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[54] **MARINE NAVIGATION METHOD FOR GEOPHYSICAL EXPLORATION**

[75] Inventors: **John P. Norton; Noel D. Zinn; Phillip J. V. Rapatz,** all of Houston, Tex.

[73] Assignee: **Western Atlas International, Inc.,** Houston, Tex.

[21] Appl. No.: **967,673**

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[51] **Int. Cl.**[5] **G01V 1/28;** G04B 17/00

[52] **U.S. Cl.** **364/421;** 367/40; 367/41; 367/19; 367/125; 367/130; 364/443

[58] **Field of Search** 364/421, 433, 443, 460, 364/554, 578; 367/19, 125, 130, 40, 41

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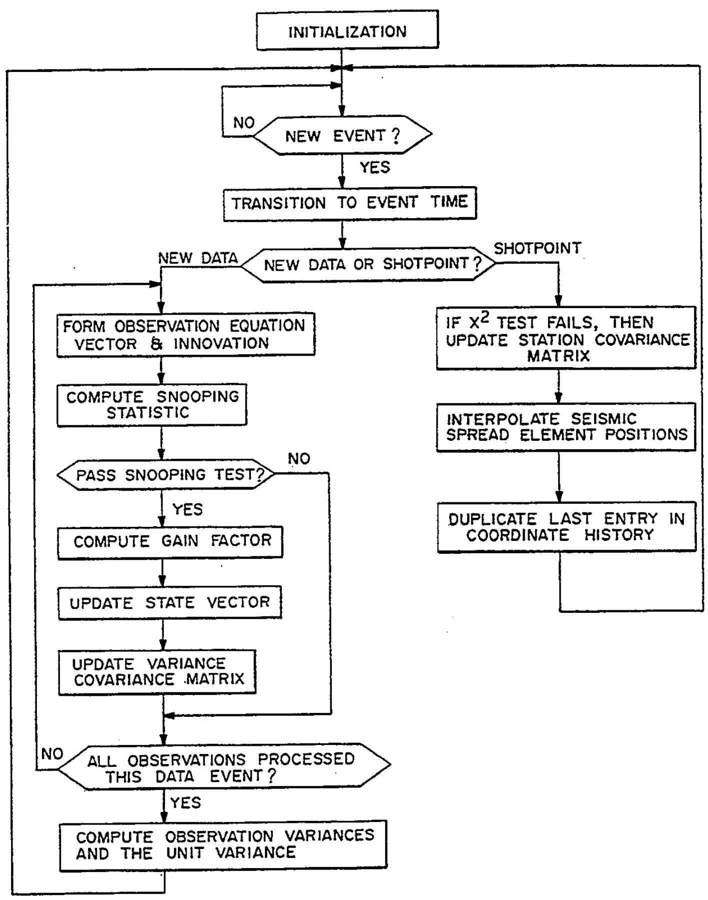
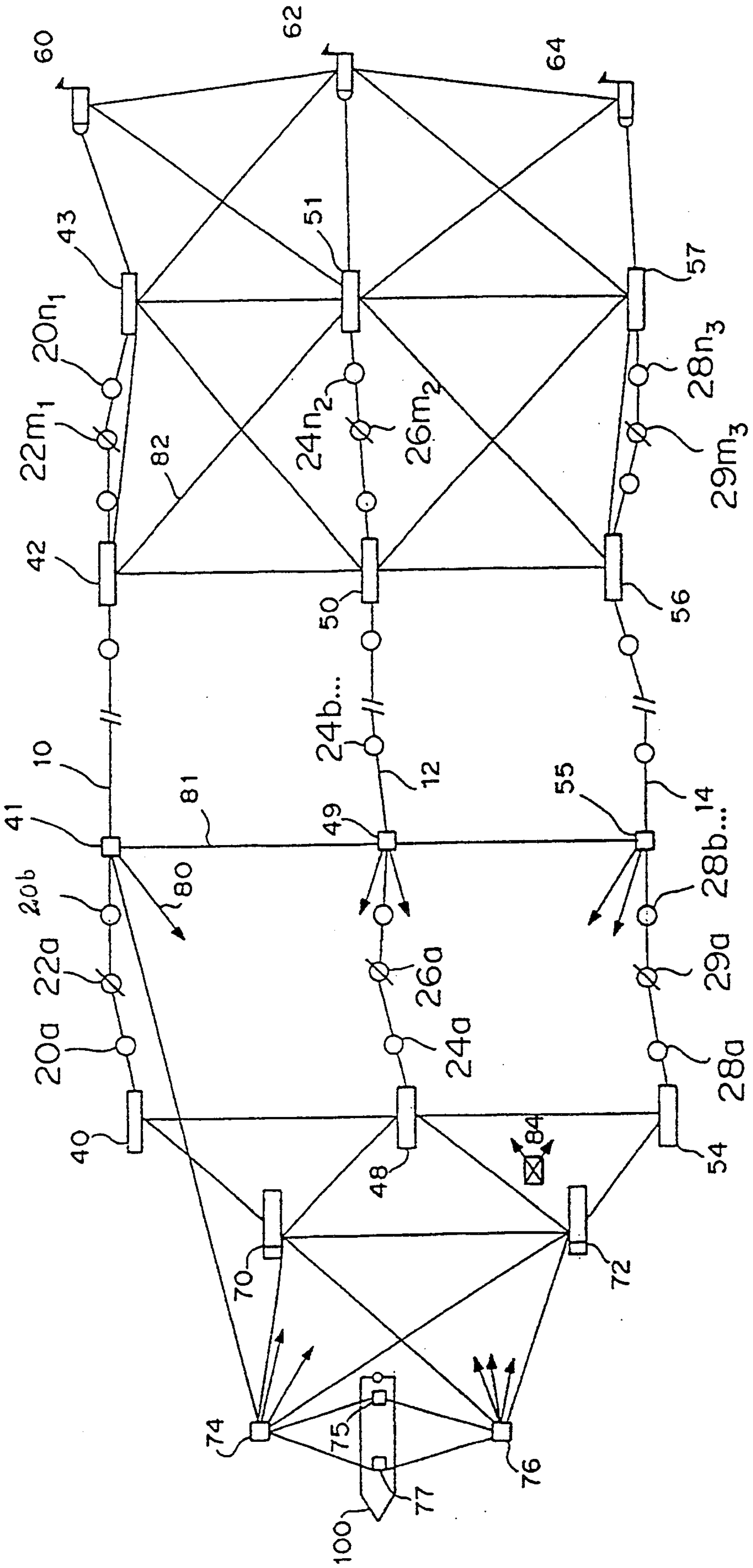
Primary Examiner—Thomas G. Black
Assistant Examiner—Susan Wieland
Attorney, Agent, or Firm—Paul S. Madan

