (1)$$

21 In the above-described general MLE function, each β_k is a
22 weighted parameter associated with the n sample x_k observations
23 to be estimated. A constant term, β_0 , is also included in this
24 general relationship. The term β_0 is typically determined by
25 setting $x_{ki} = 1$. Estimation of these parameters for both linear

1 models and nonlinear models is carried out with conventional
2 analytical procedures that are well known to those skilled in the
3 art.

4 The above-described general MLE function may be employed in
5 the present invention to represent a general linear regression
6 model of Y on x . More particularly, the recursive projection
7 regression method of the present invention derives a set of
8 special models from this general model, by selecting specific
9 functional forms of $E(Y_i)$. In this way, the constructed function
10 (i.e., the regression curve representing the locus of conditional
11 means over the domain of the x values) may be utilized to
12 compensate for the gap of missing data within the time-series
13 data signal, with the smallest possible error (least bias).

14 Two specific linear models have been found to yield
15 excellent results when used in connection with one preferred
16 embodiment of the present invention. More particularly, a
17 polynomial model and a trigonometric (Fourier type) model have
18 been found to provide regression curves exhibiting excellent fit
19 to the quantized time-dependent data signals generated by
20 underwater acoustic sensing devices or contact localization
21 motion analysis units of the type used in connection with naval
22 sonar systems. For example, a general polynomial form of the
23 above-described general MLE function can be derived by setting
24 each x_{ki} equal to t^{k-1} and omitting the observation index i , as
25 follows:
26

$$E(Y_j) = \beta_0 + \beta_1 t + \beta_2 t^2 + \beta_3 t^3 \dots + \beta_r t^r, \text{ where } t = 1, 2, 3, \dots, n. \quad (2)$$

It will be understood that "t" represents the discrete time observations measured by measuring means typically employed in conjunction with a naval sonar system or the like.

The steps comprising the polynomial fit method of the present invention are disclosed in the flow chart shown in FIG.

3. More particularly, the application of a polynomial model will be understood to be a step-wise procedure comprising the steps of: measuring the time series (indicated at 132); low pass filtering (indicated at 134); observing missing data in the time series (indicated at 136); selecting a window parameter from table 1 (indicated at 138); fitting a linear curve through the first data gap (indicated at 140); measuring and recording a root-mean-square statistic (indicated at 142); fitting the next highest polynomial order to the first data gap (indicated at 144); repeating steps 138 and 142 (indicated at 146); repeating steps 144 and 146 (indicated at 148); recording and storing the solution (indicated at 150); and repeating the entire process until all data gaps are compensated (indicated at 152). It will be appreciated that a linear fit is first made (step 140) to the data signal of interest. Then, successively higher orders are introduced until the first non-missing data points immediately following a data gap, and the corresponding model projected point or points, achieve a convergent minimum difference (step 146). Solution convergence for the polynomial model is based on the

1 determination of a smallest root-mean-square value from among a
2 plurality of successive models, of increasing order, that are fit
3 to the data signal (step 148).

4 It will be understood that, occasionally, a data signal may
5 contain certain periodicities which may not be well modeled by
6 polynomial or other regression curves. To the end of providing a
7 solution in these cases, the recursive projection regression
8 method of the present invention includes provision of a
9 regression curve that is derived from a partial sum of a Discrete
10 Fourier series by applying a Discrete Fourier Transform (DFT) to
11 the data signal. As will be appreciated by those skilled in the
12 art, a DFT may be derived from the above-disclosed general MLE
13 function by setting $k = 2r+1$, $x_1 = 1$, $x_k = \cos(j-1)t$ for $j = 2$,
14 $\dots$, $r+1$; and $x_j = \sin(j-4-1)t$ for $j = r+2$, $\dots$, $2r+1$, as follows:

$$E(Y_i) = a_0 + a_1 \cos t + a_2 \cos 2t + \dots + a_r \cos rt + b_1 \sin t + b_2 \sin 2t + \dots + b_r \sin rt \quad (3)$$

16
17 As with a polynomial model, for the DFT, the solution to the
18 problem of data gap compensation for the set of points in the
19 (t,y) plane is obtained by simultaneously solving a derived
20 system of normal equations. The details of this type of solution
21 technique parallel those disclosed hereinabove in connection with
22 the polynomial fit model. More particularly, and turning now to
23 FIG. 4, the DFT technique of the present invention comprises the
24 steps of: measuring the time series (indicated at 162); low pass
25 filtering (indicated at 164); observing missing data in the time

