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3 INTEGRATED CABLE NAVIGATION AND CONTROL SYSTEM

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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 any royalties
9 thereon or therefor.

10
11 BACKGROUND OF THE INVENTION

12 (1) Field of the Invention

13 The present invention relates to a system for planning and
14 precisely executing offshore cable laying operations. More
15 specifically, the present invention relates to a system for
16 accurate guidance of a vessel and deployment of cable in undersea
17 cable laying operations.

18 (2) Description of the Prior Art

19 Conventional systems for planning and executing undersea
20 pipe or cable laying operations typically rely upon driving a
21 vessel on the desired predetermined track of the cable or pipe.
22 The cable is deployed off the stern of the vessel and is expected
23 to fall in approximately the path followed by the vessel.
24 However, water currents and wave action can have a great impact
25 upon the point at which the cable touches the sea floor.
26 Additionally, when the cable is being laid on a curved path the

1 point at which the cable touches the sea bed will deviate from
2 the vessel path.

3 To compensate for curves in the cable path and for water
4 currents, pipe and cable laying vessels often employ a towed
5 device to monitor the position of the cable on the sea floor.
6 Based on the position information, the vessel can modify its
7 current course to control the placement of the cable.
8 Alternatively, the tension on the pipe or cable as it exits the
9 vessel is measured and used to compute a vessel course which will
10 place the cable at the proper point on the sea bed.

11 While these conventional techniques enable guidance of a
12 vessel to deploy pipe or cable along a predetermined path, they
13 suffer from several disadvantages which can limit their use for
14 some applications. The use of a second vessel to deploy the
15 towed device to monitor the touchdown point of the cable greatly
16 increases the cost of deploying the cable. Using a towed device
17 deployed from the cable laying vessel eliminates the costs
18 associated with the second vessel. However, this method requires
19 that the cable or pipe deployed contain a transducer to emit a
20 signal which can be used to track the pipe or cable.

21 The use of cable tension to position the vessel limits the
22 size and weight of the cable deployed. Cable placement can be
23 greatly affected by currents. Lighter cables can greatly deviate
24 from the desired track without producing a significant change in
25 the tension on the cable. Therefore, systems relying on cable
26 tension typically require heavy cables which tend to produce a
27 large amount or a significant change in tension on the cable.

1 information regarding cable or pipe payout rate to a payout
2 operator to enable accurate placement of undersea pipe and cable.
3 The system includes cable control sensors for monitoring cable
4 length, payout rate, and cable tension; navigation sensors for
5 monitoring vessel position, heading, and speed; and environmental
6 sensors for monitoring the water depth and current profile. A
7 cable navigation and control processor uses data collected by the
8 cable control sensors, navigation sensors, and environmental
9 sensors and compares this data with a predetermined cable payout
10 plan to compute the ideal vessel heading and speed and the
11 appropriate cable payout rate.

12 13 BRIEF DESCRIPTION OF THE DRAWINGS

14 A more complete understanding of the invention and many of
15 the attendant advantages thereto will be readily appreciated as
16 the same becomes better understood by reference to the following
17 detailed description when considered in conjunction with the
18 accompanying drawings wherein like reference numerals and symbols
19 designate identical or corresponding parts throughout the several
20 views and wherein:

21 FIG. 1 is a block diagram of an integrated cable navigation
22 and control system in accordance with the present invention;

23 FIG. 2 illustrates an embodiment of the integrated cable
24 navigation and control system of the present invention; and

25 FIG. 3 is a block diagram of the functional units for an
26 integrated cable navigation and control processor.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The present invention provides a system to aid in navigating a vessel used in laying undersea pipe or cable. The system can be used to collect survey data including water depth, bottom profiles, and average current speed and direction to aid in determining a suitable course to follow while laying the cable. During cable deployment, the system is designed to provide information regarding vessel position, heading, and speed to a navigator or the helm and information regarding cable or pipe payout rate to a payout operator to enable accurate placement of undersea pipe and cable.

Referring now to FIG. 1, there is shown a block diagram of an Integrated Cable Navigation and Control System (ICNCS) 10 in accordance with the present invention. A Cable Navigation Control Processor (CNCP) 20 collects cable payout speed and payout length acquired by cable control sensor 30, water depth and current data acquired by environmental sensor 40, and vessel position data acquired by navigation sensor 50. CNCP 20 uses the data from sensors 30, 40, and 50 along with a predetermined cable payout plan stored in CNCP 20, to compute the ideal vessel heading and speed and the cable payout rate. CNCP 20 formats ideal ship heading and speed and cable payout rate data and outputs selected data as cable control instructions 60 or as vessel navigation instructions 70.