[57] **ABSTRACT**

The present invention provides a method for on-line real-time processing of processing navigational data for determining the location of sensor and receiver points in a navigational network having a number of different types of devices. Observations from these devices are obtained using a coordinate system that follows appropriate nominal sailing lines. Outlying observations are discarded using w-statistics for the observations. Any correlated observations such as compass azimuths are uncorrelated. The uncorrelated observations are then sequentially processed in an extended sequential Kalman filter, which provides the best estimate of the station coordinates. These estimated coordinates are then used to determine the location of the source and receiver points.

8 Claims, 3 Drawing Sheets

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24b...
12
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14
41
81
49
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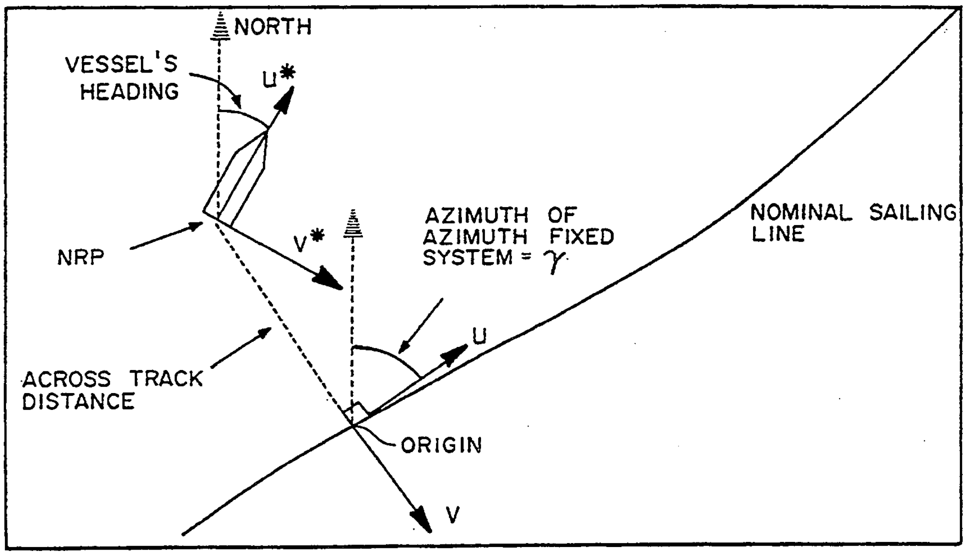
FIG. 1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NOMINAL SAILING LINE
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v