1 series (indicated at 166); selecting a window parameter from
2 table 1 (indicated at 168); measuring and recording a root-mean-
3 square statistic (indicated at 170); repeating steps 168 and 170
4 until a best solution is achieved (indicated at 172); recording
5 and storing the best solution (indicated at 174); and repeating
6 steps 162 to 174 until all the data gaps are compensated
7 (indicated at 176). It will be appreciated that a Discrete
8 Fourier Transform (DFT) is performed adaptively to predict the
9 post-gap data points required to achieve a convergent value
10 (steps 168-176). The method of the present invention selects the
11 smallest of a plurality of smallest root-mean-square values
12 derived for each model (step 172). More particularly, the model
13 that demonstrates an overall minimum root-mean-square value is
14 selected as the best model for compensating for the missing data
15 values. This best model is then recorded and stored. As before,
16 solution convergence is based on a root-mean-square analysis.

17 Finally, the plurality of models (polynomial, DFT, and
18 others as applicable) are compared to decide which model provides
19 the overall best fit to the existing data and data gaps. More
20 particularly, the model providing the smallest bias, i.e., the
21 smallest difference between the first non-missing data point or
22 points immediately following a data gap and the corresponding
23 model projected point or points, to achieve a convergent minimum
24 difference based on the root-mean-square analysis. The selected
25 model is then employed to compensate for the data gap. It will,
26 of course, be understood that other linear and/or nonlinear

1 regression models may be used, with equal effect, in deriving an
2 optimum fit.

3 It will be appreciated that with each of the foregoing
4 models, a portion of the data immediately preceding each data gap
5 is selected as a "data window". More particularly, a data window
6 is selected that has a size "w" corresponding to a preselected
7 number of data points from that portion of the data signal
8 immediately preceding each data gap. The number of data points
9 that determine the size of the data window, "w", is selected
10 according to the level of noise present in the data signal. The
11 resultant synthesized values are provided to a utilization means,
12 such as the processing section (indicated at reference numeral 12
13 therein) of the analysis system for processing undersea submarine
14 warfare acoustic signals for determination of presence and nature
15 of chaotic signal components, disclosed in the above-identified
16 copending application.

17 In one embodiment of the present invention, a historical
18 data base of passive acoustic target signal values (obtained from
19 typical target motion situations) are utilized to empirically
20 determine three distinct data window intervals for high, moderate
21 and low signal-to-noise levels, respectively. Table 1 lists the
22 preferred number of data points in a particular data window as a
23 function of the data gap size and the background noise levels
24 present in the data signal.

Table I. Window Size Parameter Values

Gap Interval

Noise Level ***	Short (≤ 2 points)	Moderate (3-10 points)	Long (> 10 points)
High	7m+	10-12m**	all*
Moderate	4-6m	7-9m	all
Low	1-3m	3-6m	all

* Total data streams adjacent to a gap, including possibly entire history

** m is number of missing data points in a representative gap based on the U.S. Navy's standard rate of gathering data stream sample points, namely a sample rate of three (3) acoustic samples per minute.

*** Based on typical contact localization motion analysis noise levels.

EXAMPLE

By way of an example, the polynomial model may be applied to a hypothetical data signal as shown in FIGS. 5 and 6. In application of the polynomial model presented hereinabove, a data gap is filled by projecting an rth order polynomial regression

1 fit across the data gap. FIG. 3 summarizes the method steps of
2 the polynomial fit approach.

3 The polynomial fit approach is exemplified for the
4 hypothetical time series shown in FIG. 5. This graph represents
5 a time series record for up to 101 measurements taken at one
6 second intervals (one measurement per second). The first
7 measurement is at time 0 (t_0) and the last is at time 100 (t_{100}).
8 Also seen in FIG. 5 are four "data gaps" (i.e., time intervals
9 during which measurements were expected but, for one or more
10 reasons, were not recorded for data processing). For example,
11 the first data gap begins immediately following the 11th
12 measurement and extends over the interval t_{12} to t_{19} . Three other
13 data gaps may also be observed in FIG. 5.

14 The polynomial fit algorithm begins with the entire time
15 series that has been stored in arrays. Then, the method steps in
16 the polynomial fit algorithm for a measured time series with
17 missing data are as follows:

18 For the first data gap in the data signal.

19 A window is first formed with an operator specified size w
20 (entered by the operator, and based on the guidelines disclosed
21 in Table 1). If the operator specifies a window size that is too
22 large, it is reduced to within the number of data points
23 preceding the data gap under consideration. Next, within this
24 window a linear regression curve is fit. Then, within that same
25 window a quadratic regression curve is fit. A set of residual
26 values are determined for the linear and quadratic regression

1. fits. These residual values are then compared with one another.
2. A selection is made, by selection means, based on the order of
3. fit that provides the smallest root-mean-square value. The model
4. that provides this smallest root-mean-square value is then
5. recorded and stored.

