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(54) Title: VISUALLY CORRELATED RADAR SYSTEMS AND METHODS

(57) Abstract: Techniques are disclosed for systems and methods to provide visually correlated radar imagery for mobile structures. A visually correlated radar imagery system includes a radar system, an imaging device, and a logic device configured to communicate with the radar system and imaging device. The radar system is adapted to be mounted to a mobile structure, and the imaging device may include an imager position and/or orientation sensor (IPOS). The logic device is configured to determine a horizontal field of view (FOV) of image data captured by the imaging device and to render radar data that is visually or spatially correlated to the image data based, at least in part, on the determined horizontal FOV. Subsequent user input and/or the sonar data may be used to adjust a steering actuator, a propulsion system thrust, and/or other operational systems of the mobile structure.

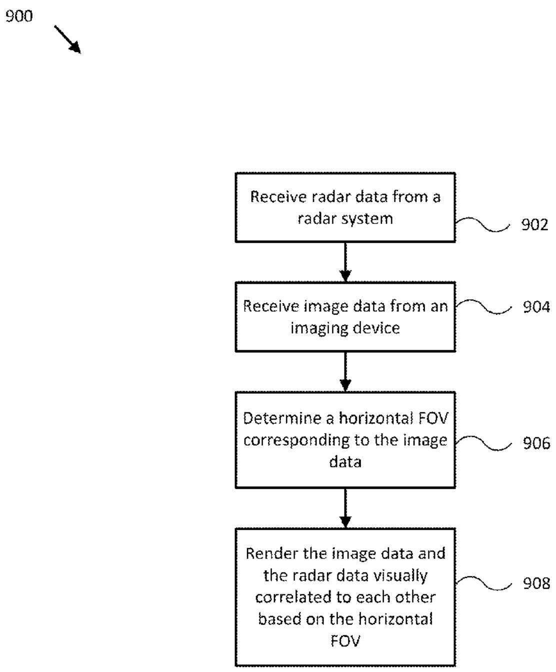

FIG. 9

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VISUALLY CORRELATED RADAR SYSTEMS AND METHODS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority to and the benefit of U.S. Provisional Patent Application No. 62/480,301 filed March 31, 2017 and entitled “VISUALLY CORRELATED RADAR SYSTEMS AND METHODS”, which is hereby incorporated by reference in its entirety.

This application is related to U.S. Patent Application 15/443,836 filed February 27, 2017 and entitled "AUGMENTED REALITY SONAR IMAGERY SYSTEMS AND METHODS," which is a continuation of International Patent Application No. PCT/US2015/045962 filed August 19, 2015 and entitled "AUGMENTED REALITY SONAR IMAGERY SYSTEMS AND METHODS," which claims priority to and the benefit of U.S. Provisional Patent Application No. 62/044,906 filed September 2, 2014 and entitled "AUGMENTED REALITY SONAR IMAGERY SYSTEMS AND METHODS," all of which are incorporated herein by reference in their entirety.

This application is related to U.S. Patent Application No. 15/445,717 filed February 28, 2017 and entitled “ROTATING ATTITUDE HEADING REFERENCE SYSTEMS AND METHODS,” which is a continuation of PCT/US2015/047991 filed September 1, 2015 and entitled “ROTATING ATTITUDE HEADING REFERENCE SYSTEMS AND METHODS,” which claims priority to and the benefit of U.S. Provisional Application No. 62/212,955 filed September 1, 2015 and entitled “ROTATING ATTITUDE HEADING REFERENCE SYSTEMS AND METHODS,” U.S. Provisional Application No. 62/099,090 Filed December 31, 2014 and entitled “ROTATING ATTITUDE HEADING REFERENCE SYSTEMS AND METHODS,” and U.S. Provisional Patent Application No. 62/044,911 filed September 2, 2014 and entitled “REMOTE SENSING WITH INTEGRATED ORIENTATION AND POSITION SENSORS SYSTEMS AND METHODS,” all of which are incorporated herein by reference in their entirety.

U.S. Patent Application 15/445,717 is also a continuation-in-part of U.S. Patent Application No. 14/941,497 filed December 13, 2015 and entitled "AUTOMATIC COMPASS CALIBRATION SYSTEMS AND METHODS," which is a continuation of International Patent Application No. PCT/US2014/038286 filed May 5, 2014 and entitled "AUTOMATIC COMPASS CALIBRATION SYSTEM AND CORRESPONDING METHOD," which claims priority to and the benefit of U.S. Provisional Patent Application No. 61/823,906 filed May 15, 2013 and entitled "AUTOMATIC COMPASS CALIBRATION SYSTEMS AND METHODS" and U.S. Provisional Patent Application No. 61/823,903 filed May 15, 2013 and entitled "AUTOMATIC COMPASS CALIBRATION SYSTEMS AND METHODS, all of which are incorporated herein by reference in their entirety.

This application is related to International Patent Application No. PCT/US2018/015315 filed January 25, 2018 and entitled "THREE DIMENSIONAL TARGET SELECTION SYSTEMS AND METHODS," which claims priority to and the benefit of U.S. Provisional Patent Application No. 62/451,427 filed January 27, 2017 and entitled "THREE DIMENSIONAL TARGET SELECTION SYSTEMS AND METHODS," which is incorporated herein by reference in its entirety.

This application is related to U.S. Patent Application No. 15/893,431 filed February 9, 2018 and entitled "3D BOTTOM SURFACE RENDERING SYSTEMS AND METHODS," which claims priority to and the benefit of U.S. Provisional Patent Application No. 62/458,529 filed February 13, 2017 and entitled "3D BOTTOM SURFACE RENDERING SYSTEMS AND METHODS," which is incorporated herein by reference in its entirety.

This application is related to U.S. Patent Application No. 15/893,465 filed February 9, 2018 and entitled "3D SCENE ANNOTATION AND ENHANCEMENT SYSTEMS AND METHODS," which claims priority to and the benefit of U.S. Provisional Patent Application No. 62/458,533 filed February 13, 2017 and entitled "3D SCENE ANNOTATION AND ENHANCEMENT SYSTEMS AND METHODS," which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

One or more embodiments of the invention relate generally to radar systems and more particularly, for example, to systems and methods for providing radar data that is visually or spatially correlated to image data.

BACKGROUND

Various ranging sensor systems, including radar, LIDAR, sonar, and image/video imaging systems can provide sensor data of an environment about a vehicle to assist in navigation. Conventional systems often include a display configured to provide traditionally recognizable ranging imagery based on the sensor data to a user.

Radar imagery is typically provided without reference to any corresponding visible feature or features, and so a user can easily confuse which radar returns (and corresponding bearings, sizes, and other critical characteristics) are attributable to specific objects in view of the user. At the same time, consumer market pressures and convenience dictate easier to use systems that include a variety of user-defined features and that produce high quality resulting imagery. Thus, there is a need for an improved methodology to provide feature-rich radar systems, particularly in the context of providing easily intuited radar data and/or imagery important to general operation of a vehicle, such as a watercraft.

SUMMARY

Techniques are disclosed for systems and methods to provide visually correlated radar imagery for mobile structures. A visually correlated radar imagery system may include imaging devices, radar systems, and logic devices configured to communicate with the radar systems and imaging devices. Each radar system may be adapted to be mounted to a mobile structure, and each imaging device may include an imager position and/or orientation sensor (IPOS). The logic devices may be configured to determine a horizontal field of view (FOV) of image data captured by the imaging devices and to render radar data that is visually or spatially correlated to the image data based, at least in part, on the determined horizontal FOV. Subsequent user input and/or the radar data may be used to adjust a steering actuator, a propulsion system thrust, and/or other operational systems of the mobile structure.

In various embodiments, a visually correlated radar imagery system may include one or more orientation sensors, position sensors, gyroscopes, accelerometers, and/or additional sensors, actuators, controllers, user interfaces, mapping systems, and/or other modules mounted to or in proximity to a vehicle. Each component of the system may be implemented with a logic device adapted to form one or more wired and/or wireless communication links for transmitting and/or receiving sensor signals, control signals, or other signals and/or data between the various components.

In one embodiment, a system may include a logic device configured to communicate with a radar system adapted to be mounted to a mobile structure and with an imaging device configured to image a scene about the mobile structure. The logic device may be configured to receive radar data from the radar system and image data captured by the imaging device, determine a horizontal FOV corresponding to the image data, and render the image data and radar data. The radar data may be rendered vertically above or below the rendered image data, and the rendered radar data may be visually correlated to the rendered image data based, at least in part, on the determined horizontal FOV.

In another embodiment, a method may include receiving radar data from a radar system adapted to be mounted to a mobile structure, receiving image data captured by an imaging device configured to image a scene about the mobile structure, determining a horizontal FOV corresponding to the image data, and rendering the image data and radar data, where the radar data is rendered vertically above or below the rendered image data, and where the rendered radar data is visually correlated to the rendered image data based, at least in part, on the determined horizontal FOV.

The scope of the invention is defined by the claims, which are incorporated into this section by reference. A more complete understanding of embodiments of the invention will be afforded to those skilled in the art, as well as a realization of additional advantages thereof, by a consideration of the following detailed description of one or more embodiments. Reference will be made to the appended sheets of drawings that will first be described briefly.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1A illustrates a block diagram of an augmented reality imagery system in accordance with an embodiment of the disclosure.

Fig. 1B illustrates a diagram of an augmented reality imagery system in accordance with an embodiment of the disclosure.

Fig. 2 illustrates a diagram of an augmented reality imagery system in accordance with an embodiment of the disclosure.

Fig. 3 illustrates a diagram of an augmented reality imagery system in accordance with an embodiment of the disclosure.

Fig. 4 illustrates a diagram of an augmented reality imagery system in accordance with an embodiment of the disclosure.

Fig. 5 illustrates a flow diagram of various operations to operate an augmented reality imagery system in accordance with an embodiment of the disclosure.

Figs. 6-7 illustrate display views including visually correlated radar data in accordance with embodiments of the disclosure.

Figs. 8A-B illustrate display views including visually correlated radar data in accordance with embodiments of the disclosure.

Fig. 9 illustrates a flow diagram of various operations to provide visually correlated radar data in accordance with an embodiment of the disclosure.

Embodiments of the invention and their advantages are best understood by referring to the detailed description that follows. It should be appreciated that like reference numerals are used to identify like elements illustrated in one or more of the figures.

DETAILED DESCRIPTION

In accordance with various embodiments of the present disclosure, rendering of radar data visually correlated to image data may be provided by a logic device configured to communicate with an imaging device and/or a radar system (e.g., and/or various other types of ranging sensor systems) including one or more orientation sensors, gyroscopes, accelerometers, position sensors, and/or speed sensors providing measurements of an orientation, a position, an acceleration, and/or a speed of the imaging device, the radar system, other ranging sensor systems, and/or a coupled mobile structure. For example, the sensors may be mounted to or within the mobile structure (e.g., a watercraft, aircraft, motor vehicle, and/or other mobile structure), or may be integrated with the imaging device, the radar system, and/or the other ranging sensor systems used to generate sensor data of an environment of the mobile structure.

In accordance with additional and/or supplemental embodiments of the present disclosure, augmented reality sonar imagery may be provided by a portable imaging device and a sonar system including one or more sonar transducer assemblies, orientation sensors, gyroscopes, accelerometers, position sensors, and/or speed sensors providing measurements of an orientation, a position, an acceleration, and/or a speed of the portable imaging device, the sonar transducer assemblies, and/or a coupled mobile structure. For example, the sensors may be mounted to or within the mobile structure (e.g., a watercraft, aircraft, motor vehicle, and/or other mobile structure), or may be integrated with the portable imaging device and/or the sonar transducer assemblies. Embodiments of the present disclosure produce augmented reality sonar imagery that can be referenced to visible objects in the same field of view (FOV), thereby providing sonar imagery that is more intuitive and easier to interpret than sonar data provided by conventional systems and/or methods.

Fig. 1A illustrates a block diagram of system 100 in accordance with an embodiment of the disclosure. In various embodiments, system 100 may be adapted to measure an orientation, a position, an acceleration, and/or a speed of mobile structure 101, sonar system 110, and/or user interface 120. System 100 may then use these measurements to form various views of sonar data provided by sonar system 110 and/or to adjust an orientation of sonar system 110 according to a desired operation of sonar system 110 and/or mobile structure 101. In some embodiments, system 100 may display resulting sonar data and/or imagery to a user through user interface 120, and/or use the sonar data and/or imagery to control operation of mobile structure 101, such as controlling steering actuator 150 and/or propulsion system 170 to steer mobile structure 101 according to a desired heading, such as heading angle 107, for example.

In the embodiment shown in Fig. 1A, system 100 may be implemented to provide radar data, sonar data, and/or imagery for a particular type of mobile structure 101, such as a drone, a watercraft, an aircraft, a robot, a vehicle, and/or other types of mobile structures. In one embodiment, system 100 may include one or more of a sonar system 110, a user interface

120, a controller 130, an orientation sensor 140, a speed sensor 142, a gyroscope/ accelerometer 144, a global positioning satellite system (GPS) 146, a steering sensor/actuator 150, a propulsion system 170, a radar system 182, and one or more other sensors and/or actuators, such as other modules 180. In some embodiments, one or more of the elements of system 100 may be implemented in a combined housing or structure that can be coupled to mobile structure 101 and/or held or carried by a user of mobile structure 101.

Directions 102, 103, and 104 describe one possible coordinate frame of mobile structure 101 (e.g., for headings or orientations measured by orientation sensor 140 and/or angular velocities and accelerations measured by gyroscope 144 and accelerometer 145). As shown in Fig. 1A, direction 102 illustrates a direction that may be substantially parallel to and/or aligned with a longitudinal axis of mobile structure 101, direction 103 illustrates a direction that may be substantially parallel to and/or aligned with a lateral axis of mobile structure 101, and direction 104 illustrates a direction that may be substantially parallel to and/or aligned with a vertical axis of mobile structure 101, as described herein. For example, a roll component of motion of mobile structure 101 may correspond to rotations around direction 102, a pitch component may correspond to rotations around direction 103, and a yaw component may correspond to rotations around direction 104.

Heading angle 107 may correspond to the angle between a projection of a reference direction 106 (e.g., the local component of the Earth's magnetic field) onto a horizontal plane (e.g., referenced to a gravitationally defined "down" vector local to mobile structure 101) and a projection of direction 102 onto the same horizontal plane. In some embodiments, the projection of reference direction 106 onto a horizontal plane (e.g., referenced to a gravitationally defined "down" vector) may be referred to as Magnetic North. In various embodiments, Magnetic North, a "down" vector, and/or various other directions, positions, and/or fixed or relative reference frames may define an absolute coordinate frame, for example, where directional measurements referenced to an absolute coordinate frame may be referred to as absolute directional measurements (e.g., an "absolute" orientation). In some embodiments, directional measurements may initially be referenced to a coordinate frame of a particular sensor (e.g., a sonar transducer assembly or other module of sonar system 110, and/or user interface 120) and be transformed (e.g., using parameters for one or more coordinate frame transformations) to be referenced to an absolute coordinate frame and/or a coordinate frame of mobile structure 101. In various embodiments, an absolute coordinate frame may be defined and/or correspond to a coordinate frame with one or more undefined axes, such as a horizontal plane local to mobile structure 101 and referenced to a local gravitational vector but with an unreferenced and/or undefined yaw reference (e.g., no reference to Magnetic North).

Sonar system 110 may be implemented as one or more electrically and/or mechanically coupled controllers, transmitters, receivers, transceivers, signal processing logic devices, various electrical components, transducer elements of various shapes and sizes, multichannel transducers/transducer modules, transducer assemblies, assembly brackets, transom brackets, and/or various actuators adapted to adjust orientations of any of the components of sonar system 110, as described herein.

For example, in various embodiments, sonar system 110 may be implemented and/or operated according to any of the systems and methods described in U.S. Provisional Patent Application 62/005,838 filed May 30, 2014 and entitled "MULTICHANNEL SONAR SYSTEMS AND METHODS", and/or U.S. Provisional Patent Application 61/943,170 filed February 21, 2014 and entitled "MODULAR SONAR TRANSDUCER ASSEMBLY SYSTEMS AND METHODS", both of which are hereby incorporated by reference in their entirety. In other embodiments, sonar system 110 may be implemented according to other sonar system arrangements that can be used to detect objects within a water column and/or a floor of a body of water.