Cable control instructions 60 can be outputted to a display device (not shown) associated with a system operator managing CNCP 20, transmitted to a cable control operator either

1 electronically or verbally, or any combination thereof.

2 Similarly, vessel navigation instructions 70 can be passed to the
3 helm or a navigator verbally and/or electronically.

4 The present invention is shown more particularly in FIG. 2,
5 in which is shown a schematic diagram of an embodiment of an
6 ICNCS 10. In FIG. 2, cable control sensor 30 comprises a load
7 cell 32 or similar device for measuring the downward tension on
8 the cable being deployed and an associated display unit 34 for
9 monitoring the operation of the load cell. Additionally, a cable
10 speed/length sensor 36 such as an optical shaft encoder, a
11 magnetic pickup sensor or the like is installed on the cable
12 payout engine to measure the cable payout speed and the length of
13 the cable deployed. Sensor 36 has an associated display 38 such
14 as a tachometer installed in the vicinity of the cable payout
15 engine operator for readout.

16 Optical shaft encoders operate by accumulating pulses
17 related to the unit of length being measured. The encoder
18 typically includes a optical source such as a solid state light
19 emitting diode, an optical sensor such as a silicon cell, and an
20 integrated circuit to provide output signals in a variety of
21 square wave forms compatible with conventional electronic logic.
22 The shaft encoder is connected directly to the shaft of the
23 payout engine and, for each revolution of the shaft, generates a
24 constant number of pulses. The optical encoder counts the number
25 of pulses and produces an output signal indicating the payout
26 speed of the cable.

1 Magnetic pickup sensors operate by sensing motion of ferrous
2 (magnetic) material targets (gear teeth, boltheads, keyways,
3 etc.) that produce fluctuations in the magnetic flux-field of the
4 pickup as they pass. The resulting signal voltage is directly
5 proportional to the speed of the passing targets. Magnetic
6 pickups are good at moderate-to-high speeds for sensing speed
7 applications. At low speeds the signal level drops below the
8 counter-input threshold, resulting in possible loss of counts.

9 Either an optical shaft encoder, a magnetic pickup sensor or
10 a combination thereof can be installed to fit a selected
11 application. The specific application depends on the type of
12 cable engine and data requirements. Additionally, depending on
13 the type of sensor employed, additional equipment such as a
14 tachometer 38 to display the cable payout speed and a serial
15 output (RS232) to current loop converter to convert the
16 tachometer output to a serial output signal 38a which is
17 compatible with CNCP 20 may be required.

18 Compression load cell 32 is instrumented either on the cable
19 payout engine or on a cable overboard chute. This sensor
20 measures the downward tension on the cable. A remote display 34
21 monitors operation of the load cell. Display unit 34 generates
22 an output 34a containing cable tension data which is directed to
23 CNCP 20. Cable tension is not needed to for CNCP 20 to generate
24 navigation or cable control instructions. Cable tension is
25 monitored to ensure it does not exceed the rated tension.
26 Excessive cable tension may indicate that the cable is snagged on
27 the bottom.

1 Environmental sensors 40 acquire water data such as depth or
2 current speed and direction. Sensors 40 comprise a current
3 profiler 42 and a precision depth recorder (PDR) 44, both of
4 which provide output data to CNCP 20. Current profiler 42
5 supplies current speed and direction data and PDR 44 provides
6 water depth output data. PDRs operate on the principle of echo
7 sounding, which is based on the accurate measurement of time
8 required for an acoustic pulse to be transmitted, reflected from
9 the bottom, and return to the receiver. A conventional PDR
10 having a serial output 44a can be used to supply depth data to
11 CNCP 20.

12 Current profiler 42 which can be an Acoustic Doppler Current
13 Profiler (ADCP), an expendable current profiler (XCP) or the like
14 provides real-time current profile data to CNCP 20. These
15 current profiles aid in planning the cable payout and vessel
16 course. The use of current profiler 42 during cable deployment
17 allows updating the cable payout and vessel course plans and
18 provides for more intelligent decision-making should problem
19 situations arise. The current acting on the cable is an
20 important parameter affecting the placement accuracy of the
21 cable. Currents can significantly affect the cable slack and
22 induce cable tensions which, in turn, can drag the cable already
23 laid on the bottom.