6. Next, the order of the regression fit is increased to cubic
7. order, and a set of residual values are determined for the cubic
8. order regression fit. These residual values are then compared
9. with the residual values for the model that provided the smallest
10. root-mean-square value for the linear and quadratic regression
11. fit. One model is then selected that gives the smallest root-
12. mean-square value overall from among the models tested. This
13. model is then recorded and stored. This procedure is continued
14. as disclosed hereinabove for ever higher orders until reduction
15. in the root-mean-square value becomes negligible. The order that
16. provides the smallest root-mean-square value overall is then
17. selected, stored, and recorded as a final solution fit. The
18. entire procedure is then applied to each data gap until a
19. regression curve is fit for each gap.

20. The above example summarizes the method of the present
21. invention as it may be applied to the four data gaps shown in
22. FIG. 5. FIG. 6 shows the results of the recursive projection
23. regression method applied to the four data gaps shown in FIG. 5.
24. It should be noted that in the above example, the quadratic
25. polynomial regression curve was found to be the optimum fit with
26. which to data-fill the missing measurements comprising the first

1 data gap. FIG. 6 shows the first gap that was filled in by
2 projecting a solution across the interval t_{12} to t_{19} . Similarly,
3 in FIG. 6, the projected optimum solution is displayed for the
4 second data gap which was based on a third-order (cubic) fit.
5 Following the above steps of the procedure, the remaining data
6 gaps were filled.

7 The present method is by no means limited to models herein
8 disclosed, as the method may be employed advantageously for
9 various other, more specialized models. Some examples of such
10 specialized models are discussed in the earlier cited textbook by
11 P.G. Hoel et al.

12 Additionally, specific statistical criteria may be applied,
13 at certain decision nodes within the steps of the method of the
14 present invention, without departing from its scope. For
15 example, the linear regression models may be accompanied by a
16 statistical hypothesis test in deciding the degree of sufficient
17 fit. Also, although a preferred embodiment of the recursive
18 projection regression method is based primarily on a general
19 linear model other, nonlinear, models are to be assumed within
20 the domain of the claims set forth hereinbelow. Some indication
21 of the meaning and utility of nonlinear models is provided in the
22 above cited textbook by P.G. Hoel, et al.

23 Furthermore, the present invention may be utilized as a
24 portion of software means for use in flexibly programming a
25 general purpose computer of the sort used in connection with
26 naval sonar systems or the like. Such software means will become

1 obvious to those having ordinary skill in the art upon review of
2 the method of the present invention as disclosed in the herein
3 appended claims. Likewise, the method of the present invention
4 may also be implemented on one or a combination of electronic
5 component means, as a portion of a dedicated hardware system
6 associated with a naval sonar or target motion analysis sensor
7 system. Such electronic component means may, for example,
8 comprise one or a series of dedicated integrated circuits, wide-
9 band transistors and function modules. The function of each
10 circuit, transistor or module is fully described by literature
11 supplied by the manufacturers of these types of components, and
12 the manner in which such a circuit would operate would become
13 obvious to those having ordinary skill in the art of electronics
14 upon review of the method of the present invention, as disclosed
15 herein by the appended claims.

16 The advantages of the invention will be readily appreciated.

17 Currently time series discontinuities in naval sonar systems
18 are not compensated. The present invention constitutes a novel
19 method for compensating such data record gaps, thereby enhancing
20 the integrity of the signal structure, and resulting in a
21 reduction of statistical biases in subsequent target motion
22 analysis signal processing.

23 Another advantage of the present invention is the provision
24 of a method for filling in at least one missing interval of data
25 within a quantized time-dependent data signal that enhances the

1 continuity of that data signal's structure, thereby reducing
2 statistical biases in subsequent signal processing.

3 A further advantage of the invention is the provision of a
4 method for filling in at least one missing interval of data
5 within a quantized time-dependent data signal that is easily
6 adapted for implementation with standard electronic components or
7 via software means.

8 A still further advantage of the invention is the provision
9 of synthesized data to compensate for discontinuities in input
10 data in connection with the operation of submarine carried
11 analysis systems for processing passive undersea acoustic
12 contact, or target, transmitted signals for determination of
13 presence and nature of chaotic signal components.