FIG. 2

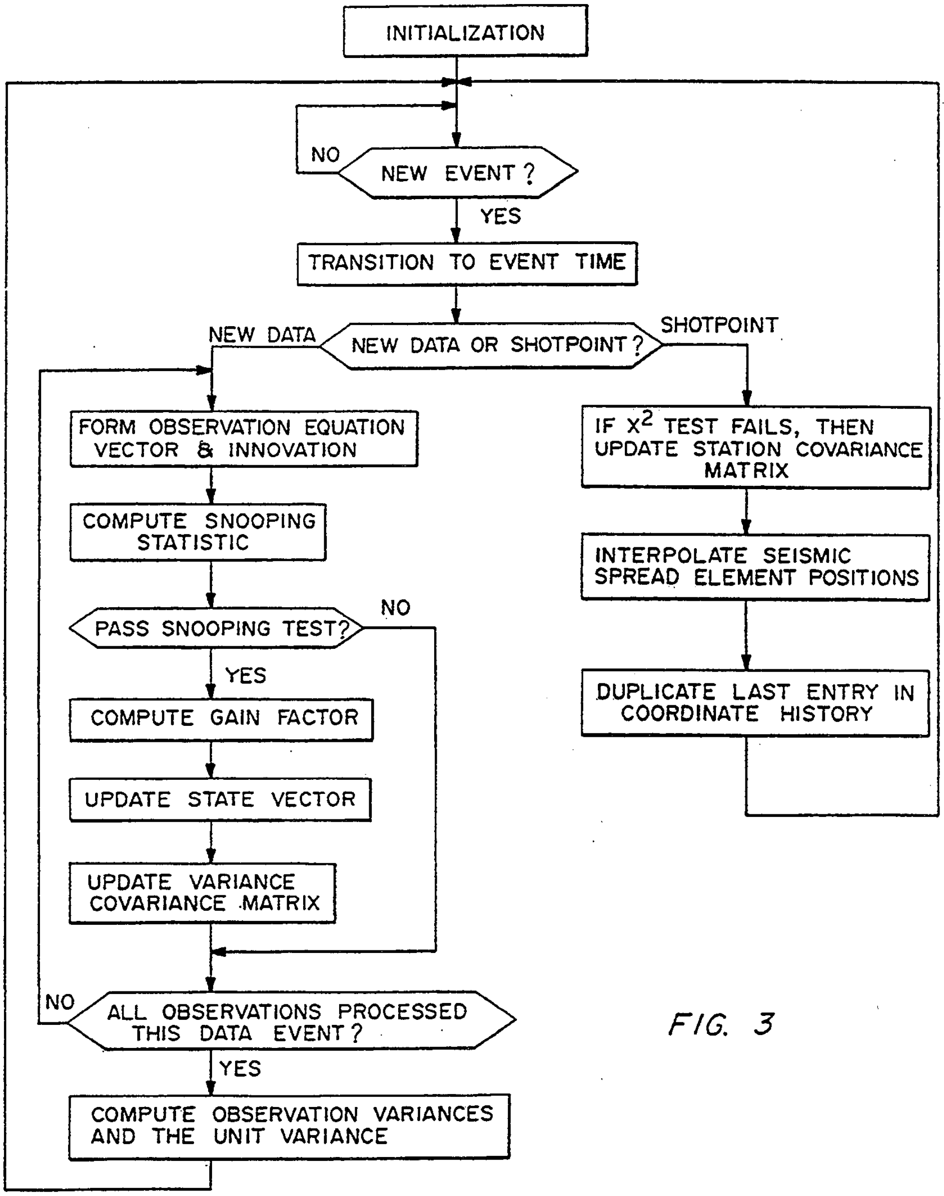
INITIALIZATION
NO
NEW EVENT ?
YES
TRANSITION TO EVENT TIME
NEW DATA
NEW DATA OR SHOTPOINT ?
SHOTPOINT
FORM OBSERVATION EQUATION VECTOR & INNOVATION
COMPUTE SNOOPING STATISTIC
PASS SNOOPING TEST?
NO
YES
COMPUTE GAIN FACTOR
UPDATE STATE VECTOR
UPDATE VARIANCE COVARIANCE MATRIX
NO
ALL OBSERVATIONS PROCESSED THIS DATA EVENT ?
YES
COMPUTE OBSERVATION VARIANCES AND THE UNIT VARIANCE
IF X2 TEST FAILS, THEN UPDATE STATION COVARIANCE MATRIX
INTERPOLATE SEISMIC SPREAD ELEMENT POSITIONS
DUPLICATE LAST ENTRY IN COORDINATE HISTORY

FIG. 3

MARINE NAVIGATION METHOD FOR GEOPHYSICAL EXPLORATION

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates generally to marine seismic surveying and more particularly to a method of determining the position of sources and receivers used in the seismic spread in marine geophysical surveying.