More generally, sonar system 110 may be configured to emit one, multiple, or a series of acoustic beams, receive corresponding acoustic returns, and convert the acoustic returns into sonar data and/or imagery, such as bathymetric data, water depth, water temperature, water column/volume debris, bottom profile, and/or other types of sonar data. Sonar system 110 may be configured to provide such data and/or imagery to user interface 120 for display to a user, for example, or to controller 130 for additional processing, as described herein.

In some embodiments, sonar system 110 may be implemented using a compact design, where multiple sonar transducers, sensors, and/or associated processing devices are located within a single transducer assembly housing that is configured to interface with the rest of system 100 through a single cable providing both power and communications to and from sonar system 110. In some embodiments, sonar system 110 may include orientation and/or position sensors configured to help provide two or three dimensional waypoints, increase sonar data and/or imagery quality, and/or provide highly accurate bathymetry data, as described herein.

For example, fisherman desire highly detailed and accurate information and/or imagery of underwater structure and mid water targets (e.g., fish). Conventional sonar systems can be expensive and bulky and typically cannot be used to provide enhanced and/or augmented reality underwater views, as described herein. Embodiments of sonar system 110 include low cost single, dual, and/or multichannel sonar systems that can be configured to produce detailed two and three dimensional sonar data and/or imagery. In some embodiments, sonar system 110 may consolidate electronics and transducers into a single waterproof package to reduce size and costs, for example, and may be implemented with a single connection to other devices of system 100 (e.g., via an Ethernet cable with power over Ethernet, an integral power cable, and/or other communication and/or power transmission conduits integrated into a single interface cable).

In various embodiments, sonar system 110 may be configured to provide many different display views from a variety of selectable perspectives, including down imaging, side imaging, and/or three dimensional imaging, using a selection of configurations and/or processing methods, as described herein. In some embodiments, sonar system 110 may be implemented with a single transducer assembly housing incorporating one or two transducers and/or associated electronics. In other embodiments, sonar system 110 may be implemented with a transducer assembly housing incorporating a multichannel transducer and/or associated electronics. In such embodiments, sonar system 110 may be configured to transmit acoustic beams using a transmission channel and/or element of a multichannel transducer, receive acoustic returns using multiple receive channels and/or elements of the multichannel transducer, and to perform beamforming and/or interferometry processing on the acoustic returns to produce two and/or three dimensional sonar imagery. In some embodiments, one or more sonar transmitters of sonar system 110 may be configured to use CHIRP transmissions to improve range resolution and hence reduce ambiguities typically inherent in interferometry processing techniques.

In various embodiments, sonar system 110 may be implemented with optional orientation and/or position sensors (e.g., similar to orientation sensor 140, gyroscope/accelerometer 144, and/or GPS 146) that may be incorporated within the transducer assembly housing to provide three dimensional orientations and/or positions of the transducer assembly and/or transducer(s) for use when processing or post processing sonar data for display. The sensor information can be used to correct for movement of the transducer assembly between ensonifications to provide improved alignment of corresponding acoustic returns/samples, for example, and/or to generate imagery based on the measured orientations and/or positions of the transducer assembly. In other embodiments, an external orientation and/or position sensor can be used alone or in combination with an integrated sensor or sensors.

In embodiments where sonar system 110 is implemented with a position sensor, sonar system 110 may be configured to provide a variety of sonar data and/or imagery enhancements. For example, sonar system 110 may be configured to provide accurate positioning of sonar data and/or user-defined waypoints remote from mobile system 101. Similarly, sonar system 110 may be configured to provide accurate two and/or three dimensional aggregation and/or display of a series of sonar data; without position data, a sonar system typically assumes a straight track, which can cause image artifacts and/or other inaccuracies in corresponding sonar data and/or imagery. Additionally, when implemented with a position sensor and/or interfaced with a remote but relatively fixed position sensor (e.g., GPS 146), sonar system 110 may be configured to generate accurate and detailed bathymetric views of a floor of a body of water.

In embodiments where sonar system 110 is implemented with an orientation and/or position sensor, sonar system 110 may be configured to store such location/position information along with other sensor information (acoustic returns, temperature measurements, text descriptions, water depth, altitude, mobile structure speed, and/or other sensor and/or control information) available to system 100. In some embodiments, controller 130 may be configured to generate a look up table so that a user can select desired configurations of sonar system 110 for a particular location or to coordinate with some other sensor information. Alternatively, an automated adjustment algorithm can be used to select optimum configurations based on the sensor information.

For example, in one embodiment, mobile structure 101 may be located in an area identified on an chart using position data, a user may have selected a user setting for a configuration of sonar system 110, and controller 130 may be configured to control an actuator and/ or otherwise implement the configuration for sonar system 110 (e.g., to set a particular orientation). In still another embodiment, controller 130 may be configured to receive orientation measurements for mobile structure 101. In such embodiment, controller 130 may be configured to control the actuators associated with the transducer assembly to maintain its orientation relative to, for example, the mobile structure and/or the water surface, and thus improve the displayed sonar images (e.g., by ensuring consistently oriented acoustic beams and/or proper registration of a series of acoustic returns). In various embodiments, controller 130 may be configured to control steering sensor/actuator 150 and/or propulsion system 170 to adjust a position and/or orientation of mobile structure 101 to help ensure proper registration of a series of acoustic returns, sonar data, and/or sonar imagery.

Although Fig. 1A shows various sensors and/or other components of system 100 separate from sonar system 110, in other embodiments, any one or combination of sensors and components of system 100 may be integrated with a sonar assembly, an actuator, a transducer module, and/or other components of sonar system 110. For example, orientation sensor 140 may be integrated with a transducer module of sonar system 110 and be configured to provide measurements of an absolute and/or relative orientation (e.g., a roll, pitch, and/or yaw) of the transducer module to controller 130 and/or user interface 120, both of which may also be integrated with sonar system 110.

User interface 120 may be implemented as a display, a touch screen, a keyboard, a mouse, a joystick, a knob, a steering wheel, a ship’s wheel or helm, a yoke, and/or any other device capable of accepting user input and/or providing feedback to a user. In various embodiments, user interface 120 may be adapted to provide user input (e.g., as a type of signal and/or sensor information) to other devices of system 100, such as controller 130. User interface 120 may also be implemented with one or more logic devices that may be adapted to execute instructions, such as software instructions, implementing any of the various processes and/or methods described herein. For example, user interface 120 may be adapted to form communication links, transmit and/or receive communications (e.g., sensor signals, control signals, sensor information, user input, and/or other information), determine various coordinate frames and/or orientations, determine parameters for one or more coordinate frame transformations, and/or perform coordinate frame transformations, for example, or to perform various other processes and/or methods.

In various embodiments, user interface 120 may be adapted to accept user input, for example, to form a communication link, to select a particular wireless networking protocol and/or parameters for a particular wireless networking protocol and/or wireless link (e.g., a password, an encryption key, a MAC address, a device identification number, a device operation profile, parameters for operation of a device, and/or other parameters), to select a method of processing sensor signals to determine sensor information, to adjust a position and/or orientation of an articulated sensor, and/or to otherwise facilitate operation of system 100 and devices within system 100. Once user interface 120 accepts a user input, the user input may be transmitted to other devices of system 100 over one or more communication links.

In one embodiment, user interface 120 may be adapted to receive a sensor or control signal (e.g., from orientation sensor 140 and/or steering sensor/actuator 150) over communication links formed by one or more associated logic devices, for example, and display sensor and/or other information corresponding to the received sensor or control signal to a user. In related embodiments, user interface 120 may be adapted to process sensor and/or control signals to determine sensor and/or other information. For example, a sensor signal may include an orientation, an angular velocity, an acceleration, a speed, and/or a position of mobile structure 101. In such embodiment, user interface 120 may be adapted to process the sensor signals to determine sensor information indicating an estimated and/or absolute roll, pitch, and/or yaw (attitude and/or rate), and/or a position or series of positions of mobile structure 101, for example, and display the sensor information as feedback to a user. In one embodiment, user interface 120 may be adapted to display a time series of various sensor information and/or other parameters as part of or overlaid on a graph or map, which may be referenced to a position and/or orientation of mobile structure 101. For example, user interface 120 may be adapted to display a time series of positions, headings, and/or orientations of mobile structure 101 and/or other elements of system 100 (e.g., a transducer assembly and/or module of sonar system 110) overlaid on a geographical map, which may include one or more graphs indicating a corresponding time series of actuator control signals, sensor information, and/or other sensor and/or control signals.

In some embodiments, user interface 120 may be adapted to accept user input including a user-defined target heading, route, and/or orientation for a transducer module, for example, and to generate control signals for steering sensor/actuator 150 and/or propulsion system 170 to cause mobile structure 101 to move according to the target heading, route, and/or orientation. In further embodiments, user interface 120 may be adapted to accept user input including a user-defined target attitude for an actuated device (e.g., sonar system 110) coupled to mobile structure 101, for example, and to generate control signals for adjusting an orientation of the actuated device according to the target attitude. More generally, user interface 120 may be adapted to display sensor information to a user, for example, and/or to transmit sensor information and/or user input to other user interfaces, sensors, or controllers of system 100, for instance, for display and/or further processing. In one embodiment, user interface 120 may be integrated with one or more sensors (e.g., imaging modules, position and/or orientation sensors, other sensors) and/or be portable (e.g., such as a portable touch display or smart phone, for example, or a wearable user interface) to facilitate user interaction with various systems of mobile structure 101.

Controller 130 may be implemented as any appropriate logic device (e.g., processing device, microcontroller, processor, application specific integrated circuit (ASIC), field programmable gate array (FPGA), memory storage device, memory reader, or other device or combinations of devices) that may be adapted to execute, store, and/or receive appropriate instructions, such as software instructions implementing a control loop for controlling various operations of sonar system 110, steering sensor/actuator 150, mobile structure 101, and/or system 100, for example. Such software instructions may also implement methods for processing sensor signals, determining sensor information, providing user feedback (e.g., through user interface 120), querying devices for operational parameters, selecting operational parameters for devices, or performing any of the various operations described herein (e.g., operations performed by logic devices of various devices of system 100).

In addition, a machine readable medium may be provided for storing non-transitory instructions for loading into and execution by controller 130. In these and other embodiments, controller 130 may be implemented with other components where appropriate, such as volatile memory, non-volatile memory, one or more interfaces, and/or various analog and/or digital components for interfacing with devices of system 100. For example, controller 130 may be adapted to store sensor signals, sensor information, parameters for coordinate frame transformations, calibration parameters, sets of calibration points, and/or other operational parameters, over time, for example, and provide such stored data to a user using user interface 120. In some embodiments, controller 130 may be integrated with one or more user interfaces (e.g., user interface 120), and, in one embodiment, may share a communication module or modules. As noted herein, controller 130 may be adapted to execute one or more control loops for actuated device control, steering control (e.g., using steering sensor/actuator 150) and/or performing other various operations of mobile structure 101 and/or system 100. In some embodiments, a control loop may include processing sensor signals and/or sensor information in order to control one or more operations of sonar system 110, mobile structure 101, and/or system 100.

Orientation sensor 140 may be implemented as one or more of a compass, float, accelerometer, and/or other digital or analog device capable of measuring an orientation of mobile structure 101 (e.g., magnitude and direction of roll, pitch, and/or yaw, relative to one or more reference orientations such as gravity and/or Magnetic North) and providing such measurements as sensor signals that may be communicated to various devices of system 100. In some embodiments, orientation sensor 140 may be adapted to provide heading measurements for mobile structure 101. In other embodiments, orientation sensor 140 may be adapted to provide roll, pitch, and/or yaw rates for mobile structure 101 (e.g., using a time series of orientation measurements). Orientation sensor 140 may be positioned and/or adapted to make orientation measurements in relation to a particular coordinate frame of mobile structure 101, for example.

Speed sensor 142 may be implemented as an electronic pitot tube, metered gear or wheel, water speed sensor, wind speed sensor, a wind velocity sensor (e.g., direction and magnitude) and/or other device capable of measuring or determining a linear speed of mobile structure 101 (e.g., in a surrounding medium and/or aligned with a longitudinal axis of mobile structure 101) and providing such measurements as sensor signals that may be communicated to various devices of system 100. In some embodiments, speed sensor 142 may be adapted to provide a velocity of a surrounding medium relative to sensor 142 and/or mobile structure 101.

Gyroscope/accelerometer 144 may be implemented as one or more electronic sextants, semiconductor devices, integrated chips, accelerometer sensors, accelerometer sensor systems, or other devices capable of measuring angular velocities/accelerations and/or linear accelerations (e.g., direction and magnitude) of mobile structure 101 and providing such measurements as sensor signals that may be communicated to other devices of system

100 (e.g., user interface 120, controller 130). Gyroscope/ accelerometer 144 may be positioned and/or adapted to make such measurements in relation to a particular coordinate frame of mobile structure 101, for example. In various embodiments, gyroscope/ accelerometer 144 may be implemented in a common housing and/or module to ensure a common reference frame or a known transformation between reference frames.

GPS 146 may be implemented as a global positioning satellite receiver and/or other device capable of determining absolute and/or relative position of mobile structure 101 (e.g., or an element of mobile structure 101, such as sonar system 110 and/or user interface 120) based on wireless signals received from space-born and/or terrestrial sources, for example, and capable of providing such measurements as sensor signals that may be communicated to various devices of system 100. In some embodiments, GPS 146 may be adapted to determine a velocity, speed, and/or yaw rate of mobile structure 101 (e.g., using a time series of position measurements), such as an absolute velocity and/or a yaw component of an angular velocity of mobile structure 101. In various embodiments, one or more logic devices of system 100 may be adapted to determine a calculated speed of mobile structure 101 and/or a computed yaw component of the angular velocity from such sensor information.

Steering sensor/actuator 150 may be adapted to physically adjust a heading of mobile structure 101 according to one or more control signals, user inputs, and/or stabilized attitude estimates provided by a logic device of system 100, such as controller 130. Steering sensor/actuator 150 may include one or more actuators and control surfaces (e.g., a rudder or other type of steering or trim mechanism) of mobile structure 101, and may be adapted to physically adjust the control surfaces to a variety of positive and/or negative steering angles/positions.

Propulsion system 170 may be implemented as a propeller, turbine, or other thrust-based propulsion system, a mechanical wheeled and/or tracked propulsion system, a sail-based propulsion system, and/or other types of propulsion systems that can be used to provide motive force to mobile structure 101. In some embodiments, propulsion system 170 may be non-articulated, for example, such that the direction of motive force and/or thrust generated by propulsion system 170 is fixed relative to a coordinate frame of mobile structure 101. Non-limiting examples of non-articulated propulsion systems include, for example, an inboard motor for a watercraft with a fixed thrust vector, for example, or a fixed aircraft propeller or turbine. In other embodiments, propulsion system 170 may be articulated, for example, and may be coupled to and/or integrated with steering sensor/actuator 150, for example, such that the direction of generated motive force and/or thrust is variable relative to a coordinate frame of mobile structure 101. Non-limiting examples of articulated propulsion systems include, for example, an outboard motor for a watercraft, an inboard motor for a watercraft with a variable thrust vector/port (e.g., used to steer the watercraft), a sail, or an aircraft propeller or turbine with a variable thrust vector, for example.

Other modules 180 may include other and/or additional sensors, actuators, communications modules/nodes, automatic identification system (AIS) transponders/receivers, and/or user interface devices used to provide additional environmental information of mobile structure 101, for example. In some embodiments, other modules 180 may include a humidity sensor, a wind and/or water temperature sensor, a barometer, a radar system, a visible spectrum camera, an infrared camera, and/or other environmental sensors providing measurements and/or other sensor signals that can be displayed to a user and/or used by other devices of system 100 (e.g., controller 130) to provide operational control of mobile structure 101 and/or system 100 that compensates for environmental conditions, such as wind speed and/or direction, swell speed, amplitude, and/or direction, and/or an object in a path of mobile structure 101, for example. In some embodiments, other modules 180 may include one or more actuated devices (e.g., spotlights, infrared illuminators, cameras, radars, sonars, and/or other actuated devices) coupled to mobile structure 101, where each actuated device includes one or more actuators adapted to adjust an orientation of the device, relative to mobile structure 101, in response to one or more control signals (e.g., provided by controller 130).