14 It is also to be understood that the present invention is by
15 no means limited to the particular constructions herein disclosed
16 and shown in the drawings, but also comprises any modifications
17 or equivalents
18

1 Navy Case No. 75621

2
3 METHOD FOR DATA GAP COMPENSATION

4
5 ABSTRACT OF THE DISCLOSURE

6 The present invention comprises a method for filling in
7 missing data intervals in a quantized time-dependent data signal
8 that is generated by, e.g., an underwater acoustic sensing
9 device. In accordance with one embodiment of the invention, this
10 quantized time-dependent data signal is analyzed to determine the
11 number and location of any intervals of missing data, i.e., gaps
12 in the time series data signal caused by noise in the sensing
13 equipment or the local environment. The quantized time-dependent
14 data signal is also modified by a low pass filter to remove any
15 undesirable high frequency noise components within the signal. A
16 plurality of mathematical models are then individually tested to
17 derive an optimum regression curve for that model, relative to a
18 selected portion of the signal data immediately preceding each
19 previously identified data gap. The aforesaid selected portion
20 is empirically determined on the basis of a data base of signal
21 values compiled from actual undersea propagated signals received
22 in cases of known target motion scenarios. An optimum regression
23 curve is that regression curve, linear or nonlinear, for which a
24 mathematical convergence of the model is achieved. Convergence of
25 the model is determined by application of a smallest root-mean-
26 square analysis to each of the plurality of models tested. Once

1 a model possessing the smallest root-mean-square value is derived
2 from among the plurality of models tested, that optimum model is
3 then selected, recorded, and stored for use in filling the data
4 gap. This process is then repeated for each subsequent data gap
5 until all of the identified data gaps are filled.