24 An ADCP consists of a transducer mounted to a pole attached
25 to the vessel. The transducer is hard-wired to an acquisition
26 system and operated with a personal computer. During operation
27 of the ADCP, the transducer transmits sound bursts into the

1 water. Particles carried by the water currents scatter the sound
2 back to the transducer, which is listening for this echo. As
3 echoes return from areas deeper in the water column, the
4 transducer assigns different water depths to corresponding parts
5 of the echo record. This assignment allows for the generation of
6 vertical profiles. Motion of particles in the water relative to
7 the transducer causes the echo to change in frequency. The
8 change is measured as a function of depth to obtain water
9 velocity through the water column.

10 An XCP is a stand-alone system having buoy/probe device, a
11 processor unit and a personal computer which can be shared with
12 an ADCP. An XCP buoy/probe is hand-deployed into the water. The
13 probe is released from the buoy and falls through the water
14 column. As the probe falls through the water column, raw data is
15 sent to the buoy and transmitted via radio frequency from the
16 buoy to a shipboard data acquisition system (processor). The XCP
17 measures a weak electric current generated by the motion of sea
18 water through the earth's magnetic field. The XCP interrupts
19 this magnetically induced current and measures the created
20 electric potential, which is interpreted as relative current
21 velocity and direction.

22 Navigation sensor 50 acquires vessel navigation data
23 including vessel position and vessel heading. A Global
24 Positioning System (GPS) based device 52 or the like can be used
25 to acquire vessel position data. Vessel heading data can be
26 obtained from the difference of consecutive position points.
27 Alternatively, a vessel heading sensor 54 such as a magnetic

1 electronic fluxgate compass, a digital gyrocompass, or the like
2 can be used to provide instantaneous vessel heading data to CNCP
3 20. Additionally, a heading display 56 can be used to display
4 vessel heading data to a navigator.

5 Positioning device 52 receives vessel position data from the
6 GPS satellite network. Device 52 can provide serial output data
7 directly to CNCP 20 or through a personal computer connected to
8 the device. Device 52 displays and transmits vessel position
9 data in a user-chosen format such as latitude and longitude or
10 range coordinates. The GPS positioning data can be corrected to
11 provide greater accuracy of vessel position by employing
12 conventional differential techniques such as a Coast Guard
13 differential GPS correction radio which beacons from Coast Guard
14 stations, a local high frequency transmission system broadcast
15 from a surveyed land base, or a leased commercial satellite
16 system. In a preferred embodiment, a leased commercial satellite
17 service, which is available worldwide, is used to accurately
18 position the vessel.

19 The use of either a magnetic electronic fluxgate compass or
20 a gyrocompass allows serial output of vessel heading data to CNCP
21 20. A magnetic electronic fluxgate compass continuously measures
22 the vessel's magnetic deviation and automatically compensates
23 itself to a ± 0.5 degree accuracy. If something significantly
24 alters the vessel's magnetic deviation, the compass will
25 automatically gather new data as the vessel turns and
26 recompensate itself to ensure accuracy for the new conditions.

1 While the compass provides a variety of data such as bearing to
2 next waypoint, distance to go, etc., only heading data need be
3 sent to CNCP 20. When using a gyrocompass, a digital gyro
4 repeater can be used to interface with the main gyro of the
5 vessel. This repeater decodes the gyro transmission signal,
6 displays heading data and analog turning information, and
7 provides a serial output to CNCP 20.

8 CNCP 20 comprises a general purpose computer 22, peripheral
9 devices 24, and a switch box 26. General purpose computer 22
10 which can be a microprocessor based computer, a UNIX workstation,
11 or the like receives all the data collected by cable control
12 sensors 30, environmental sensors 40, and navigation sensors 50,
13 compares the data with a predetermined cable payout plan, and
14 computes the ideal vessel heading and speed and the cable payout
15 rate. Computer 22 formats ideal ship heading and speed and cable
16 payout rate data and transmits the data as cable control
17 instructions 60 or as vessel navigation instructions 70. The
18 operation of computer 22 is explained in more detail in reference
19 to FIG. 3.