Radar system 182 may be implemented as one or more electrically and/or mechanically coupled controllers, transmitters, receivers, transceivers, signal processing logic devices, various electrical components, antenna elements of various shapes and sizes, multichannel antennas, antenna assemblies, assembly brackets, mast brackets, and/or various actuators adapted to adjust orientations of any of the components of radar system 182, as described herein. Radar system 182 may be implemented according to any one of various radar system arrangements that can be used to detect land features and/or objects protruding from or suspended above land or a surface of a body of water.

For example, radar system 182 may be configured to emit one, multiple, or a series of radar beams, receive corresponding radar returns, and convert the radar returns into radar data and/or imagery. Radar system 182 may be configured to provide such data and/or imagery to user interface 120 for display to a user, for example, or to controller 130 for additional processing, as described herein. In various embodiments, radar system 182 may be configured to receive control parameters to control operation of radar system 182. For example, radar system 182 may be configured to control or adjust one or more of a sweep rate, a sweep elevation, a sweep azimuthal width, a transmission power (maximum range), a reception amplification (sensitivity), an aperture or beam height, width, and/or shape, and/or other operating parameters of radar system 182 according to control parameters or signals provided by controller 130.

In some embodiments, sonar system 110 may include orientation and/or position sensors configured to help provide two or three dimensional waypoints, increase radar data and/or imagery quality, and/or provide highly accurate radar data, as described herein. In various embodiments, sonar system 110 may be implemented with optional orientation and/or position sensors (e.g., similar to orientation sensor 140, gyroscope/ accelerometer 144, and/or GPS 146) that may be incorporated within the antenna assembly housing to provide three dimensional orientations and/or positions of the antenna assembly and/or antenna(s) for use when processing or post processing radar data for display. The sensor information can be used to correct for movement of the antenna assembly to provide improved alignment of corresponding radar returns/samples, for example, and/or to generate imagery based on the measured orientations and/or positions of the antenna assembly. In other embodiments, an external orientation and/or position sensor can be used alone or in combination with an integrated sensor or sensors.

In embodiments where radar system 182 is implemented with an orientation and/or position sensor, radar system 182 may be configured to store such location/position information along with other sensor information (radar returns, beam azimuth, text descriptions, elevation, mobile structure speed, and/or other sensor and/or control information) available to system 100. In some embodiments, controller 130 may be configured to generate a look up table so that a user can select desired configurations of radar system 182 for a particular location or to coordinate with some other sensor information.

Alternatively, an automated adjustment algorithm can be used to select optimum configurations based on the sensor information.

In general, each of the elements of system 100 may be implemented with any appropriate logic device (e.g., processing device, microcontroller, processor, application specific integrated circuit (ASIC), field programmable gate array (FPGA), memory storage device, memory reader, or other device or combinations of devices) that may be adapted to execute, store, and/or receive appropriate instructions, such as software instructions implementing a method for providing sonar data and/or imagery, for example, or for transmitting and/or receiving communications, such as sensor signals, sensor information, and/or control signals, between one or more devices of system 100. In one embodiment, such method may include instructions to receive an orientation, acceleration, position, and/or speed of mobile structure 101 and/or sonar system 110 from various sensors, to determine a transducer orientation adjustment (e.g., relative to a desired transducer orientation) from the sensor signals, and/or to control an actuator to adjust a transducer orientation accordingly, for example, as described herein. In a further embodiment, such method may include instructions for forming one or more communication links between various devices of system 100.

In addition, one or more machine readable mediums may be provided for storing non-transitory instructions for loading into and execution by any logic device implemented with one or more of the devices of system 100. In these and other embodiments, the logic devices may be implemented with other components where appropriate, such as volatile memory, non-volatile memory, and/or one or more interfaces (e.g., inter-integrated circuit (I2C) interfaces, mobile industry processor interfaces (MIPI), joint test action group (JTAG) interfaces (e.g., IEEE 1149.1 standard test access port and boundary-scan architecture), and/or other interfaces, such as an interface for one or more antennas, or an interface for a particular type of sensor).

Each of the elements of system 100 may be implemented with one or more amplifiers, modulators, phase adjusters, beamforming components, digital to analog converters (DACs), analog to digital converters (ADCs), various interfaces, antennas, transducers, and/or other analog and/or digital components enabling each of the devices of system 100 to transmit and/or receive signals, for example, in order to facilitate wired and/or wireless communications between one or more devices of system 100. Such components may be integrated with a corresponding element of system 100, for example. In some embodiments, the same or similar components may be used to perform one or more sensor measurements, as described herein.

For example, the same or similar components may be used to create an acoustic pulse (e.g., a transmission control signal and/or a digital shaping control signal), convert the acoustic pulse to an excitation signal (e.g., a shaped or unshaped transmission signal) and transmit it to a sonar transducer element to produce an acoustic beam, receive an acoustic return (e.g., a sound wave received by the sonar transducer element and/or corresponding electrical signals from the sonar transducer element), convert the acoustic return to acoustic return data, and/or store sensor information, configuration data, and/or other data corresponding to operation of a sonar system, as described herein.

Sensor signals, control signals, and other signals may be communicated among elements of system 100 using a variety of wired and/or wireless communication techniques, including voltage signaling, Ethernet, WiFi, Bluetooth, Zigbee, Xbee, Micronet, or other medium and/or short range wired and/or wireless networking protocols and/or implementations, for example. In such embodiments, each element of system 100 may include one or more modules supporting wired, wireless, and/or a combination of wired and wireless communication techniques.

In some embodiments, various elements or portions of elements of system 100 may be integrated with each other, for example, or may be integrated onto a single printed circuit board (PCB) to reduce system complexity, manufacturing costs, power requirements, and/or timing errors between the various sensor measurements. For example, gyroscope/accelerometer 144, user interface 120, and controller 130 may be configured to share one or more components, such as a memory, a logic device, a communications module, and/or other components, and such sharing may act to reduce and/or substantially eliminate such timing errors while reducing overall system complexity and/or cost.

Each element of system 100 may include one or more batteries or other electrical power storage devices, for example, and may include one or more solar cells or other electrical power generating devices (e.g., a wind or water-powered turbine, or a generator producing electrical power from motion of one or more elements of system 100). In some embodiments, one or more of the devices may be powered by a power source for mobile structure 101, using one or more power leads. Such power leads may also be used to support one or more communication techniques between elements of system 100.

In various embodiments, a logic device of system 100 (e.g., of orientation sensor 140 and/or other elements of system 100) may be adapted to determine parameters (e.g., using signals from various devices of system 100) for transforming a coordinate frame of sonar system 110 and/or other sensors of system 100 to/from a coordinate frame of mobile structure 101, at-rest and/or in-motion, and/or other coordinate frames, as described herein. One or more logic devices of system 100 may be adapted to use such parameters to transform a coordinate frame of sonar system 110 and/or other sensors of system 100 to/from a coordinate frame of orientation sensor 140 and/or mobile structure 101, for example. Furthermore, such parameters may be used to determine and/or calculate one or more adjustments to an orientation of sonar system 110 that would be necessary to physically align a coordinate frame of sonar system 110 with a coordinate frame of orientation sensor 140 and/or mobile structure 101, for example, or an absolute coordinate frame. Adjustments determined from such parameters may be used to selectively power adjustment servos/actuators (e.g., of sonar system 110 and/or other sensors or elements of system 100), for example, or may be communicated to a user through user interface 120, as described herein.

Fig. 1B illustrates a diagram of system 100B in accordance with an embodiment of the disclosure. In the embodiment shown in Fig. 1B, system 100B may be implemented to provide sonar data and/or imagery for use with operation of mobile structure 101, similar to system 100 of Fig. 1B. For example, system 100B may include sonar system 110, integrated user interface/controller 120/130, secondary user interface 120, steering sensor/actuator 150, sensor cluster 160 (e.g., orientation sensor 140, gyroscope/accelerometer 144, and/or GPS 146), elevated sensor cluster 161 (e.g., corresponding to imaging devices, radar system 182, and/or other sensor systems), and various other sensors and/or actuators. In the embodiment illustrated by Fig. 1B, mobile structure 101 is implemented as a motorized boat including a hull 105b, a deck 106b, a transom 107b, a mast/sensor mount 108b, a rudder 152, an inboard motor 170, and an actuated sonar system 110 coupled to transom 107b. In other embodiments, hull 105b, deck 106b, mast/sensor mount 108b, rudder 152, inboard motor

170, and various actuated devices may correspond to attributes of a passenger aircraft or other type of vehicle, robot, or drone, for example, such as an undercarriage, a passenger compartment, an engine/engine compartment, a trunk, a roof, a steering mechanism, a headlight, a radar system, and/or other portions of a vehicle.

As depicted in Fig. 1B, mobile structure 101 includes actuated sonar system 110, which in turn includes transducer assembly 112 coupled to transom 107b of mobile structure 101 through assembly bracket/actuator 116 and transom bracket/electrical conduit 114. In some embodiments, assembly bracket/actuator 116 may be implemented as a roll, pitch, and/or yaw actuator, for example, and may be adapted to adjust an orientation of transducer assembly 112 according to control signals and/or an orientation (e.g., roll, pitch, and/or yaw) or position of mobile structure 101 provided by user interface/controller 120/130. For example, user interface/controller 120/130 may be adapted to receive an orientation of transducer assembly 112 configured to ensonify a portion of surrounding water and/or a direction referenced to an absolute coordinate frame, and to adjust an orientation of transducer assembly 112 to retain ensonification of the position and/or direction in response to motion of mobile structure 101, using one or more orientations and/or positions of mobile structure 101 and/or other sensor information derived by executing various methods described herein.

In another embodiment, user interface/controller 120/130 may be configured to adjust an orientation of transducer assembly 112 to direct sonar transmissions from transducer assembly 112 substantially downwards and/or along an underwater track during motion of mobile structure 101. In such embodiment, the underwater track may be predetermined, for example, or may be determined based on criteria parameters, such as a minimum allowable depth, a maximum ensonified depth, a bathymetric route, and/or other criteria parameters. Transducer assembly 112 may be implemented with a sonar position and/or orientation sensor (SPOS), which may include one or more sensors corresponding to orientation sensor 140, gyroscope/accelerometer 144 and/or GPS 146, for example, that is configured to provide absolute and/or relative positions and/or orientations of transducer assembly 112 to facilitate actuated orientation of transducer assembly 112.

In one embodiment, user interfaces 120 may be mounted to mobile structure 101 substantially on deck 106b and/or mast/sensor mount 108b. Such mounts may be fixed, for example, or may include gimbals and other leveling mechanisms/actuators so that a display of user interfaces 120 can stay substantially level with respect to a horizon and/or a "down" vector (e.g., to mimic typical user head motion/orientation), for example, or so the display can be oriented according to a user's desired view. In another embodiment, at least one of user interfaces 120 may be located in proximity to mobile structure 101 and be mobile/portable throughout a user level (e.g., deck 106b) of mobile structure 101. For example, a secondary user interface 120 may be implemented with a lanyard, strap, headband, and/or other type of user attachment device and be physically coupled to a user of mobile structure 101 so as to be in proximity to the user and mobile structure 101. In various embodiments, user interfaces 120 may be implemented with a relatively thin display that is integrated into a PCB of the corresponding user interface in order to reduce size, weight, housing complexity, and/or manufacturing costs.

As shown in Fig. 1B, in some embodiments, speed sensor 142 may be mounted to a portion of mobile structure 101, such as to hull 105b, and be adapted to measure a relative water speed. In some embodiments, speed sensor 142 may be adapted to provide a thin profile to reduce and/or avoid water drag. In various embodiments, speed sensor 142 may be mounted to a portion of mobile structure 101 that is substantially outside easy operational accessibility. Speed sensor 142 may include one or more batteries and/or other electrical power storage devices, for example, and may include one or more water-powered turbines to generate electrical power. In other embodiments, speed sensor 142 may be powered by a power source for mobile structure 101, for example, using one or more power leads penetrating hull 105b. In alternative embodiments, speed sensor 142 may be implemented as a wind velocity sensor, for example, and may be mounted to mast/sensor mount 108b to have relatively clear access to local wind.

In the embodiment illustrated by Fig. 1B, mobile structure 101 includes direction/longitudinal axis 102, direction/lateral axis 103, and direction/vertical axis 104 meeting approximately at mast/sensor mount 108b (e.g., near a center of gravity of mobile structure 101). In one embodiment, the various axes may define a coordinate frame of mobile structure 101 and/or sensor cluster 160.

Each sensor adapted to measure a direction (e.g., velocities, accelerations, headings, or other states including a directional component) may be implemented with a mount, actuators, and/or servos that can be used to align a coordinate frame of the sensor with a coordinate frame of any element of system 100B and/or mobile structure 101. Each element of system 100B may be located at positions different from those depicted in Fig. 1B. Each device of system 100B may include one or more batteries or other electrical power storage devices, for example, and may include one or more solar cells or other electrical power generating devices. In some embodiments, one or more of the devices may be powered by a power source for mobile structure 101. As noted herein, each element of system 100B may be implemented with an antenna, a logic device, and/or other analog and/or digital components enabling that element to provide, receive, and process sensor signals and interface or communicate with one or more devices of system 100B. Further, a logic device of that element may be adapted to perform any of the methods described herein.

Fig. 2 illustrates a diagram of an augmented reality imagery system including a portable imaging device 220 in accordance with an embodiment of the disclosure. In various embodiments, portable imaging device 220 may be implemented with similar functionality as that described with reference to user interface 120 and/or controller 130 in Figs. 1A and 1B. In the embodiment shown in Fig. 2, portable imaging device 220 may be configured to provide visible spectrum imagery (e.g., using a visible spectrum imaging module 223), infrared spectrum imagery (using optional infrared imaging module 224), and/or sonar imagery (using sonar system 110 of Figs. 1A and 1B) of scene 200 to a user 290 using a display 226. For example, portable imaging device 220 may be configured to display rendered image data (e.g., provided by imaging modules 223 and/or 224) in a portion of a field of view (FOV) of display 226 that is above waterline 205 and to display rendered sonar data in a portion of the FOV that is below waterline 205.

Image data provided by imaging modules 223 and/or 224 may include an image of a surface of a body of water 205a and various objects or structures above waterline 205, such as the sun 201, a tree 202, and/or a beach 203. Such image data may be processed using feature/pattern recognition techniques to determine a location of waterline 205 within the image data (e.g., if imaging modules 223 and/or 224 are oriented to capture a portion of scene 200 including waterline 205). Sonar data, which may be provided by bathymetric charts and/or past or current use of sonar system 110 of Figs. 1A and 1B, may include data representative of waterline 205, a floor 206 of body of water 205a, a bank 206a of floor 206, a bottom feature 207 (e.g., a rock or sunken ship), fish 208, other submerged objects 209 (e.g., trash, seaweed), and/or other underwater features within or surrounding body of water 205a. Such underwater features may be indicated and/or differentiated through use of any combination of contour lines, color and/or greyscale mapping and/or shading, three dimensional rendering, and/or other volumetric rendering techniques. In some embodiments, surface orientations of various underwater features (e.g., of side 207a or top 207b of bottom feature 207, or of side 208a of fish 208) may be detected and/or differentiated using similar sonar data and/or image processing techniques. The portions of either or both the image data and the sonar data that are rendered and displayed by display 226, and the techniques used to render the imagery, may be selected based on the location of waterline 205 relative to an FOV of display 226 to provide augmented reality sonar imagery, as described herein.

As shown, portable imaging device 220 may include one or more controllers 221 (e.g., including memory 222), imaging modules (e.g., visible spectrum imaging module 223 and/or infrared imaging module 224), other sensors (e.g., imager position and/or orientation sensor 225), display 226, communication module 227, and/or other modules 228 facilitating operation of portable imaging device 220, which may or may not all be disposed within a common housing 240. In other embodiments, one or more of the modules shown in Fig. 2 may be integrated with a stationary user interface and/or mount (e.g., coupled to deck 106b or mast/sensor mount 108b of mobile structure 101 in Fig. 1B) and be configured to communicate with devices within housing 240 through a distributed embodiment of communication module 227.

Visible spectrum imaging module 223 and infrared imaging module 224 may be electronic devices configured to capture imagery/image data of scene 200 according to their respective spectrums and provide images to controller 221. In some embodiments, visible spectrum imaging module 223 and infrared imaging module 224 may be implemented according to any similar devices described in U.S. Patent Application 14/138,058, filed December 21, 2013, and entitled “COMPACT MULTI-SPECTRUM IMAGING WITH FUSION”, which is hereby incorporated by reference in its entirety. Moreover, imagery provided by imaging modules 223 and 224 may be combined (e.g., blended, overlaid, fused, or otherwise combined) to provide combined (e.g., from multiple source spectrums) imagery/image data that may be rendered by portable imaging device 220 and/or displayed using display 226 using any of the methods described in U.S. Patent Application 14/138,058 (incorporated by reference above) and/or as further described herein.