2. Background of the Invention

In marine seismic exploration, one or more streamer cables, each typically between 2000 and 5000 meters long and one or more acoustic pulse sources, usually air gun subarrays containing several individual air guns are towed behind a vessel in a body of water. Each streamer cable contains several sensors, typically hydrophones, spaced along the length of the streamer cable. During operation, the air guns are activated every few seconds to produce a shock wave or an acoustic pulse. The acoustic pulse is transmitted to the earth's substrata lying underneath the air gun. The acoustic pulse is reflected and refracted by the substrata layers back to the earth's surface and then to the sensors located in the streamer cables. These sensors detect the returning acoustic pulses and produce signals (dam) representative of such returning acoustic pulses. The dam is then processed to determine the structure of the earth below the surveyed area.

During the survey, the vessel is constantly moving along a predetermined course at a predetermined speed. Thus, the air guns and the sensors contained in the streamer cables are constantly moving while the survey is being performed. In order to accurately process the signals from the hydrophones (the dam), the location of the hydrophones and the location of the air gun subarrays must be determined at the time the air guns are activated.

To determine the positions of the sources and the receivers, it is typical to use a network containing a large number of different types of navigational devices. These navigational devices are placed at known locations along the streamer cable, on the air gun subarrays, on the vessel and at various other locations on various other equipment used for performing geophysical surveying. The placement of the navigational devices form a complex network which provides many hundreds of observations.

In recent years, more and more surveys are being done to obtain three-dimensional (3-D) mapping of the earth's substrata. Additionally, larger vessels using several streamer cables and air gun subarrays and multiple vessels are now routinely used for performing geophysical surveys. Use of such surveying methods requires more accurately determining the positions of the sources and receivers than has been done in the past.

To obtain more accurate positions of the sources and receivers, the trend in the industry has been to use an increasingly complex network of stations consequently increasing the number of observations by several folds.

Experience has shown that errant measurements (observations) are quite common and that if not corrected, can reduce the quality of the results obtained by processing such data. Various methods have been employed in the prior art to process the observations in real time on-board the seismic vessel. However, due to the increased complexity of the networks used, the diversity and sheer number of observations, these prior art techniques do not provide the desired accuracy, partially due to their inability to correct the errant measurements.

The present invention provides an on-line, real-time method for processing navigational observations for computing more accurate locations of the source and receiver points.

SUMMARY OF THE INVENTION

The present invention provides a method for determining the location of sensor and receiver points in a navigational network having a number of different types of devices. Observations from these devices are obtained using a coordinate system that follows appropriate nominal sailing lines. The w-statistics for the observations are computed to discard observations which fall outside the norm for those observations. Any correlated observations are uncorrelated. The uncorrelated observations are then sequentially processed in an extended sequential Kalman filter, which provides the corrected or estimated values of the observations. These estimated values are then used to determine the location of the source and receiver points.

Examples of the more important features of the method of the invention have been summarized rather broadly in order that the detailed description thereof that follows may be better understood, and in order that the contribution to the art may be better appreciated. There are, of course, additional features of the invention that will be described hereinafter and which will form the subject matter of the claims appended hereto.

BRIEF DESCRIPTION OF THE DRAWINGS

For detailed understanding of the present invention, references should be made to the following embodiment, taken in conjunction with the accompanying drawings, in which like elements have been given like numerals and wherein:

FIG. **1** shows a network of stations, sources and receivers;

FIG. **2** shows a graphical representation of a coordinate system for use in the method of the invention;

FIG. **3** shows a flow diagram of containing certain steps used in the method of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The present invention provides a method for computing in real time the positions of source and receiver points in a navigational network using diversified navigational devices. The method utilizes sequential processing of connected uncorrelated observations (innovations) in the order they are received to determine the location of source and receiver points.

FIG. **1** shows a typical network of stations, source points, receiver points and certain ranges between certain of the stations. This figure shows a placement of three streamer cables **10**, **12** and **14** and two air gun sub-arrays **70** and **72** behind a vessel **100**. Each air gun subarray contains several individual air guns typically forming a single source point. Each streamer cable contains a number of receivers (hydrophones) placed along the length of the cable. These hydrophones or groups of hydrophones form receiver points. Cable compasses are placed along the streamer cables to provide tangential azimuths at these locations. FIG. **1** shows cable compasses **22***a* . . . **22**m_1 for cable **10**, **26***a* .

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