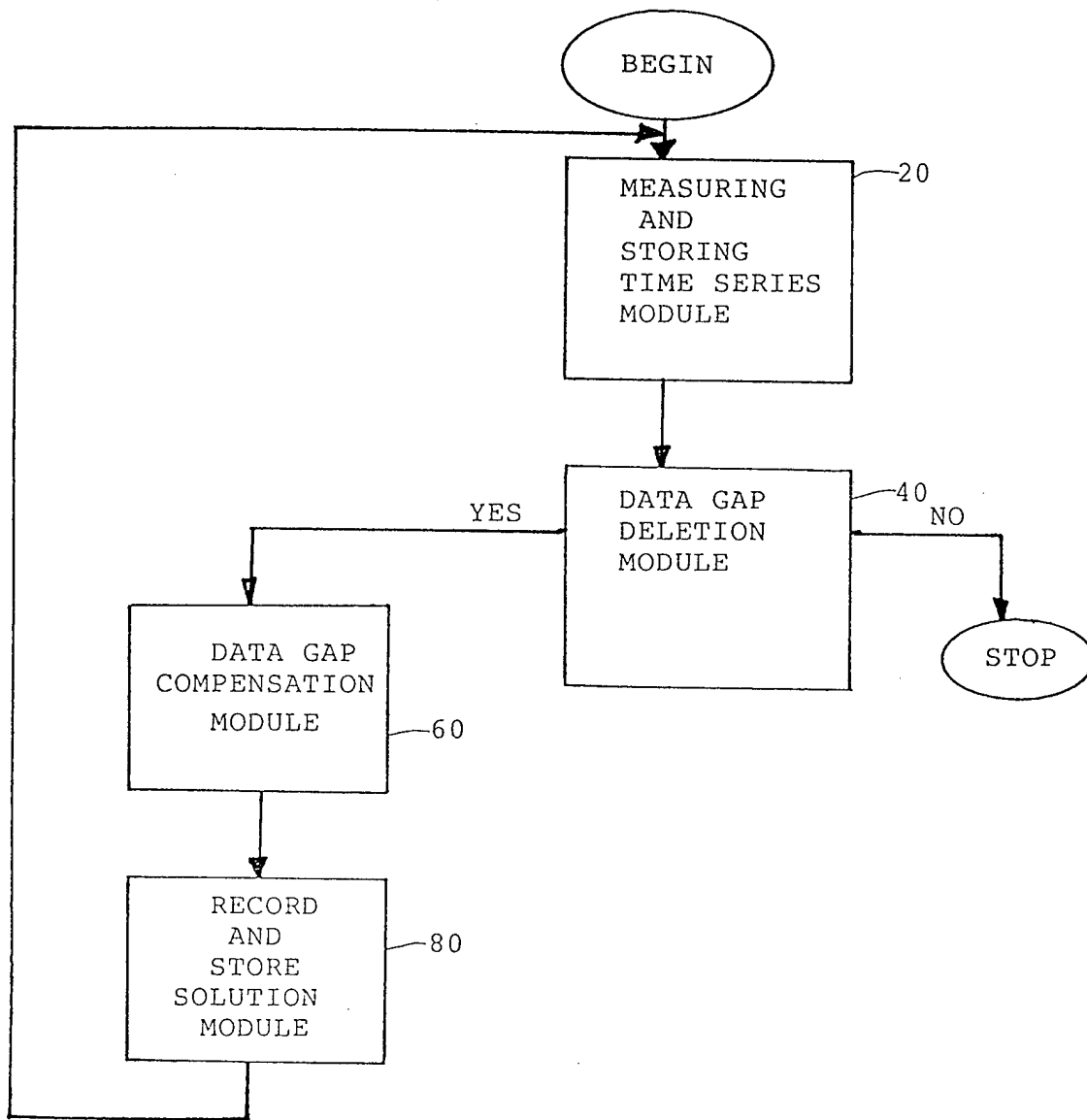


FIG. 1

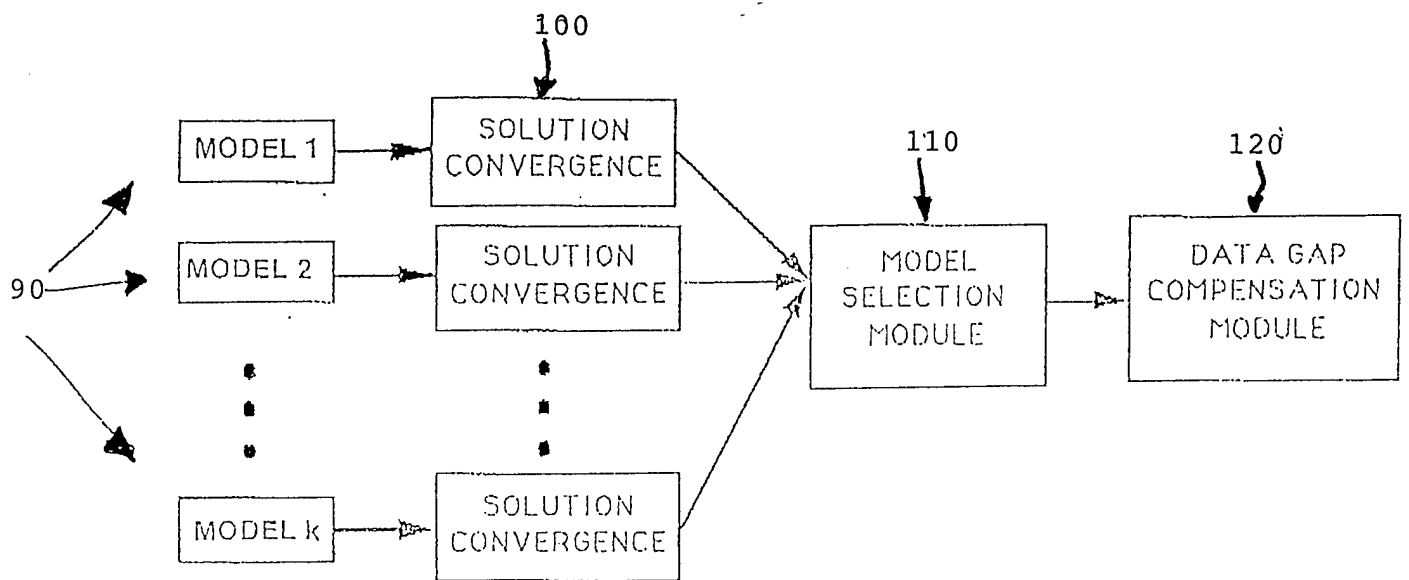