More generally, portable imaging device 220 may include a variety of imaging modules adapted to capture imagery (e.g., image and/or video data) according to visible spectrum, infrared, and other spectrums, for example, and provide corresponding image data to controller 221 or other controllers or devices for rendering and/or display. In some embodiments, imaging modules 223 and/or 224 may be mounted to a mobile structure separate from portable imaging device 220 (e.g., to deck 106b or mast/sensor mount 108b of mobile structure 101 in Fig. 1B, using a fixed or actuated mounts such as elevated sensor cluster 161) and be configured to provide imagery to controller 221 using wired and/or wireless communications through communication module 227. In such embodiments, multiple portable imaging devices may be configured to share image data provided by imaging modules mounted to the mobile structure.

Controller 221 and/or memory 222 may each be implemented as any appropriate logic device (e.g., processing device, microcontroller, processor, application specific integrated circuit (ASIC), field programmable gate array (FPGA), memory storage device, memory reader, or other device or combinations of devices) that may be adapted to execute, store, and/or receive appropriate instructions, such as software instructions implementing a control loop for controlling various operations of mobile structure 101, for example, similar to controller 130. In some embodiments, controller 221 may be in communication with various modules of portable imaging device 220 and be configured to receive imagery/image data of scene 200 from imaging modules 223 and/or 224, determine waterline 205 of a body of water 205a in scene 200 (e.g., from image data, position data, and/or orientation data provided by the portable imaging device), render or display image data in any portion of an FOV of display 226 that extends above waterline 205, and/or render and/or display sonar data in any portion of the FOV of display 226 that extends below waterline 205.

In some embodiments, controller 221 may be configured to receive the sonar data and/or imagery from controller 130 and/or sonar system 110 of Figs. 1A or 1B, for example, based on a measured position and/or orientation of portable imaging device 220, either of imaging modules 223 and 224, and/or display 226, provided by imager position and/or orientation sensor (IPOS) 225. Such sonar data and/or imagery may include data from charts, prior ensonifications, and/or current sonar data or imagery provided by, for example, sonar system 110. In further embodiments, controller 221 may be tasked with generating sonar imagery from sonar data, correlating sensor data with sonar data/imagery, communicating operational parameters and/or sensor information with other devices, and/or other operations of systems 100 and/or 100B of Figs. 1A and 1B. In various embodiments, controller 221 and memory 222 may be integrated together, for example, or may be implemented in a distributed manner across a number of individual controllers and/or memories.

In the embodiment shown in Fig. 2, portable imaging device 220 includes IPOS 225. IPOS 225 may be implemented as one or more orientation sensors, GPS sensors, differential GPS sensors, orientation/position reference transducers and/or optical sensors (e.g., for actuators), visible spectrum and/or infrared imaging modules, and/or other sensors configured to measure a relative and/or absolute orientation and/or position of portable imaging device 220 and/or each of imaging modules 223 and 224 and display 226 and provide such measurements to controller 221. For example, in one embodiment, IPOS 225 may include one or more remote infrared imaging modules (e.g., implemented similar to infrared imaging module 224) fixed to a mobile structure and a number of infrared registration marks disposed on housing 240, and controller 221 may be configured to determine a relative position and/or orientation of portable imaging device 220 from the size and/or position of the infrared registration marks and/or other related characteristics of portable imaging device 220 in image data captured by the one or more remote infrared imaging modules. Such relative position and/or orientation may be relative to a position and/or orientation of the remote infrared imaging modules and/or the mobile structure.

In some embodiments, IPOS 225 may be distributed amongst the various modules of portable imaging device 220 and include one or more individual module IPOSs configured to measure positions and/or orientations of image modules 223 and/or 224 and a separate display IPOS configured to measure a position and/or orientation of display 226. In various embodiments, controller 221 may be configured to combine image data and sonar data according to IPOS measurements and/or measurements of an orientation and/or position of a coupled sonar system (e.g., from a corresponding SPOS) and/or mobile structure to produce combined imagery, such as visible spectrum images of scene 200 above waterline 205 and/or three dimensional sonar images of scene 200 below waterline 205. In other embodiments, controller 221 may be configured to use orientation and/or position measurements of portable imaging device 220, imaging modules 223 and 224, display 226, and/or a mobile structure to control one or more actuators to adjust a position and/or orientation of imaging modules 223 and 224 and/or portions of an associated sonar system (e.g., transducer assembly 112) to image or ensonify a particular position and/or orientation of scene 200 relative to an FOV of display 226.

Display 226 may be implemented as one or more LCDs, OLEDs, touch screen displays, projection devices, and/or other digital displays that may be configured to display image data from imaging modules 223 and 224 and/or sonar data (e.g., from sonar system 110 of Figs. 1A and 1B) rendered by controller 221 to user 290. In various embodiments, display 226 may be characterized by an FOV that is a function of the available pixel dimensions of display 226, the position and/or orientation of display 226, the FOVs of imaging modules 223 and/or 224, and an effective optical zoom level applied to the image data provided by imaging modules 223 and/or 224. For example, where imaging modules 223 and 224 are within the same housing 240 as display 226, the position and orientation of display 226 may be substantially the same as that of imaging modules 223 and/or 224, and the FOV of display 226 may be the same as that for imaging modules 223 and/or 224 as modified by the effective zoom level and the pixel dimensions of display 226. In other embodiments, where imaging modules 223 and/or 224 are mounted outside of housing 240, the FOV of display 226 may be dependent on the absolute or relative position and/or orientation of display 226 as compared to that of imaging modules 223 and/or 224.

In some embodiments, the effective optical zoom level may be adjusted to produce an FOV for display 226 that substantially reproduces a direct view of scene 200 as experienced by user 290, for example, so that objects within scene 200 are approximately the same size when viewed by user 290 with or without use of portable imaging device 220. In such embodiments, the effective optical zoom level may be adjusted by sensing a distance between user 290 and display 226 and then selecting the effective optical zoom level based on that distance to reproduce the direct view of scene 200. In other embodiments, the effective optical zoom level may be adjusted by user input to reproduce the direct view and/or to select a higher or lower effective optical zoom level to increase or decrease the FOV of and/or the image detail produced by display 226. The effective optical zoom level may be adjusted using digital image processing techniques, manual and/or actuated adjustment of optical components within imaging modules 223 and/or 224, or any combination of image processing or optical adjustments.

Communication module 227 may be implemented as any wired and/or wireless interface configured to communication sensor data, configuration data, parameters, and/or other data and/or signals between portable imaging device 220 and other elements of mobile structure 101 (e.g., as shown in Figs. 1A and 1B) and/or amongst modules of portable imaging device 220. As described herein, in some embodiments, communication module 227 may be implemented in a distributed manner such that portions of communication module 227 are implemented within one or more modules of portable imaging device 220 that may or may not be disposed within housing 240.

Other modules 228 may include other and/or additional sensors, sensor arrays, actuators, logic devices, communications modules/nodes, power and/or power distribution components, and/or user interface devices used to provide additional environmental information and/or configuration parameters, for example, and/or to adjust a position and/or orientation of portable imaging device 220. In some embodiments, other modules 228 may include various environmental sensors providing measurements and/or other sensor signals that can be displayed to a user and/or used by other devices of portable imaging device 220 (e.g., controller 221) to facilitate operation of portable imaging device 220. In some embodiments, other modules 228 may include one or more buttons and/or other user input devices configured to accept manual user input. In other embodiments, other modules may include one or more distance detectors configured to detect user 290 and/or measure or estimate a distance between display 226 and user 290.

In various embodiments, portable imaging device 220 may be implemented in a single housing 240 with a single display (e.g., display 225) adapted to be held by user 290 while user 290 views the display. In other embodiments, housing 240 may be mounted to a mobile structure using a fixed or actuated mount to provide a fixed or actuated view relative to an orientation of the mobile structure. In some embodiments, portable imaging device 220 may be implemented as a wearable device, such as a pair of glasses including a plurality of displays configured to provide the same image to each eye of user 290 individually or to provide stereoscopic imagery to both eyes of user 290. Such stereoscopic imagery may be generated using multiple instances of imaging modules 223 and/or 224, for example, or by applying various image processing techniques to image and/or sonar data to provide a simulation of depth.

Fig. 3 illustrates a diagram of an augmented reality imagery system including an embodiment of portable imaging device 220 of Fig. 2, in accordance with an embodiment of the disclosure. In the embodiment shown in Fig. 3, portable imaging device 220 is oriented to illustrate imagery displayed by display 226 as viewed by user 290 of Fig. 2, where the effective optical zoom level is adjusted to reproduce a direct view of scene 200 (except for a relatively small portion of the direct view obscured by housing 240 and/or user input device 228.

Scene 200 includes features above waterline 205 illustrated in Fig. 2 and additionally includes mountains/land features 204, surface 205c of body of water 205a, and deck 106b (e.g., of mobile structure/boat 101 in Fig. 1B). Also shown in Fig. 3, and in particular in the FOV of display 226, are detected waterline 205b, portion 330 of the FOV that extends below waterline 205b, and portion 334 of the FOV that extends above waterline 205b. Portable imaging device 220 may in some embodiments be configured to render detected waterline 205b in display 226 to illustrate a detected location of waterline 205 relative to the FOV of display 226. Portion 330 may include imagery representing bottom feature 207, fish 208, and submerged object 209, similar to objects illustrated in Fig. 2. For example, as shown in Fig. 3, portion 330 may include a number of contour lines 332 rendered by a controller (e.g., controller 221 of Fig. 2) to distinguish depths, relative distances, various characteristics of bathymetric data, and/or other characteristics of underwater features. Alternatively, or in addition, portion 330 may include icons and/or other types of graphical indicators configured to illustrate a position and/or distance to fish 208 or submerged object 209, and/or to distinguish between the two (e.g., based on fish detection processing performed on acoustic returns from fish 208 and/or submerged object 209). Although the FOV of display 226 in Fig. 3 is shown to include both portions 330 and 334, a different position and/or orientation of display 226 and/or portable imaging device 220 could result in portion 330 or 334 encompassing the entire FOV of display 226.

In some embodiments, age or source of sonar data may be differentiated by rendering substantially real time sonar data differently from prior-acquired and/or survey map sonar data (e.g., a 3^{rd} party provided chart or collection of bathymetric data for a particular body of water stored in memory, such as memory 222 of Fig. 2). For example, substantially real time sonar data may be rendered in color and prior-acquired and/or survey map sonar data may be rendered in greyscale. In some embodiments, a relative age of once real time sonar data may be indicated by reducing a chrominance level of the sonar data as the sonar data ages. In additional embodiments, portable imaging device 220 (e.g., controller 221 of Fig. 2) may be configured to detect or determine various surfaces of underwater features based on acoustic returns from the surfaces and/or one or more volumetric renderings of corresponding sonar data, and the relative or absolute orientations of the various surfaces may be determined from the volumetric renderings. In such embodiments, portable imaging device 220 may be configured to indicate the relative or absolute surface orientations in portion 330 by mapping the surface orientations to a color and/or intensity map and rendering the sonar data corresponding to the determined surfaces in a corresponding color.

Also shown in portion 330 of the FOV of display 226 is overlapping portion 336, which indicates where deck 106b would otherwise obscure direct view of surface 205c. In some embodiments, portable imaging device 220 may be configured to determine whether portion 330 overlaps with a view of a mobile structure disposed on surface 205c (e.g., mobile structure 101 of Figs. 1A or 1B), thereby forming overlapping portion 336. If overlapping portion 336 exists, portable imaging device 220 may be configured to blend image data of the mobile structure (e.g., captured by imaging modules 223 and/or 224) with sonar data in overlapping portion 336 and rendering the blended data in the overlapping portion 336. In embodiments where portable imaging device 220 is worn by a user and generally occludes direct view of the user's surroundings, the blended imagery can provide a user with a view of sonar data beneath the mobile structure but protect the user from stumbling into objects on the mobile structure and/or walking off deck 106b.

Fig. 4 illustrates a diagram of an augmented reality imagery system including wearable portable imaging device 420 in accordance with an embodiment of the disclosure. In various embodiments, portable imaging device 420 may be implemented with similar functionality as that described with reference to portable imaging device 220 in Figs. 2 and 3. In the embodiment shown in Fig. 4, wearable portable imaging device 420 is oriented to illustrate imagery displayed by displays 426 (e.g., one per user eye) as viewed by a user wearing portable imaging device 420, where the effective optical zoom level is adjusted to reproduce a direct view of scene 200 (except for a relatively small portion of the direct view obscured by imaging modules 423 and/or frame 440).

Fig. 4 includes some of the features above waterline 205 illustrated in scene 200 of Figs. 2 and 3, and, in particular in the FOV of displays 426, includes detected waterlines 205b, portions 430 of the FOV that extend below respective waterlines 205b, and portions 434 of the FOV that extend above respective waterlines 205b. Portions 430 may include color and/or intensity shading 432 rendered by a controller (e.g., controller 221 of Fig. 2) to distinguish depths, relative distances, various characteristics of bathymetric data, and/or other characteristics of various underwater features.

As illustrated in Fig. 4, wearable portable imaging device 420 may include one or more imaging modules 423, which may be implemented as visible spectrum and/or infrared imaging modules configured to provide monocular (e.g., copied to both displays 426) and/or stereoscopic image data depending on the number and arrangement of imaging modules and the type of image processing applied to image data provided by imaging modules 423. In addition, an IPOS (e.g., IPOS 225 of Fig. 2) may be integrated with any of imaging modules 423, displays 426, and/or frame 440 and be configured to provide a position and/or orientation of one or more of the features to facilitate determining FOVs for displays 426. In some embodiments, portable imaging device 420 may be configured to determine portion 430 of the FOV of display 426 and use an SPOS and actuator in an associated transducer assembly (e.g., actuator 116 coupled to transducer assembly 112 of sonar system 110 in Fig. 1B) to ensonify at least a subset of portion 430 substantially in real time as a user adjusts a position or orientation of wearable portable imaging device 420 by, for example, moving the user's head. Sonar data provided by the associated transducer assembly may be rendered using position data and/or orientation data provided by the SPOS to correlate the sonar data with portion 430, for example, and/or to facilitate other rendering processing described herein.

In some embodiments, displays 426 may be implemented with substantially transparent display panels, where the only portions of displays 426 that obscure a direct view of scene 200, as seen by a user wearing portable imaging device 420, are those portions actively displaying rendered image data. In such embodiments, portable imaging device 420 may be configured to render and display portions 430 and/or detected waterlines 205b using displays 426 without also rendering portions 434.

Power for portable imaging device 420 may be embedded within frame 440 and/or electrically coupled to portable imaging device 420 through use of a wire harness and/or an external power source, such as a battery pack or a power source for a mobile structure.

Fig. 5 illustrates a flow diagram of process 500 to provide augmented reality sonar data and/or imagery for mobile structure 101 in accordance with embodiments of the disclosure. In some embodiments, the operations of Fig. 5 may be implemented as software instructions executed by one or more logic devices associated with corresponding electronic devices, sensors, and/or structures depicted in Figs. 1A through 4. More generally, the operations of Fig. 5 may be implemented with any combination of software instructions and/or electronic hardware (e.g., inductors, capacitors, amplifiers, actuators, or other analog and/or digital components).

It should be appreciated that any step, sub-step, sub-process, or block of process 500 may be performed in an order or arrangement different from the embodiments illustrated by Fig. 5. For example, in other embodiments, one or more blocks may be omitted from or added to the process. Furthermore, block inputs, block outputs, various sensor signals, sensor information, calibration parameters, and/or other operational parameters may be stored to one or more memories prior to moving to a following portion of a corresponding process. Although process 500 is described with reference to systems described in reference to Figs. 1A-4, process 500 may be performed by other systems different from those systems and including a different selection of electronic devices, sensors, assemblies, mobile structures, and/or mobile structure attributes.