20 Peripheral devices 24 can comprise any of several
21 conventional devices such as external hard disks, printers, or
22 the like to provide the capability to record sensor data, cable
23 control and navigation instructions, and any system messages
24 during cable deployment. Peripherals 24 can also provide the
25 ability to playback stored data.

26 Switch box 26 receives measured data from navigation
27 sensors, environmental sensors and cable control sensors,

1 performs any necessary data conversion, and generates a single
2 multiplexed input data stream which is sent to computer 22. In a
3 preferred embodiment, each sensor provides data over a standard
4 serial (RS232) connection and switch box 26 is simply used to
5 increase the number of available serial ports available to
6 computer 22. In such an embodiment, switch box 26 can comprise
7 any of several conventional multiplexers or shared communication
8 devices. If computer 22 contains enough serial ports the sensors
9 can be directly connected to computer 22, thereby eliminating the
10 need for data acquisition processor 26. However, it is often
11 desirable to have redundant sensors and switch box 26 provides
12 the ability to quickly and easily choose which sensor output data
13 to direct to transmit to computer 22 for processing. Similarly,
14 switch box 26 can comprise one or more workstations, each being
15 connected to one or more sensors, which communicate with computer
16 22 through ethernet using transmission control protocol/internet
17 protocol (TCP/IP) or through a similar communication means.

18 Cable control instructions 60 can be outputted to a display
19 device (not shown) associated with computer 22 and transmitted to
20 a cable control operator either verbally or electronically by a
21 system operator monitoring computer 22. Optionally, instructions
22 60 can be sent to a cable control workstation monitored by a
23 cable payout operator. Similarly, vessel navigation instructions
24 70 can be sent to a display device associated with computer 22
25 and passed to the helm or a navigator verbally and/or
26 electronically. Preferably, instructions 70 are transmitted to a
27 navigation workstation with a display device located in the helm.

1 The cable control workstation and navigation workstation can be
2 connected to computer 22 using conventional means such as through
3 ethernet using TCP/IP or similar communication means.

4 Referring now to FIG. 3, there is shown a block diagram of
5 the functional units for an integrated cable navigation control
6 processor in accordance with the present invention. In FIG. 3, a
7 system executive module 80 controls and coordinates data
8 transfers between and the data processing functions across sensor
9 interface module 82, tracking module 84, operator interface
10 module 86, and data archive/playback module 88.

11 Sensor interface module 82 is responsible for reading data
12 from each serial port connected to an environmental, navigation
13 or cable control sensor, formatting the data for use by tracking
14 module 84, and sending the data to module 84.

15 Tracking module 84 is responsible for receiving all the data
16 collected and formatted by sensor interface module 82. Module 84
17 is also responsible for interpreting all the sensor data to
18 generate the ideal vessel heading and speed data and the desired
19 cable payout data. Module 84 operates on the navigation sensor
20 data by performing least-squares filtering on the GPS device 52
21 positional data to provide a smooth vehicle track. Module 84
22 uses this smoothed track along with data from vessel heading
23 sensor 54 to calculate vessel course and speed. Vessel course
24 and speed can be obtained from the difference between two GPS
25 coordinate readings to accurately determine the vessel's true
26 course and speed.

1 Module 84 collects environmental and cable control data to
2 determine the current cable payout rate, the actual cable length
3 onboard and payed out, and the undersea cable position. Module
4 84 compares these values with planned values from the cable
5 payout table and computes cable navigation data such as along and
6 across track errors, range and time to next waypoint, ideal
7 payout rate, and the ideal vessel position, heading, speed, and
8 course given the cable laying course and geometry. Module 84
9 also formats the cable navigation data and separates the data
10 into either cable control instructions or navigation
11 instructions.

12 Operator interface module 86 is responsible for reading the
13 cable control instructions and navigation instructions generated
14 by module 84 and displaying the instructions along with any
15 system status or error messages at the appropriate workstation.
16 Module 84 is responsible for receiving all system message packets
17 off the ethernet, formatting data and instructions into system
18 message packets, and sending the data out over the ethernet.