FIG. 2

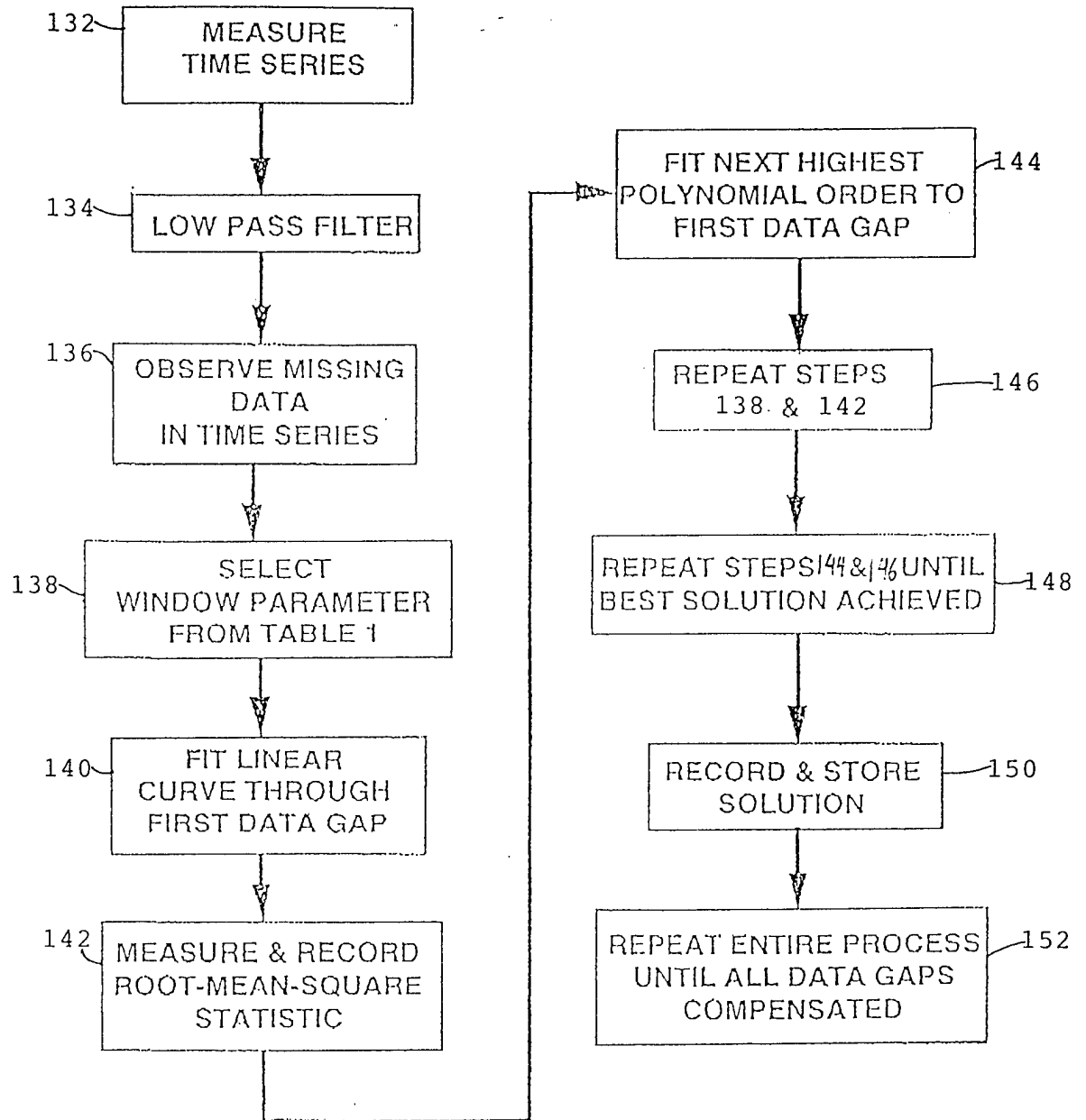


FIG. 3