Process 500 represents a method for providing augmented reality sonar data and/or imagery using systems 100, 100B, 220, and/or 420 in accordance with embodiments of the disclosure. At the initiation of process 500, various system parameters may be populated by prior execution of a process similar to process 500, for example, or may be initialized to zero and/or one or more values corresponding to typical, stored, and/or learned values derived from past operation of process 500, as described herein.

In block 502, a logic device receives sensor data from a portable imaging device. For example, controller 130 of systems 100 or 100B and/or controller 221 of portable imaging device 220 may be configured to receive visible spectrum image data and/or infrared image data from corresponding imaging modules 223 and/or 224, and position and/or orientation data corresponding to imaging modules 223 and/or 224 and/or display 226 of portable imaging device 220 from IPOS 225. In some embodiments, the controller may be configured to receive position and/or orientation data corresponding to display 225 and then use the position and/or orientation data to aim imaging modules 223 and/or 224 (e.g. using control signals provided to actuators coupled to imaging modules 223 and/or 224) so that their FOVs substantially overlap with an FOV and/or relative orientation of display 226.

In block 504, a logic device determines a waterline of a body of water relative to a field of view of a display. For example, controller 130 of systems 100 or 100B and/or controller 221 of portable imaging device 220 may be configured to determine a waterline using the image data, position data, and/or orientation data acquired in block 502. In some embodiments, the controller may be configured to use feature and/or pattern recognition processing to detect a location of waterline 205 within image data provided by imaging modules 223 and/or 224. The controller may then use the various position and/or orientation data, the location of waterline 205 within the image data, various characteristics of display 226, and/or an effective optical zoom level to determine waterline 205b of body of water 205a relative to the FOV of display 226, as described herein.

In block 506, a logic device receives sonar data from a sonar transducer assembly. For example, controller 130 of systems 100 or 100B and/or controller 221 of portable imaging device 220 may be configured to receive sonar data from sonar transducer assembly 112 of sonar system 110. In some embodiments the controller may be configured to transmit position and/or orientation data corresponding to portion 330 of the field of view of display 226 that extends below waterline 205b, determined in block 504, to sonar system 110 to aim transducer assembly 112 (e.g., using actuator 116 and/or an associated SPOS) at portion 330 (e.g., or to sweep transducer assembly 112 through portion 330) to acquire substantially real time sonar data corresponding to portion 330. In other embodiments, the controller may be configured to transmit such position and/or orientation data to receive sonar data limited to portion 330, such as from prior-acquired sonar data and/or from a survey map limited by partitioning the sonar data according to corresponding position and/or orientation data, which may be provided by an SPOS when the sonar data was acquired.

In block 508, a logic device renders sonar data in a portion of an FOV that extends below a waterline. For example, controller 130 of systems 100 or 100B and/or controller 221 of portable imaging device 220 may be configured to render sonar data acquired in block 506 in portion 330, as determined in part through operation of blocks 502 and/or 504. In some embodiments, the controller may be configured to render image data provided by imaging modules 223 and/or 224 in portion 334 (e.g., the portion of the FOV of display 226 that extends above waterline 205b). In such embodiments, the controller may be configured to generate combined image data from visible spectrum data and infrared image data and render the combined image data in at least a part of portion 334. In other embodiments, the controller may be configured to determine whether portion 330 overlaps with a view of mobile structure 101 (e.g., whether portion 336 exists) and blend (e.g., fuse, alpha blend, or otherwise combine) image data provided by imaging modules 223 and/or 224 with sonar data in overlapping portion 336 when rendering portion 336.

In various embodiments, the controller may be configured to apply various types of image processing to the sonar data when rendering portions 330 and/or 336, such as processing to visually differentiate real time and prior-acquired sonar data, to visually indicate a relative age of different portions of sonar data, to visually indicate surface orientations of underwater features, and/or to provide additional methods to visually differentiate different underwater features and/or different underwater feature characteristics from one another. Similarly, in some embodiments, the controller may be configured to apply various types of image processing to image data when rendering portion 334, such as processing to differentiate above-water objects from one another in low light or otherwise limited visibility environments.

In further embodiments, image data, position data, orientation data, and/or sonar data acquired and/or processed in blocks 502-508 may be used to control operation of mobile structure 101, such as by controlling steering sensor/actuator 150 and/or propulsion system 170 to steer mobile structure 101 according to an orientation of display 226, for example, and/or according to positions and/or depths of floor 206, bottom feature 207, fish 208, and/or submerged objects 209.

It is contemplated that any one or combination of methods to provide augmented reality sonar imagery may be performed according to one or more operating contexts of a control loop, for example, such as a startup, learning, running, and/or other type operating context. For example, process 500 may proceed back to block 502 and proceed through process 500 again to produce updated augmented reality sonar imagery, as in a control loop.

Embodiments of the present disclosure can thus provide augmented reality sonar imagery. Such embodiments may be used to provide sonar imagery to assist in navigation for a mobile structure, survey of a body of water, and/or to assist in the operation of other systems, devices, and/or sensors coupled to the mobile structure. In some embodiments, such augmented reality sonar imagery may be generated to include other ranging sensor data, such as radar data from radar system 182. In alternative embodiments, radar data from radar system 182 may be rendered so as to be visually correlated with images of an area about mobile structure 101 captured by one or more imaging devices, for example, as described herein.

As noted herein, embodiments of the present disclosure provide techniques for rendering visually correlated radar and image data that can be implemented with minimal user input and with intuitive user feedback, thereby providing radar-augmented imagery that is easier to interpret than conventional imagery provided by conventional radar and/or imaging systems and/or methods, particularly while operating a mobile structure.

For example, b-scan radar data imagery (e.g., radar data presented in a b-scan display format) typically provides a plot of radar return intensity as a function of azimuth angle along a horizontal axis and range along a vertical axis, where the azimuth angle refers to the bearing (e.g., absolute or relative) from the radar system along a particular radar beam path, and the range refers to the distance between the radar system and a detected radar return/object. Such display format makes it relatively easy to measure the relative position (e.g., range and bearing) and/or absolute position (e.g., latitude and longitude) of a detected object generating radar returns within the radar data, and, for this reason, the b-scan radar display format has historically been used in targeting systems. However, translating the b-scan radar data imagery into an accurate visual identification of an object can still be difficult, particularly for a novice user navigating an area crowded with multiple objects each generating their own radar returns.

Similarly, images captured by a camera/imaging device generally provide a plot of image data as a function of azimuth angle along a horizontal axis, such that two imaged objects on the same bearing/heading but at different ranges or elevations are vertically aligned. In various embodiments, to ensure such image data is horizontally aligned with the horizon (e.g., and thereby the coordinate frame of the radar system), the imaging devices may be horizontally stabilized (e.g., using gimbals, actuators, weights, and/or other horizontal stabilization systems), for example, and/or the image data may be processed to rotate the image data to horizontally align the image data with the horizon. For example, controller 130 of systems 100 or 100B and/or controller 221 of portable imaging device 220 may be configured to detect a waterline in the image data and rotate the image data to substantially align the detected waterline with a horizontal axis of the image data.

In embodiments where the radar data is displayed or rendered in a b-scan format, the rendered radar data may be visually correlated to corresponding rendered image data by limiting the azimuthal width of the rendered radar data to match the horizontal FOV of the rendered image data, for example, and placing the rendered radar data above or below the rendered image data, such that objects depicted in the rendered image data are vertically aligned with corresponding radar returns in the rendered radar data. Such visual correlation may be performed using radar data displayed or rendered in display format different from the b-scan format, for example, such as the plan position indicator (PPI) display format (e.g., a plot of radar return intensities as a function of azimuth angle about the center of the plot and range radially out from the center of the plot). Both the radar data and the image data may updated continuously, such as with scanning radar systems and video data streams.

In embodiments where the radar data is provided in a b-scan format, the rendered radar data may be vertically aligned over or next to the rendered image data. The rendered radar data may be limited to and/or aligned with the FOV of the rendered image data. Panning or changing the magnification/zoom level of the imaging device can adjust the portion of the radar data that is rendered to retain visual correlation between the rendered image data and the rendered radar data.

In some embodiments, renderings including the visually correlated radar and image data may also include one or more adjustable or selectable an electronic bearing line (EBL) indicators (e.g., a line or beam rendered as an overlay on the rendered radar data and/or image data) to help identify objects and/or corresponding object characteristics (e.g., position, range, bearing, and/or other object characteristics). In other embodiments, the rendered image data may be used to help visually align the radar data to a heading of a mobile structure (e.g., to ships head), such that the azimuth angles reported by radar system 182 are aligned with/calibrated to headings reported by, for example, orientation sensor 140.

Once a visual correlation between the radar data and the image data has been determined (e.g., one or more of an azimuthal width, range, and/or extents of the radar data), the image data may in some embodiments be rendered next to radar data rendered in a PPI display format. Panning or changing the magnification/zoom level of the imaging device, or panning the radar system, allows a correlation of objects in sensor data from the two sources. In various embodiments, the image data may correspond to images and/or video captured by portable imaging devices, such as portable imaging devices 220 and 420 described herein, and the renderings may be displayed using one or more of a display of user interface 120, display 226 of portable imaging device 220, and/or displays 426 of portable imaging device 420.

Figs. 6-8B illustrate display views including visually correlated radar data in accordance with embodiments of the disclosure. For example, Fig. 6 shows display view 600 including radar data portion 610 rendered above image data portion 630. Radar data portion 610 may alternatively be rendered below image data portion 630. As shown in Fig. 6, radar data portion 610 includes radar data 612 with radar returns 614 presented in a b-scan display format, as described herein. In some embodiments, display view 600, radar data portion 610, and/or image data portion 630 may also include range indicators 616, range guidelines 618, azimuth angle (e.g., bearing/heading) indicators 620, and/or azimuth angle guidelines 622 rendered as graphical overlays (e.g., over radar data 612 and/or image data 632) to facilitate measurement or estimation of range and bearing/heading to a detected/imaged object, such as detected objects 634, identified objects 640, and/or identified ship 644.

Also shown in Fig. 6 is image data portion 630, which includes image data 632 depicting waterline 205 and objects 634 including identified buoys 640 and identified ship 644. As used herein, identified objects refers to specific objects detected within either or both radar data 612 and image data 632 that are linked with additional object characteristics derived from other data sources, such as chart data (e.g., identifying navigation buoys 640) and/or AIS data (e.g., position, identification, and/or other AIS data, including various object characteristics) provided by an AIS transponder on identified ship 644 and received by an AIS receiver on mobile structure 101 (e.g., other modules 180). Detected objects refers more generally to any objects detected within either or both radar data 612 and image data 632, such as mooring buoys 634 (e.g., corresponding to radar returns 614).

As described herein, radar data 612 in radar data portion 610 of display view 600 may be visually correlated to image data 632 in image data portion 630 of display view 600 based, at least in part, on a horizontal FOV 638 of image data 632 rendered in image data portion 630 of display view 600. In general, horizontal FOV 638 (depicted in Fig. 6 as a dashed line with lead and lag arrows) may be characterized by, for example, one or more of an azimuthal breadth/width of image data 632, the FOV bearing/heading (e.g., roughly corresponding to electronic heading line (EHL) 636 in Fig. 6) of image data 632, and/or the port and starboard azimuth angle extents of image data 632, as rendered in image data portion 630 of display view 630.

In various embodiments, horizontal FOV 638 may be determined based on physical characteristics of a corresponding imaging device (e.g., imaging modules 223 and/or 224 of Fig. 2), such as its optical angular FOV, its optical magnification or zoom level, and/or other physical characteristics of the imaging device. In some embodiments, the imaging device may include an IPOS (IPOS 225 of Fig. 2) and/or other sensors configured to provide a position and/or orientation of the imaging device, thereby providing the FOV bearing/heading. In other embodiments, the imaging device may be mounted to mobile structure 101 so as to align its FOV bearing with a known bearing (e.g., 0, 90, 180, and/or 270 degrees, and/or 45 degree increments from those) relative to a heading of mobile structure 101, such that the FOV heading of the imaging device may be derived from the heading of mobile structure 101.

In further embodiments, horizontal FOV 638 may be selected to match a known or desired horizontal FOV (e.g., FOV bearing/heading, azimuthal width, azimuth extents), for example, such as a horizontal FOV corresponding to a preselected radar data azimuthal width (e.g., a range of azimuth angles producing radar data with relatively low detected noise, or a radar data azimuthal width selected to cover a particular target or bearing/heading), a desired FOV heading/bearing, a desired magnification level or resolution of image data 632, and/or other known or desired FOVs or FOV characteristics. For example, the imaging device used to capture image data 632 may be coupled to mobile structure 101 with an actuated mount (e.g., other modules 180), for example, and be controlled to align its FOV bearing/heading substantially with or at least covering a selected known or desired FOV bearing/heading.

As shown in the embodiment illustrated by Fig. 6, display view 600, radar data portion 610, and/or image data portion 630 may also include one or more identified object indicators 628, EHLs 626 and/or 636, information dialogs 642, and/or other graphical overlays. For example, identified object indicator 628, corresponding to identified ship 644 in image data 632, may be configured to indicate a heading, range, bearing, position, identification status, name, and/or other object characteristics graphically within display view 600. EHLs 626 and 636 may be configured to indicate the heading of mobile structure 101 as represented within radar data 612 and image data 632, respectively, to help provide context for the visually correlated radar and image data. Information dialogs 642 (e.g., textual or graphic dialogs, which may include one or more linking structures identifying an object to which it pertains), may be configured to provide one or more object characteristics as text or symbols associated with particular detected/image objects within display view 600.

Fig. 7 shows display view 700 including radar data portion 610 rendered above image data portion 630, similar to display view 600 of Fig. 6. Display view 700 also includes EBL 750 and EBL selector 752 rendered substantially over radar data portion 610, and EBL indicator 754, EBL 756, and EBL selector 752 rendered substantially over image data portion 630, all as graphical overlays of display view 700. EBLs 750 and 756 may be configured to indicate a common selected bearing/heading relative to mobile structure 101 as represented within radar data 612 and image data 632, respectively, to help provide context for the visually correlated radar and image data, to facilitate object identification within the visually correlated radar and image data, and/or to facilitate determining a safe, direct, and/or general bearing/heading to a detected/imaged object within the visually correlated radar and image data. In some embodiments, 756 may be rendered to extend out and approximately intersect waterline 205, which may be detected within image data 632 using methods described herein. EBL selectors 752 and 758 may correspond to user selectable graphical buttons (e.g., through use of one or more of a touch screen display, mouse, joystick, button, or other element of user interface 120 and/or portable imaging device 220) configured to adjust (e.g., increment and/or decrement) the common selected bearing/heading indicated by EBLs 750 and 756, so as to align with a desired detected/imaged object or bearing/heading. EBL indicator 754 may be configured to indicate a selected bearing/heading as text.

Figs. 8A-B show display views 800A and 800B including radar data portion 610 rendered below image data portion 630. As shown in Figs. 8A-B, radar data portion 610 includes radar data 612 with radar returns 614 presented in a PPI display format, as described herein. In some embodiments, display views 800A or 800B, radar data portion 610, and/or image data portion 630 may also include one or more of range guidelines 618, EHL 636, mobile structure graphic 801, port FOV extent indicator 860, starboard FOV extent indicator 862, and EBLs 850 and 858a/858b, rendered as graphical overlays in display views 800A and/or 800B to help provide context for the visually correlated radar and image data rendered in display views 800A and/or 800B.

Mobile structure graphic 801 may be configured to indicate a heading, bearing, position, identification status, name, and/or other object characteristics of mobile structure 101 graphically within display views 800A and/or 800B. Port FOV extent indicator 860 may be configured to indicate an azimuth angle within radar data 612 corresponding roughly to port FOV extent 864 of image data 632 rendered in image data portion 630 of display views 800A and/or 800B. Starboard FOV extent indicator 862 may be configured to indicate an azimuth angle within radar data 612 corresponding roughly to starboard FOV extent 866 of image data 632 rendered in image data portion 630 of display views 800A and/or 800B.

FOV extents 864 and 866 are shown in display view 800A as substantially vertical extents; however, in other embodiments, such as that shown in display view 800B, FOV extents 864 and 866 may each include a perspective or water surface portion below waterline 205 and a vertical portion above waterline 205, similar to water surface EBL 858a and vertical EBL 858b. More generally, FOV extent indicators 860 and 862 may be configured to indicate the approximate azimuth angles corresponding to respective intersections of FOV extents 864 and 866 with waterline 205 (e.g., which may be detected within image data 632 using any of the methods described herein). As shown by display views 800A and/or 800B, when rendered within a particular display view, image data 632 may or may not be cropped according to FOV extents 864 and 866 and/or FOV extent indicators 860 and 862.