19 Module 86 can format the cable control instructions and
20 navigation instructions to provide alphanumeric and/or geographic
21 display formats of cable control and navigation parameters
22 computed by tracking module 84. A geographic display format
23 provides a visual representation of both true and ideal vehicle
24 tracks overlaid on a map of the operation site, along with
25 individual control of all tracks' display parameters (i.e., track
26 length, time-tic display, vehicle color, etc.). The geographic
27 display also provides tools for displaying range and bearing from

1 one point to another, fixed points, vehicle position in
2 latitude/longitude, range coordinates and, if necessary, for
3 sending a modification of the cable length value. The
4 alphanumeric displays provide the operator with positional and
5 cable navigation data can be manipulated to suit the dictates of
6 the operation.

7 Data archive/playback module 88 is responsible for
8 collecting data for analysis after the cable deployment operation
9 has been completed. This data can include raw cable control,
10 environmental or navigational data, instructions, system
11 messages, or operator inputs. Module 88 stores the selected data
12 onto a tape or into a file on a hard disk. Module 88 also
13 provides the ability to read the data from a tape or disk file to
14 re-enact the deployment or for use in training operators.

15 In operation, a cable payout table is generated and stored
16 in computer 22. The payout table provides for planning the
17 cable-route waypoints, the amount of cable slack required, and
18 the cable-payout rate. The objective of the table is to
19 determine the following parameters: (1) surface coordinate with
20 deployment slack and cable fill in X- and Y-range coordinates,
21 (2) desired vessel speed, (3) desired cable engine payout rate,
22 and (4) quantity of cable payout required. These four parameters
23 can be computed directly on computer 22 or on a personal computer
24 and input to ICNCS 10 via an electronic media device or TCP/IP.

25 There are three steps in creating these four parameters.
26 First, the cable length intervals are input in a column of the
27 payout table. Next, the user-chosen cumulative change in course

1 for a desired geometry (final cable position) is input into a
2 column. From the length interval column and the desired geometry
3 column the surface coordinates without cable slack adjustments
4 are computed, completing step 1. The second step is to input the
5 user-desired deployment slack in a column. Computing new surface
6 coordinates with deployment slack finishes step 2. The final
7 step is to input the ocean-water depth along the desired cable
8 geometry. With this final input the table computes the cable
9 fill and fractional accuracies from conventional cable mechanics
10 equations, and then solves and creates a file of the four desired
11 parameters.

12 The first two steps of the payout table can be completed
13 prior to departing for sea. The third step requires collecting
14 the bathymetric and water-current speed data. These data are
15 collected during a sea trial exercise. The sea trial involves
16 maneuvering the vessel along the cable geometry per the payout
17 table with coordinates, determined during step 2, while all
18 equipment is checked for proper operation. Once the bathymetric
19 and water current speed data are collected, the data is input
20 into the payout table and the final vessel course and payout
21 rates are computed.

22 Having derived the cable payout table, the cable deployment
23 operation begins. As the vessel begins to deploy cable, the
24 cable control, environmental, and navigation sensors continuously
25 collect data which is sent to computer 22. Computer 22 compares
26 the data to the cable payout table and generates cable control
27 and navigation instructions. The cable control and navigation

1 instructions generated by computer 22 are transmitted to the
2 vessel navigator and cable control operator. The navigator and
3 cable control operator use the instructions to control the
4 vessel's course and to operate the cable payout equipment.
5 Alternatively, the navigation instructions generated by computer
6 22 can be sent directly to the vessel's navigation control system
7 to allow automated computer control of the vessel's course,
8 heading, and speed. Similarly, the cable control instructions
9 can be electronically supplied to the cable payout engine to
10 allow for automated control.

11 In operation, computer 22 also monitors the collected sensor
12 data to determine whether to update the cable payout table. When
13 the environmental data previously used to generate the planned
14 vessel course and speed and the payout rates contained in the
15 cable payout differ from the current readings by a certain
16 percentage, such as 15-20%, computer 22 may automatically update
17 the cable payout table or signal an operator to initiate a
18 rebuild of the cable payout table.