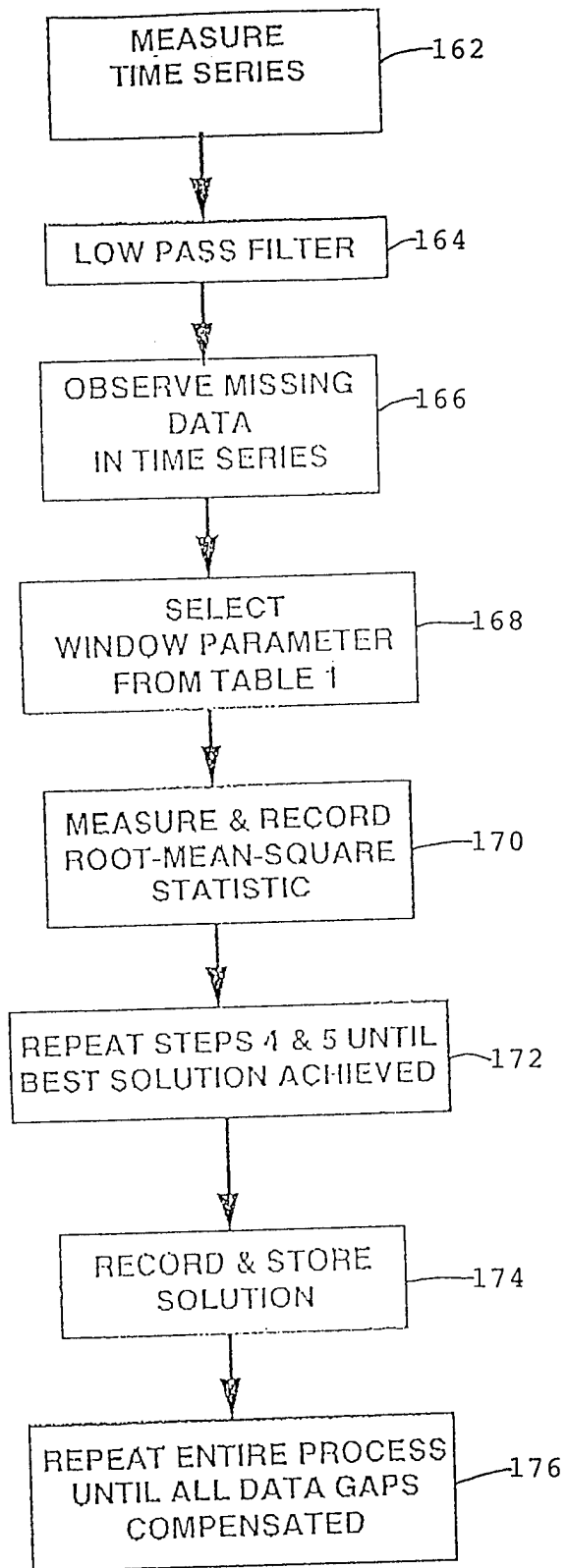
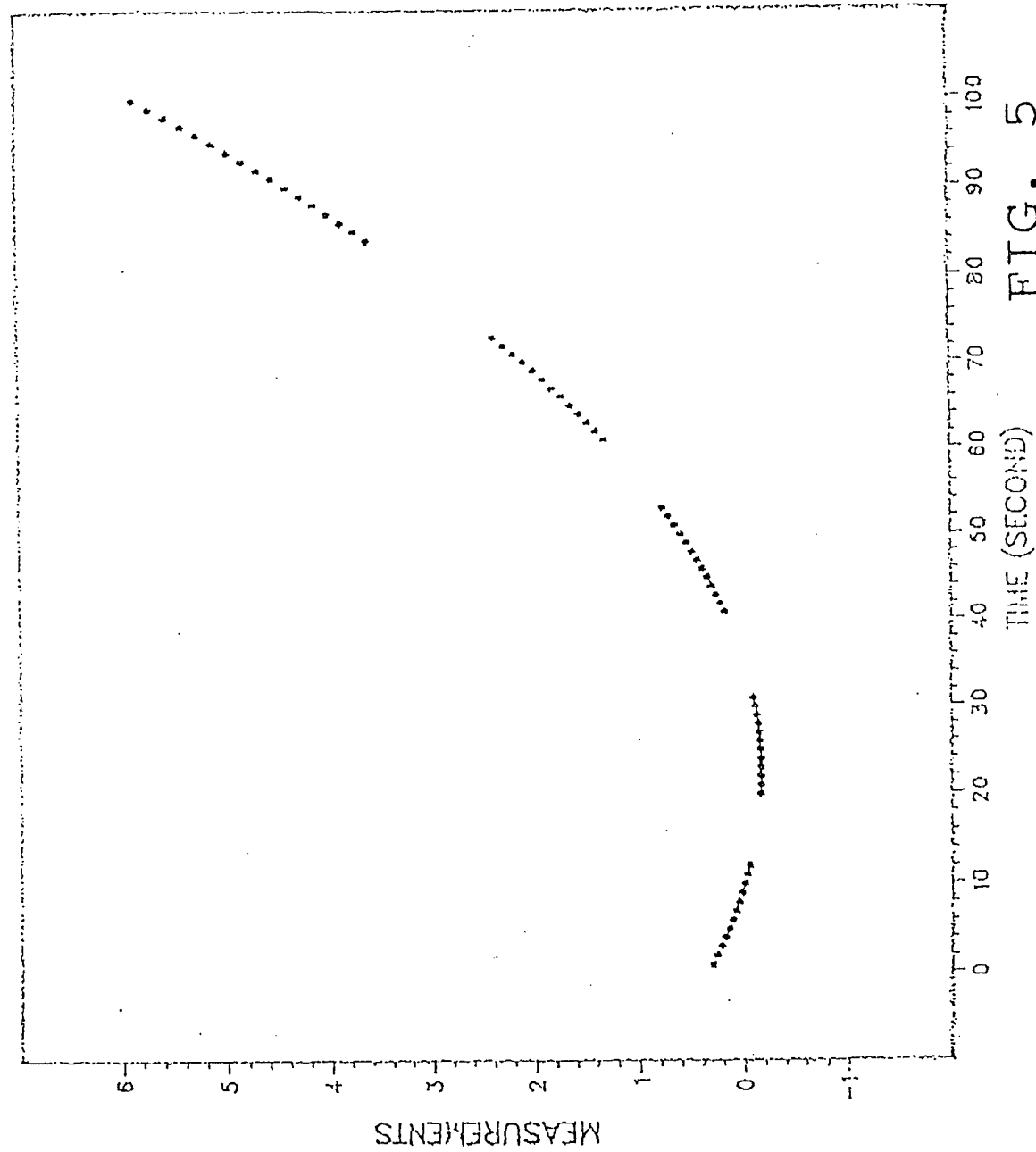