In some embodiments, EBLs 850 and 858a/858b may be configured to indicate a common selected bearing/heading within radar data 612 and image data 632, respectively, to help provide context for the visually correlated radar and image data, to facilitate object identification within the visually correlated radar and image data, and/or to facilitate determining a safe, direct, and/or general bearing/heading to a detected/imaged object within the visually correlated radar and image data, similar to EBLs 750 and 756 of Fig. 7. In other embodiments, EBLs 850 and 858a/858b may be configured to indicate a common radar beam bearing/heading within radar data 612 and image data 632, respectively, to help provide context for updates to the visually correlated radar data.

As shown in display views 800A and/or 800B, water surface EBL 858a may be configured to indicate a perspective view of a selected bearing/heading as if projected onto water surface 205c below waterline 205, and vertical EBL 858b may be configured to indicate the selected bearing/heading intersection with an estimated horizon roughly corresponding to waterline 205. For example, vertical EBL 858b may be used to help select an approximate bearing/heading corresponding to an elevated object or position, such as a land feature or structure disposed above waterline 205. In various embodiments, any of EBL 850, water surface EBL 858a, and/or vertical EBL 858b may be implemented as an EBL selector configured to be selected and/or adjusted by user input provided to a user interface (e.g., a touch screen display) similar in function to EBL selectors 752 and/or 758 in display view 700 of Fig 7.

In the embodiments shown in Figs. 8A-B, radar data portion 610 and image data portion 630 are shown scaled, without distortion between their vertical and horizontal axes, to match port/starboard FOV extent indicators 860/862 with port/starboard FOV extents 864/866, and to fit within display views 800A and/or 800B. In other embodiments, the size, shape, cropping, and/or vertical or horizontal scaling of radar data portion 610 and image data portion 630 may be adjusted and/or distorted to increase and/or maximize the width of image data portion 630, as rendered in display views 800A and/or 800B, for example, and/or to increase and/or maximize the area of display views 800A and/or 800B used to render the portion of radar data 612 between port FOV extent indicator 860 and starboard FOV extent indicator 862, yet substantially retain a PPI display format for radar data 612.

Fig. 9 illustrates a flow diagram of process 900 to provide visually correlated radar data in accordance with embodiments of the disclosure. In some embodiments, the operations of Fig. 9 may be implemented as software instructions executed by one or more logic devices associated with corresponding electronic devices, sensors, and/or structures depicted in Figs. 1A through 4. More generally, the operations of Fig. 9 may be implemented with any combination of software instructions and/or electronic hardware (e.g., inductors, capacitors, amplifiers, actuators, or other analog and/or digital components).

It should be appreciated that any step, sub-step, sub-process, or block of process 900 may be performed in an order or arrangement different from the embodiments illustrated by Fig. 9. For example, in other embodiments, one or more blocks may be omitted from or added to the process. Furthermore, block inputs, block outputs, various sensor signals, sensor information, calibration parameters, and/or other operational parameters may be stored to one or more memories prior to moving to a following portion of a corresponding process. Although process 900 is described with reference to systems described in reference to Figs. 1A-4 and display views described in reference to Figs. 6-8, process 900 may be performed by other systems different from those systems and including a different selection of electronic devices, sensors, assemblies, mobile structures, and/or mobile structure attributes, in addition to different display views and/or display technologies.

Process 900 represents a method for providing visually correlated radar data and/or imagery using systems 100, 100B, 220, and/or 420 in accordance with embodiments of the disclosure. At the initiation of process 900, various system parameters may be populated by prior execution of a process similar to process 900, for example, or may be initialized to zero and/or one or more values corresponding to typical, stored, and/or learned values derived from past operation of process 900, as described herein.

In block 902, a logic device receives radar data from a radar system. For example, controller 130 of systems 100 or 100B and/or controller 221 of portable imaging device 220 may be configured to receive radar data from radar system 182. In some embodiments the controller may be configured to control or adjust one or more of a sweep rate, a sweep elevation, a sweep azimuthal width, a transmission power, a reception amplification, an aperture or beam height, width, and/or shape, and/or other operating parameters of radar system 182, so as to focus operation of radar system 182 on a particular horizontal FOV or to acquire substantially real time radar data, for example, prior to receiving the radar data. For instance, the controller may be configured to receive such operating parameters and/or other control data as user input provided to user interface 120. In other embodiments, the controller may be configured to receive position and/or orientation data (e.g., from a radar position and/or orientation sensor or RPOS) corresponding to a position and/or orientation of radar system 182, and/or other control parameters, along with the radar data. Upon receipt of such radar data, controller 130 of systems 100 or 100B and/or controller 221 of portable imaging device 220 may be configured to organize and/or render the radar data according to a specified display format, such as b-scan or PPI.

In block 904, a logic device receives image data from an imaging device. For example, controller 130 of systems 100 or 100B and/or controller 221 of portable imaging device 220 may be configured to receive image data from visible spectrum imaging module 223 and/or infrared imaging module 224 of portable imaging device 220. In some embodiments the controller may be configured to control or adjust one or more of a FOV bearing/heading, magnification level, resolution, and/or other operating parameters of the imaging device, so as to focus operation of the imaging device on a particular horizontal FOV or to acquire substantially real time image data, for example, prior to receiving the image data. For instance, the controller may be configured to receive such operating parameters and/or other control data as user input provided to user interface 120. In other embodiments, the controller may be configured to receive position and/or orientation data (e.g., from an IPOS) corresponding to a position and/or orientation of the imaging system, and/or other control parameters, along with the radar data.

In some embodiments, the imaging device may include a visible spectrum image module and an infrared image module, and the controller may be configured to generate combined image data including visible spectrum image data and infrared image data provided by the imaging device. The controller may be configured to combine the visible spectrum image data with infrared image data according to a variety of techniques, including blending, color mapping, combining high frequency content from one image with the other image, and/or other image combining techniques. Upon receipt of image data and/or combined image data, controller 130 of systems 100 or 100B and/or controller 221 of portable imaging device 220 may be configured to crop, rotate, horizontally stabilize, and/or otherwise process the image data prior to moving to block 906.

In block 906, a logic device determines a horizontal FOV corresponding to image data. For example, controller 130 of systems 100 or 100B and/or controller 221 of portable imaging device 220 may be configured to determine a horizontal FOV corresponding to the image data received in block 904. In some embodiments the controller may be configured to determine the horizontal FOV based, at least in part, on an optical angular FOV of the imaging device and/or an optical magnification level of the imaging device. For example, the optical angular FOV and/or magnification level of the imaging device may be known and/or set by a manufacturer and/or by a particular arrangement of lenses, apertures, and sensors of the imaging device. The optical angular FOV and/or magnification level may also be selected using various optical adjustment mechanisms of the imaging device, such as by user input provided to user interface 120.

In embodiments where the imaging device includes an IPOS, the controller may be configured to determine the horizontal FOV based, at least in part, on position data and/or orientation data provided by the IPOS. For example, the controller may be configured to determine an FOV bearing/heading based on the position data and/or orientation data provided by the IPOS. With a known or selected optical angular FOV, magnification level, cropping limits, and/or other image data parameters, the FOV bearing/heading fully characterizes the horizontal FOV of the image data. In other embodiments, the imaging device may be mounted to mobile structure 101 so as to align its FOV bearing (e.g., which may correspond to the FOV bearing of the horizontal FOV) with a known bearing relative to a heading of mobile structure 101, such that the FOV heading of the imaging device may be derived from the heading of mobile structure 101, for example.

In alternative embodiments, the controller may be configured to determine the horizontal FOV by receiving user input selecting the horizontal FOV to substantially match a preselected radar data azimuthal width, a desired FOV heading or bearing, a desired magnification level for the imaging device, and/or a desired resolution of the eventual rendered image data, for example.

In block 908, a logic device renders visually correlated image data and radar data based on a horizontal FOV. For example, controller 130 of systems 100 or 100B and/or controller 221 of portable imaging device 220 may be configured to render at least a portion of the radar data received in block 902 and at least a portion of the image data received in block 904, such that the rendered radar data is visually correlated to the rendered image data based, at least in part, on the horizontal FOV determined in block 906. In various embodiments, the radar data may be rendered vertically above or below the rendered image data on a display of user interface 120, display 226 of portable imaging device/user interface 220, and/or displays 426 of portable imaging device/user interface 420, for example, as described herein.

In some embodiments the controller may be configured to render the radar data according to a b-scan display format vertically above or below the rendered image data, wherein an image width of the rendered image data substantially matches an azimuthal width of the rendered radar data, as described herein. In other embodiments, the controller may be configured to render the radar data according to a PPI display format vertically above or below the rendered image data. In such embodiments, the controller may be configured to render port and starboard FOV extent indicators over the rendered radar data, wherein the port and starboard FOV extent indicators are configured to indicate respective port and starboard FOV extents of the determined horizontal FOV, as described herein.

In various embodiments, the controller may be configured to render a first EBL over the rendered image data and a second EBL over the rendered radar data. For example, the first and second EBLs may be configured to indicate a common bearing or heading relative to mobile structure 101 as represented within the rendered radar data and the rendered image data. The controller may also be configured to render one or more EBL selectors over the rendered radar data and/or the rendered image data. For example, the EBL selector may include one or more user selectable graphical buttons configured to adjust the common bearing or heading indicated by the first and second EBLs. In some embodiments, the controller may also be configured to render one or more EHLs over the rendered image data and the rendered radar data. For example, the one or more EHLs may be configured to indicate a heading of mobile structure 101 as represented within the rendered radar data and the rendered image data, as described herein.

The controller may additionally be configured to render various graphical overlays over the rendered radar data and/or the rendered image data, for example, to provide various characteristics of detected and/or identified objects to a user. In some embodiments, the imaging device includes the display and may be a portable imaging device adapted to be held or worn by a user while the user views the display, such as while viewing an augmented reality version of the visually correlated radar and image data.

In further embodiments, image data, position data, orientation data, radar data, and/or other sensor data acquired and/or processed in blocks 902-908 may be used to control operation of mobile structure 101, such as by controlling steering sensor/actuator 150 and/or propulsion system 170 to steer mobile structure 101 according to a desired bearing, for example, and/or according to positions of one or more visualized or detected/identified objects (e.g., including various types of partially submerged objects), as described herein.

It is contemplated that any one or combination of methods to provide visually correlated radar data imagery may be performed according to one or more operating contexts of a control loop, for example, such as a startup, learning, running, and/or other type operating context. For example, process 900 may proceed back to block 902 and proceed through process 900 again to produce updated or alternative visually correlated radar data imagery, as in a control loop.

Embodiments of the present disclosure can thus provide visually correlated radar data imagery. Such embodiments may be used to provide visually correlated radar data imagery to a user of a mobile structure, such as a watercraft, to assist in navigation, for example, and/or to assist in the operation of other systems, devices, and/or sensors coupled to the mobile structure.

Where applicable, various embodiments provided by the present disclosure can be implemented using hardware, software, or combinations of hardware and software. Also where applicable, the various hardware components and/or software components set forth herein can be combined into composite components comprising software, hardware, and/or both without departing from the spirit of the present disclosure. Where applicable, the various hardware components and/or software components set forth herein can be separated into sub-components comprising software, hardware, or both without departing from the spirit of the present disclosure. In addition, where applicable, it is contemplated that software components can be implemented as hardware components, and vice-versa.

Software in accordance with the present disclosure, such as non-transitory instructions, program code, and/or data, can be stored on one or more non-transitory machine readable mediums. It is also contemplated that software identified herein can be implemented using one or more general purpose or specific purpose computers and/or computer systems, networked and/or otherwise. Where applicable, the ordering of various steps described herein can be changed, combined into composite steps, and/or separated into sub-steps to provide features described herein.

Embodiments described above illustrate but do not limit the invention. It should also be understood that numerous modifications and variations are possible in accordance with the principles of the invention. Accordingly, the scope of the invention is defined only by the following claims.

CLAIMS

What is claimed is:

1. A system comprising:

a logic device configured to communicate with a radar system adapted to be mounted to a mobile structure and with an imaging device configured to image a scene about the mobile structure, wherein the logic device is configured to:

receive radar data from the radar system and image data captured by the imaging device;

determine a horizontal field of view (FOV) corresponding to the image data; and

render the image data and radar data, wherein the radar data is rendered vertically above or below the rendered image data, and wherein the rendered radar data is visually correlated to the rendered image data based, at least in part, on the determined horizontal FOV.

2. The system of claim 1, wherein the determining the horizontal FOV comprises:

determining the horizontal FOV based, at least in part, on an optical angular FOV of the imaging device and/or an optical magnification level of the imaging device.

3. The system of claim 1, wherein the determining the horizontal FOV comprises:

receiving user input selecting the horizontal FOV to substantially match a preselected radar data azimuthal width, a desired FOV heading or bearing, a desired magnification level for the imaging device, and/or a desired resolution of the rendered image data.

4. The system of claim 1, wherein the rendering the image data and radar data comprises:

rendering the radar data according to a b-scan display format vertically above the rendered image data, wherein an image width of the rendered image data substantially matches an azimuthal width of the rendered radar data.

5. The system of claim 1, wherein the rendering the image data and radar data comprises:

rendering the radar data according to a plan position indicator display format vertically below the rendered image data; and

rendering port and starboard FOV extent indicators over the rendered radar data, wherein the port and starboard FOV extent indicators are configured to indicate respective port and starboard FOV extents of the determined horizontal FOV.

6. The system of claim 1, wherein the logic device is configured to:

render a first electronic bearing line (EBL) over the rendered image data and a second EBL over the rendered radar data, wherein the first and second EBLs are configured to indicate a common bearing or heading relative to the mobile structure as represented within the rendered radar data and the rendered image data;

render an EBL selector over the rendered radar data or the rendered image data, wherein the EBL selector comprises one or more user selectable graphical buttons configured to adjust the common bearing or heading indicated by the first and second EBLs.

7. The system of claim 1, wherein:

the imaging device comprises a visible spectrum image module and an infrared image module;

the logic device is configured to generate combined image data comprising visible spectrum image data and infrared image data provided by the imaging device; and

the rendered image data comprises the generated combined image data.

8. The system of claim 1, wherein the mobile structure comprises a watercraft, the system further comprising:

the radar system adapted to be mounted to the mobile structure; or

the imaging device configured to image the scene about the mobile structure.

9. The system of claim 1, wherein:

the imaging device comprises a portable imaging device comprising the display and an imager position and/or orientation sensor (IPOS); and

the logic device is configured to determine the horizontal FOV based, at least in part, on position data and/or orientation data provided by the IPOS.

10. The system of claim 9, wherein:

the portable imaging device is adapted to be held or worn by a user of the system while the user views the display.

11. A method comprising:

receiving radar data from a radar system adapted to be mounted to a mobile structure;

receiving image data captured by an imaging device configured to image a scene about the mobile structure;

determining a horizontal field of view (FOV) corresponding to the image data; and

rendering the image data and radar data, wherein the radar data is rendered vertically above or below the rendered image data, and wherein the rendered radar data is visually correlated to the rendered image data based, at least in part, on the determined horizontal FOV.

12. The method of claim 11, wherein the determining the horizontal FOV comprises:

determining the horizontal FOV based, at least in part, on an optical angular FOV of the imaging device and/or an optical magnification level of the imaging device.

13. The method of claim 11, wherein the determining the horizontal FOV comprises:

receiving user input selecting the horizontal FOV to substantially match a preselected radar data azimuthal width, a desired FOV heading or bearing, a desired magnification level for the imaging device, and/or a desired resolution of the rendered image data.

14. The method of claim 11, wherein the rendering the image data and radar data comprises:

rendering the radar data according to a b-scan display format vertically above the rendered image data, wherein an image width of the rendered image data substantially matches an azimuthal width of the rendered radar data.

15. The method of claim 11, wherein the rendering the image data and radar data comprises:

rendering the radar data according to a plan position indicator display format vertically below the rendered image data; and

rendering port and starboard FOV extent indicators over the rendered radar data, wherein the port and starboard FOV extent indicators are configured to indicate respective port and starboard FOV extents of the determined horizontal FOV.