19 Thus, what has been described is a system for accurate
20 guidance of a vessel and deployment of cable in undersea cable
21 laying operations that offers several significant advantages over
22 prior art systems. It will be understood that various changes in
23 the details, materials, steps and arrangement of parts, which
24 have been herein described and illustrated in order to explain
25 the nature of the invention, may be made by those skilled in the
26 art within the principle and scope of the invention

27

1 Navy Case No. 77097

2
3 INTEGRATED CABLE NAVIGATION AND CONTROL SYSTEM

4
5 ABSTRACT OF THE DISCLOSURE

6 A system for accurate guidance of a vessel and precise
7 deployment of undersea cable or pipe includes cable control
8 sensors for monitoring cable length, payout rate, and cable
9 tension; navigation sensors for monitoring vessel position,
10 heading, and speed; and environmental sensors for monitoring the
11 water depth and current profile. A cable navigation control
12 processor uses data collected by the cable control sensors,
13 navigation sensors, and environmental sensors and compares this
14 data with a predetermined cable payout plan to compute the ideal
15 vessel heading and speed and the appropriate cable payout rate.

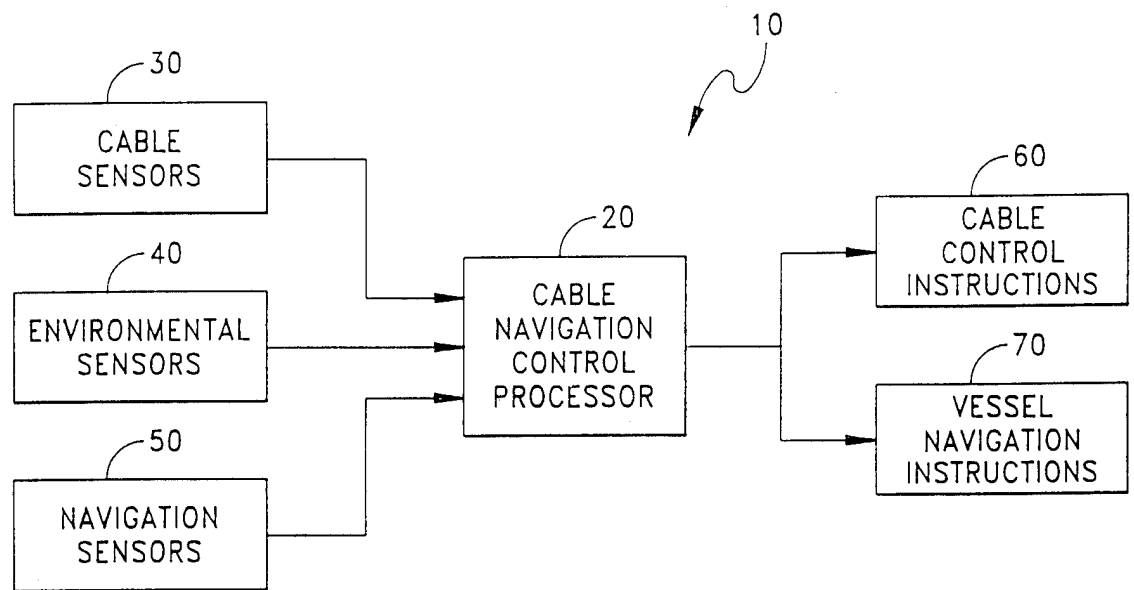


FIG. 1

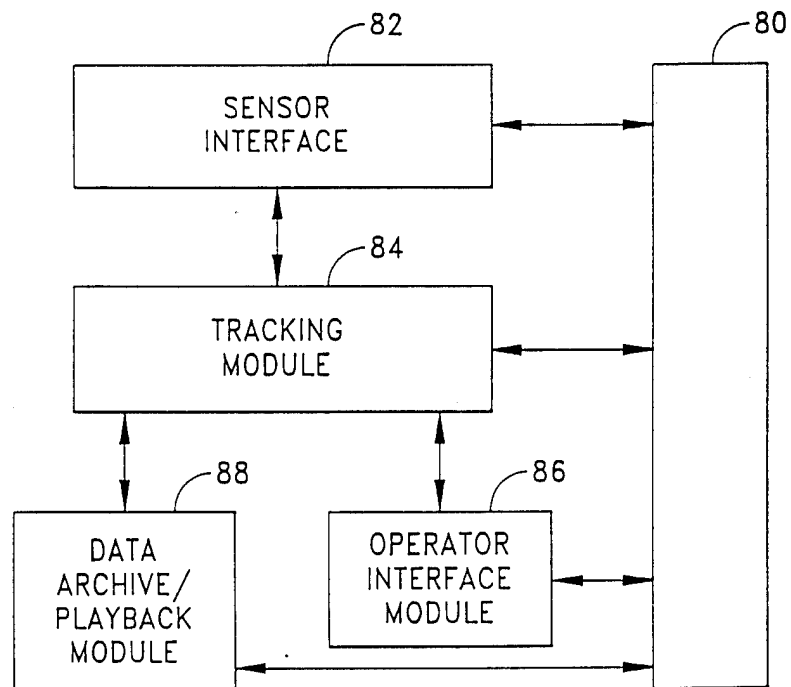


FIG. 3

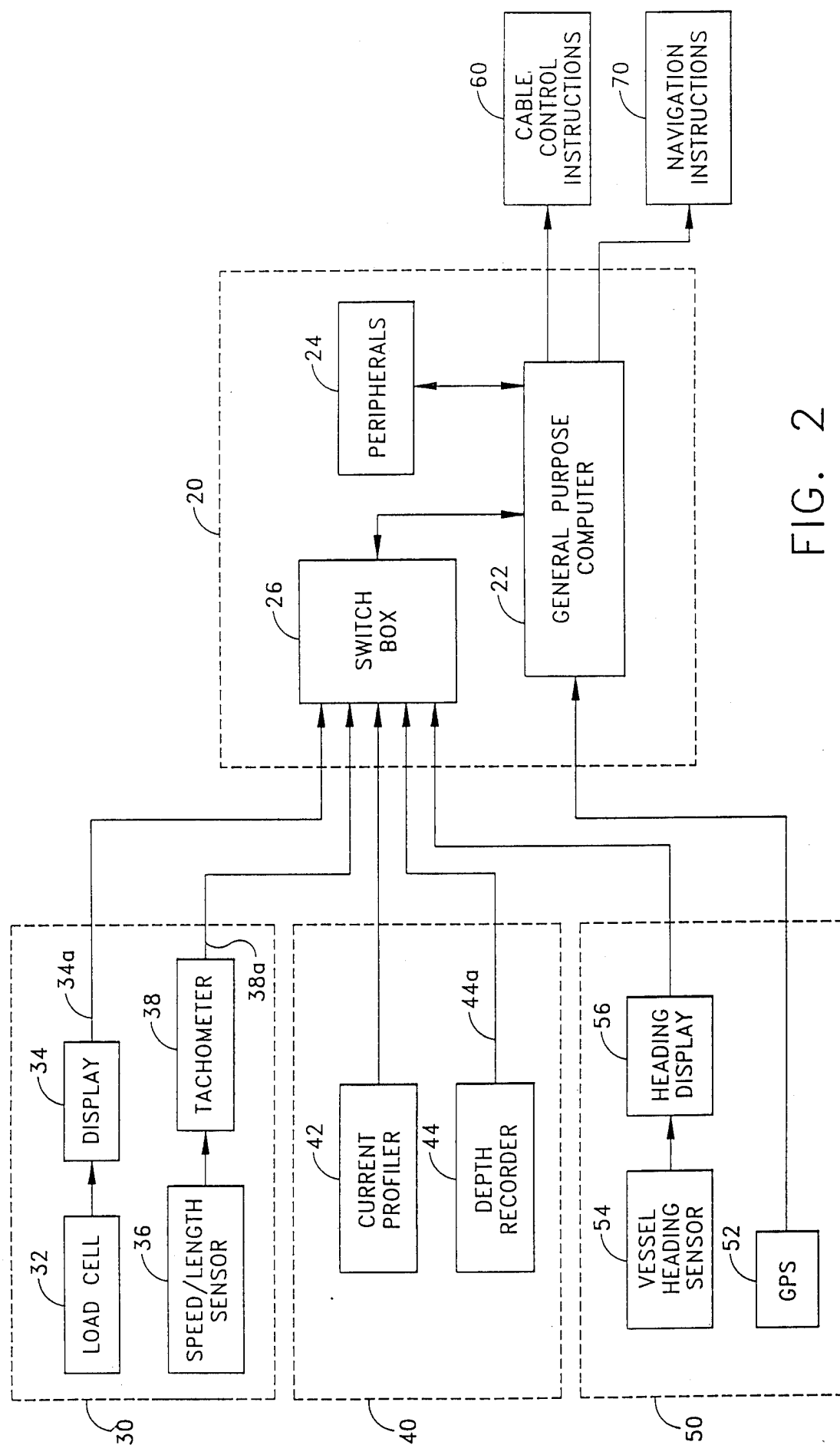


FIG. 2