FIG. 4

TIME SERIES BEFORE RPRT



TIME SERIES AFTER RPRT

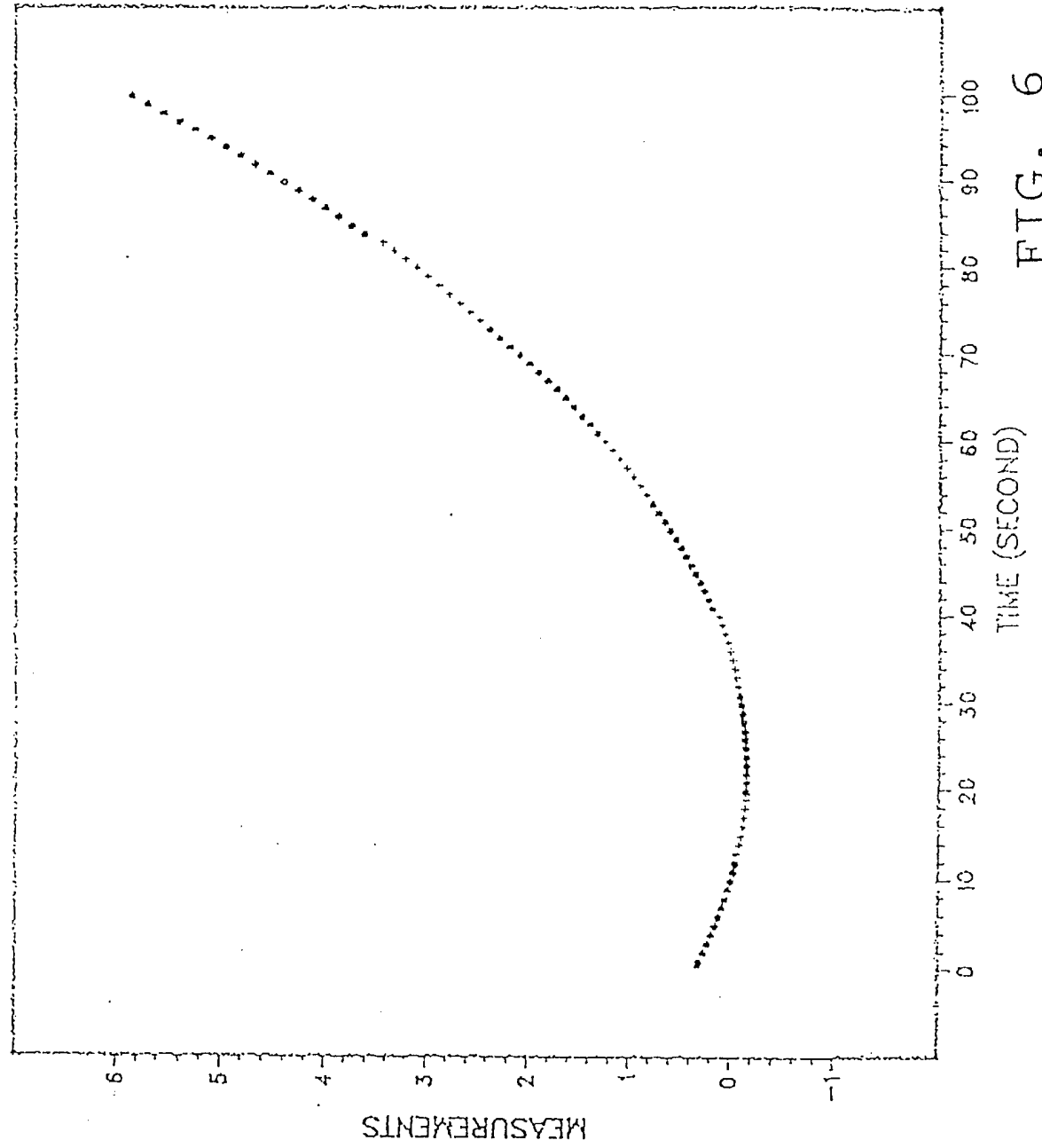


FIG. 6