16. The method of claim 11, further comprising:

rendering a first electronic bearing line (EBL) over the rendered image data and a second EBL over the rendered radar data, wherein the first and second EBLs are configured to indicate a common bearing or heading relative to the mobile structure as represented within the rendered radar data and the rendered image data;

rendering an EBL selector over the rendered radar data or the rendered image data, wherein the EBL selector comprises one or more user selectable graphical buttons configured to adjust the common bearing or heading indicated by the first and second EBLs.

17. The method of claim 11, wherein the imaging device comprises a visible spectrum image module and an infrared image module, the method further comprising:

generating combined image data comprising visible spectrum image data and infrared image data provided by the imaging device, wherein the rendered image data comprises the generated combined image data.

18. The method of claim 11, wherein the mobile structure comprises a watercraft, the method further comprising:

rendering a first electronic heading line (EHL) over the rendered image data and a second EHL over the rendered radar data, wherein the first and second EHLs are configured to indicate a heading of the mobile structure as represented within the rendered radar data and the rendered image data.

19. The method of claim 11, wherein the imaging device comprises a portable imaging device comprising the display and an imager position and/or orientation sensor (IPOS), the method further comprising:

determining the horizontal FOV based, at least in part, on position data and/or orientation data provided by the IPOS.

20. The method of claim 19, wherein:

the portable imaging device is adapted to be held or worn by a user of the system while the user views the display.

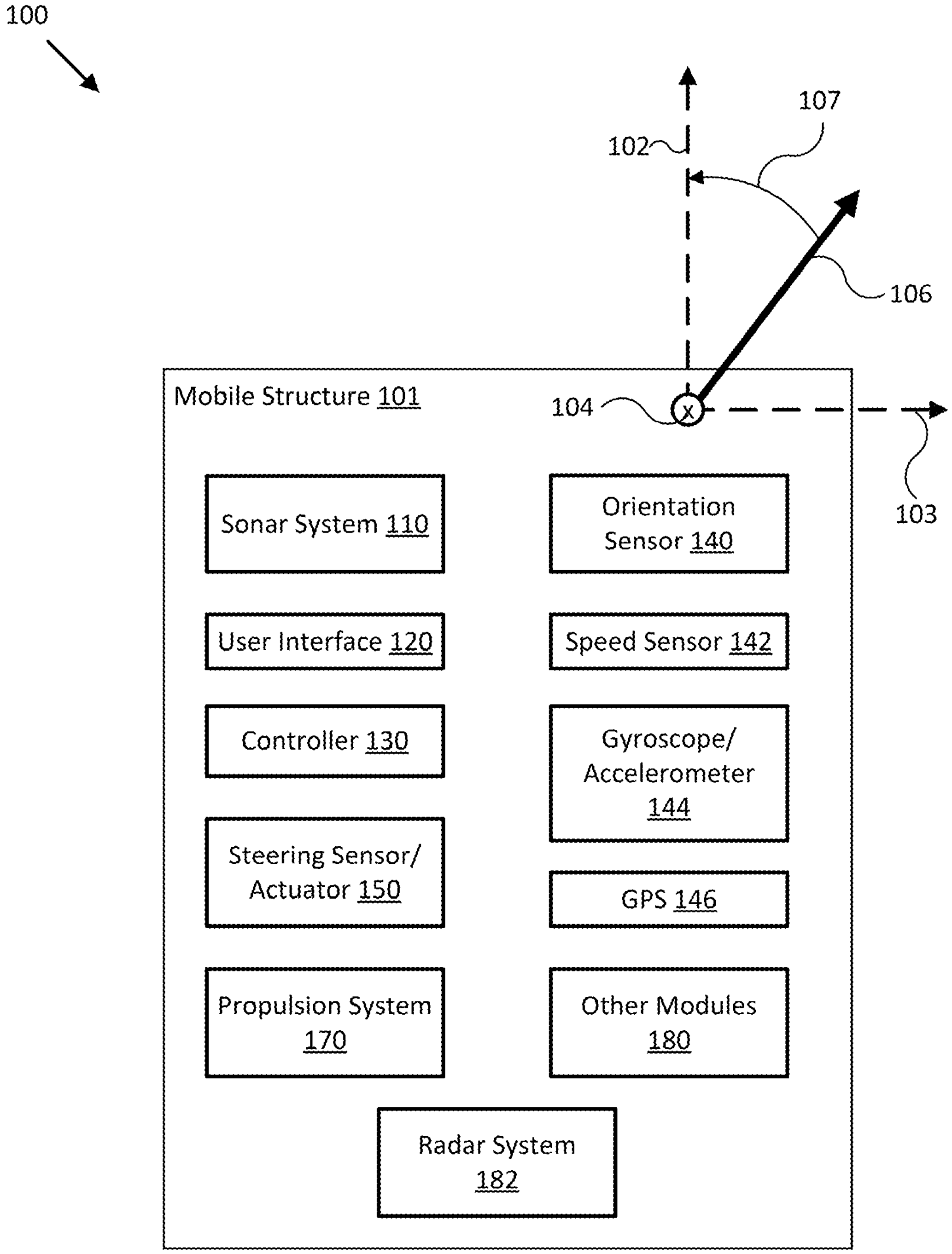

100
107
102
106
Mobile Structure 101
104
103
Sonar System 110
Orientation Sensor 140
User Interface 120
Speed Sensor 142
Controller 130
Gyroscope/ Accelerometer 144
Steering Sensor/ Actuator 150
GPS 146
Propulsion System 170
Other Modules 180
Radar System 182

FIG. 1A

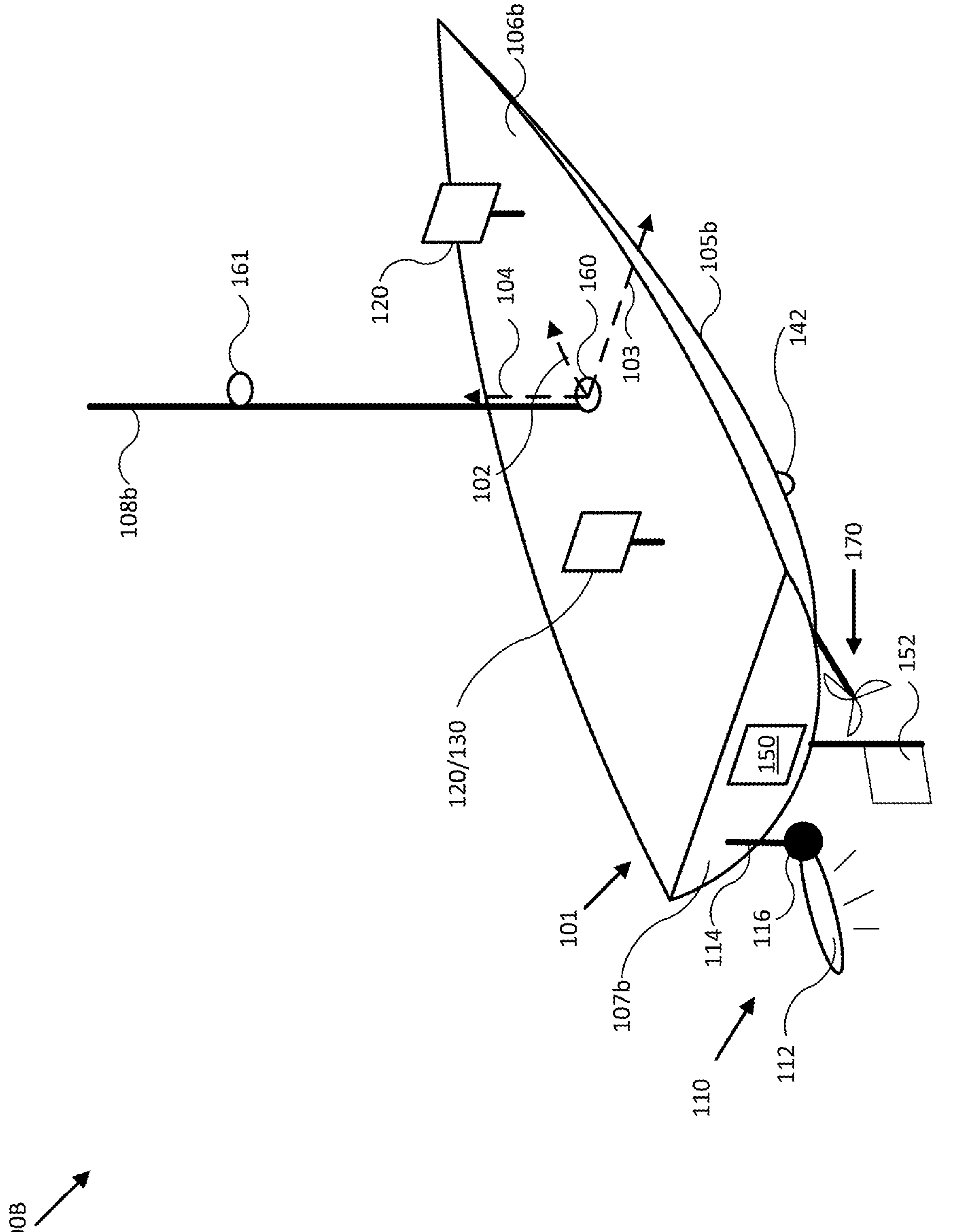

106b
120
161
104
160
105b
103
142
108b
102
170
152
120/130
150
101
114
116
107b
112
110
100B

FIG. 1B

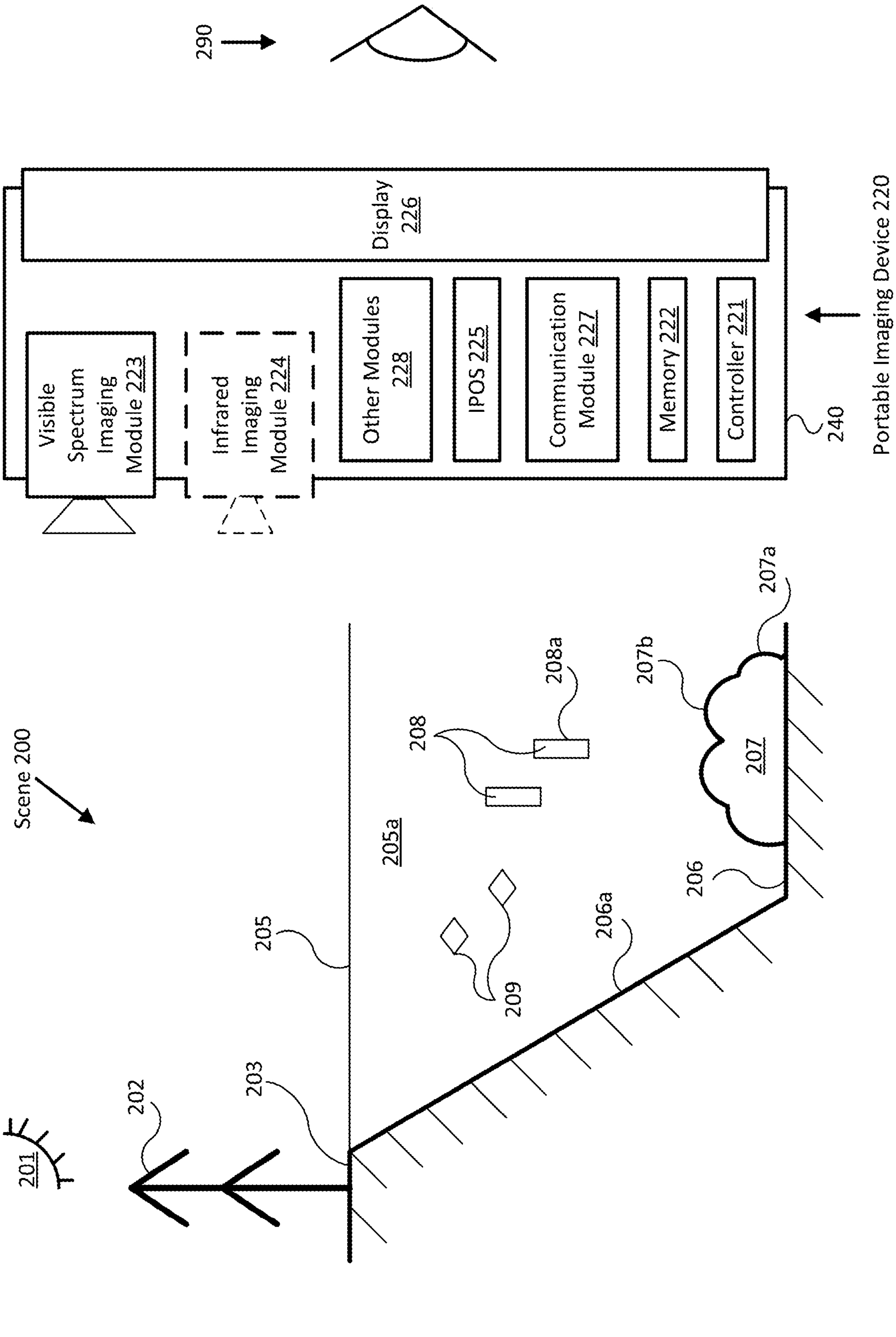
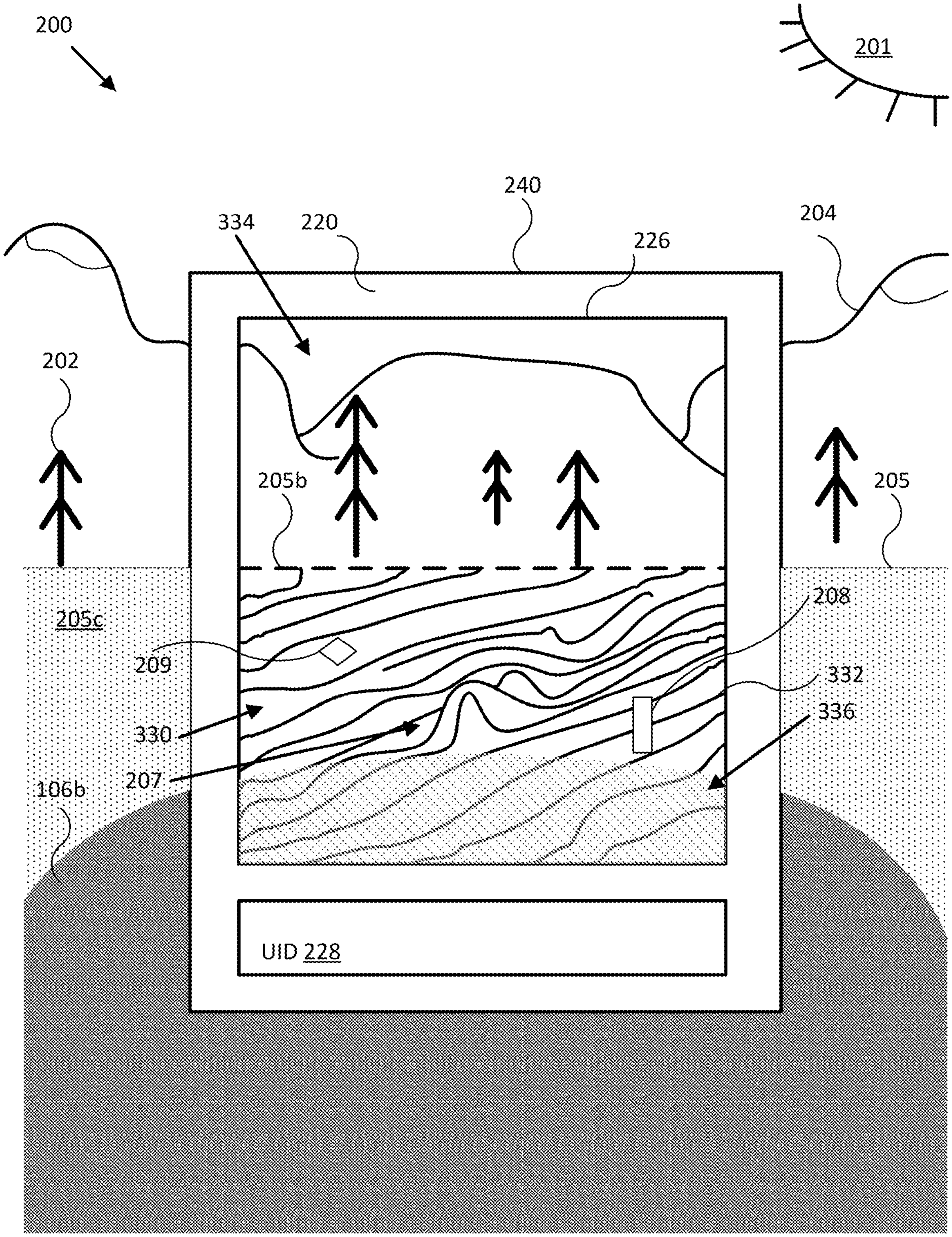

290
Display 226
Visible Spectrum Imaging Module 223
Infrared Imaging Module 224
Other Modules 228
IPOS 225
Communication Module 227
Memory 222
Controller 221
240
Portable Imaging Device 220
Scene 200
201
202
203
205
205a
206
206a
207
207a
207b
208
208a
209

FIG. 2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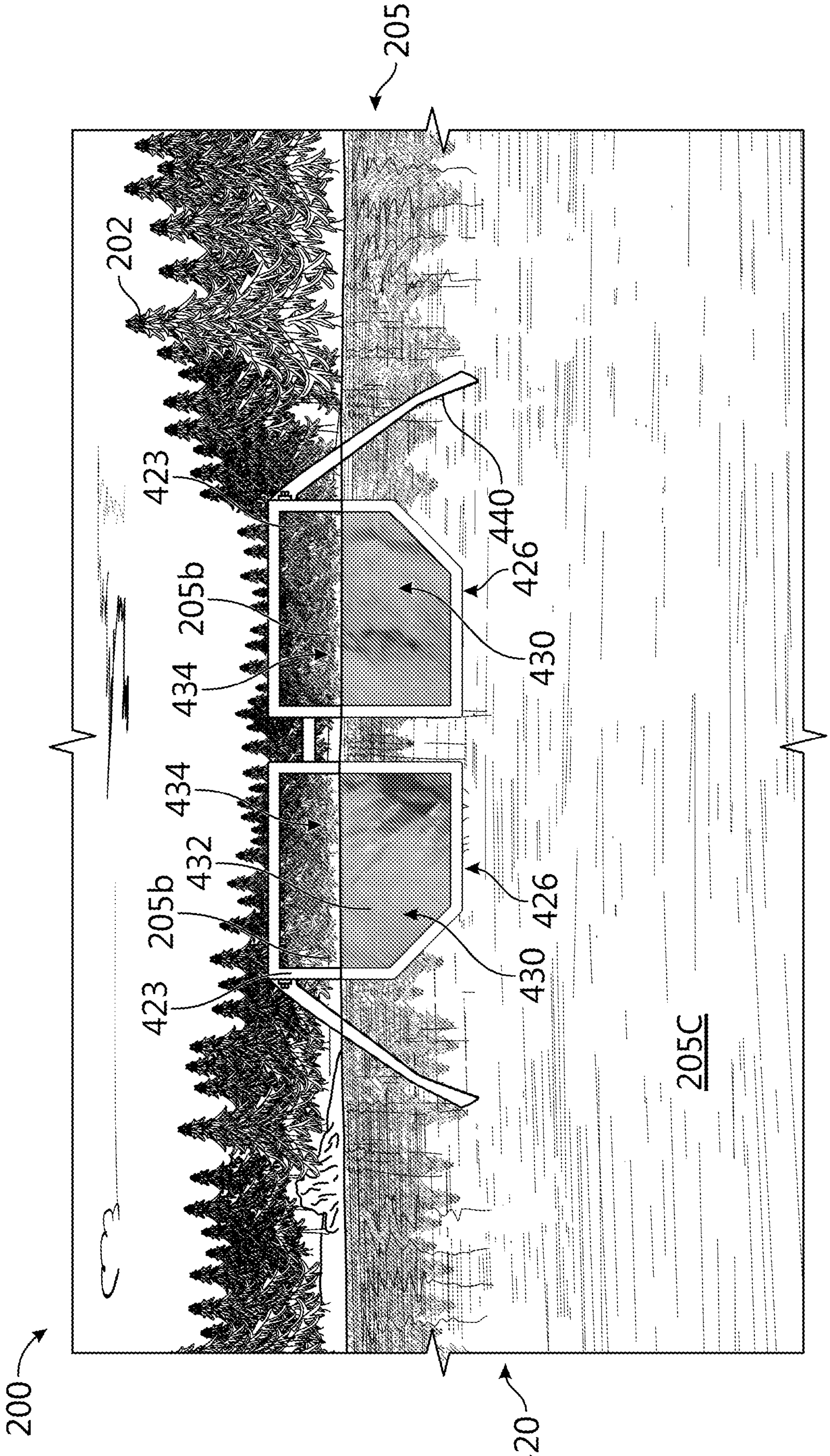
201
240
334
220
226
204
202
205b
205
205c
208
209
332
336
330
207
106b
UID 228

FIG. 3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202
423
205b
434
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426
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434
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205b
423
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205C
200
420

FIG. 4

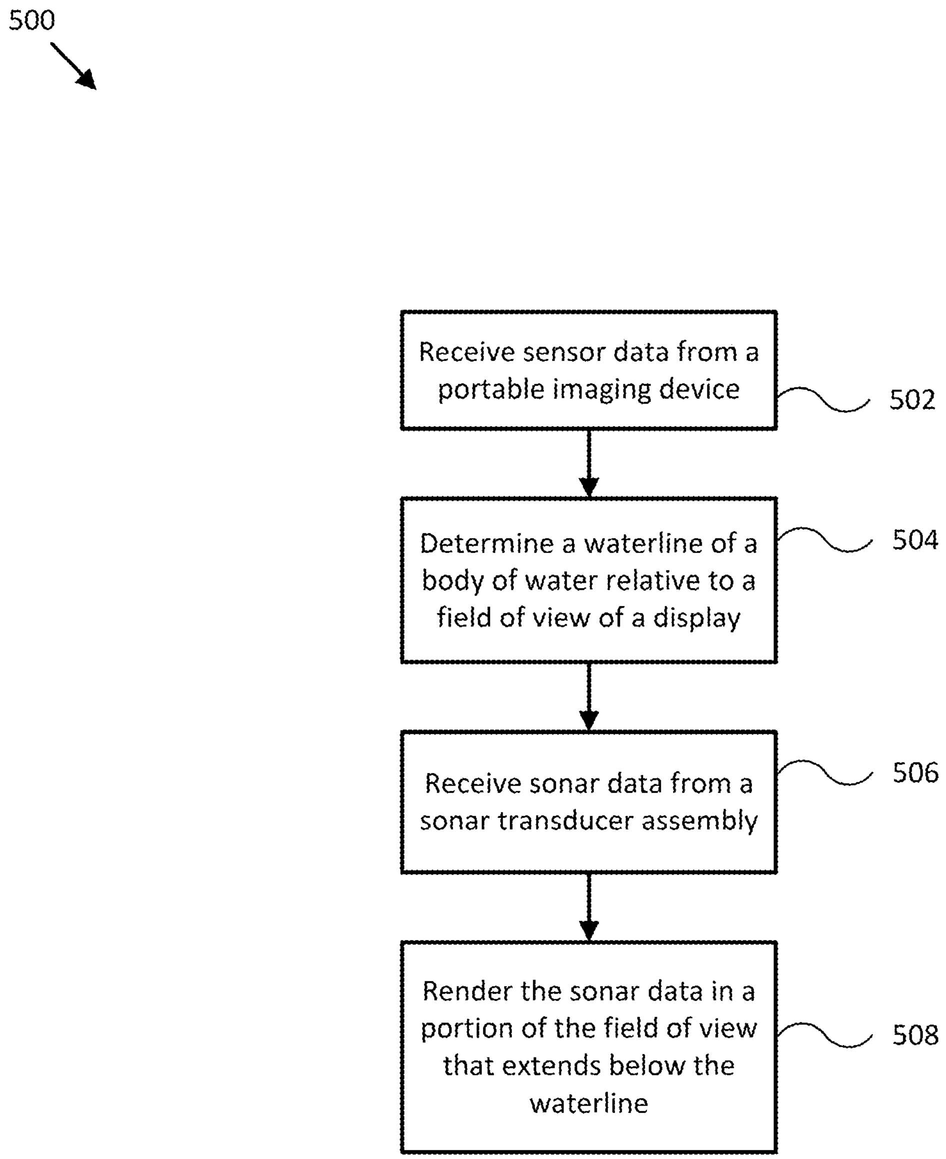
500
Receive sensor data from a portable imaging device
502
Determine a waterline of a body of water relative to a field of view of a display
504
Receive sonar data from a sonar transducer assembly
506
Render the sonar data in a portion of the field of view that extends below the waterline
508

FIG. 5

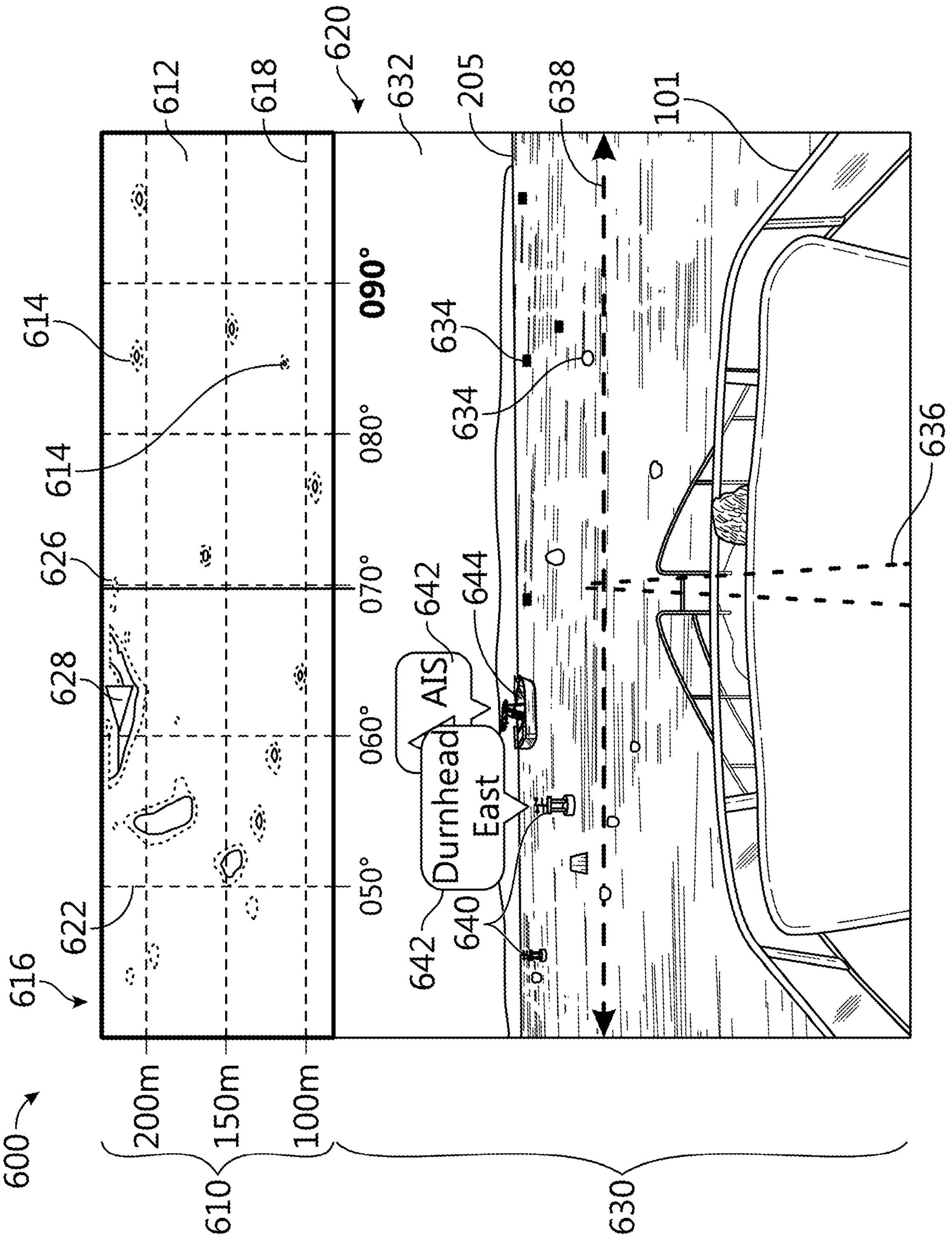
600
610
630
612
614
614
616
618
620
622
626
628
632
634
634
636
638
640
642
642
644
205
101
200m
150m
100m
050°
060°
070°
080°
090°
AIS
Durnhead East

FIG. 6

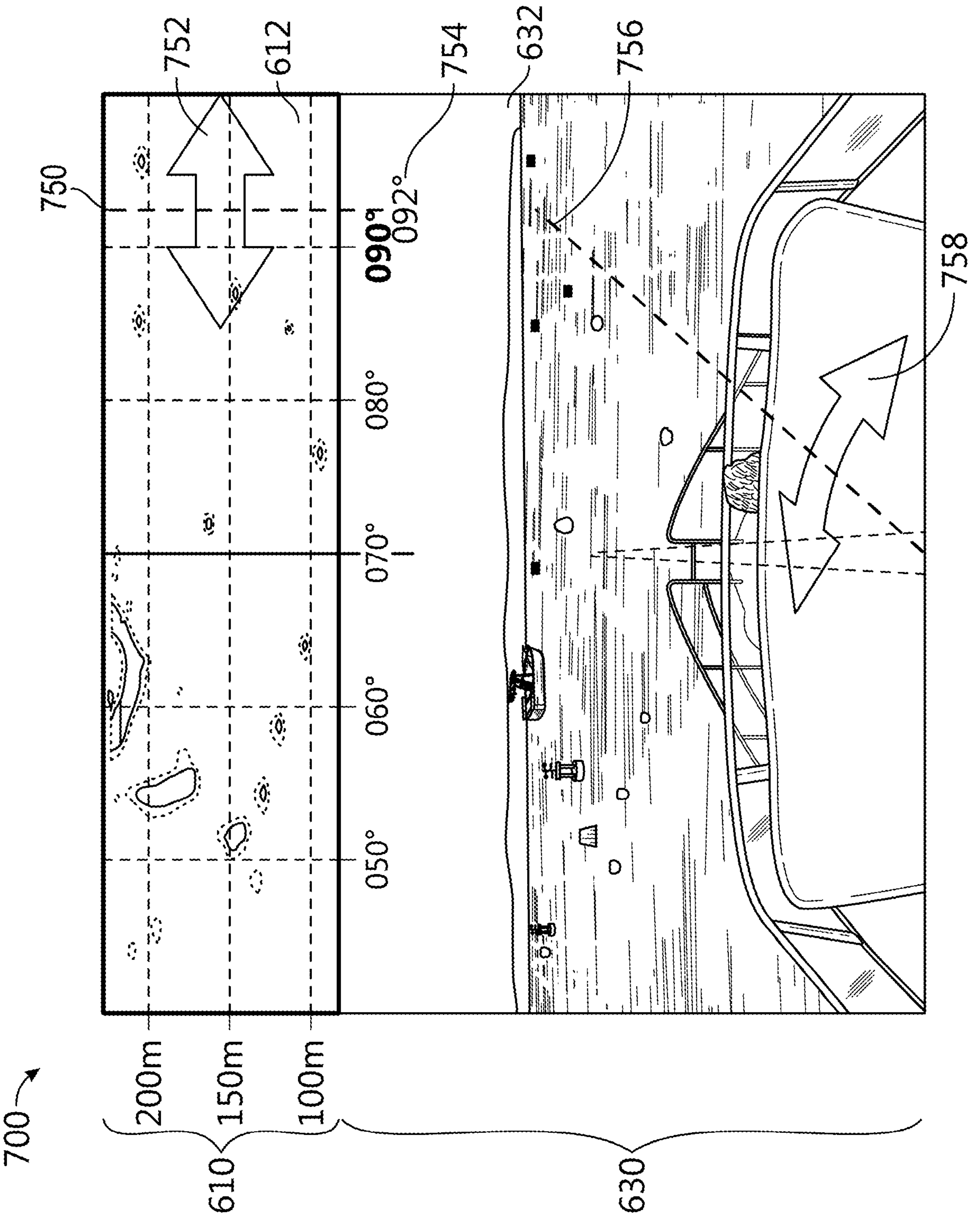
700
610
630
200m
150m
100m
050°
060°
070°
080°
090°
092°
750
752
612
754
632
756
758

FIG. 7

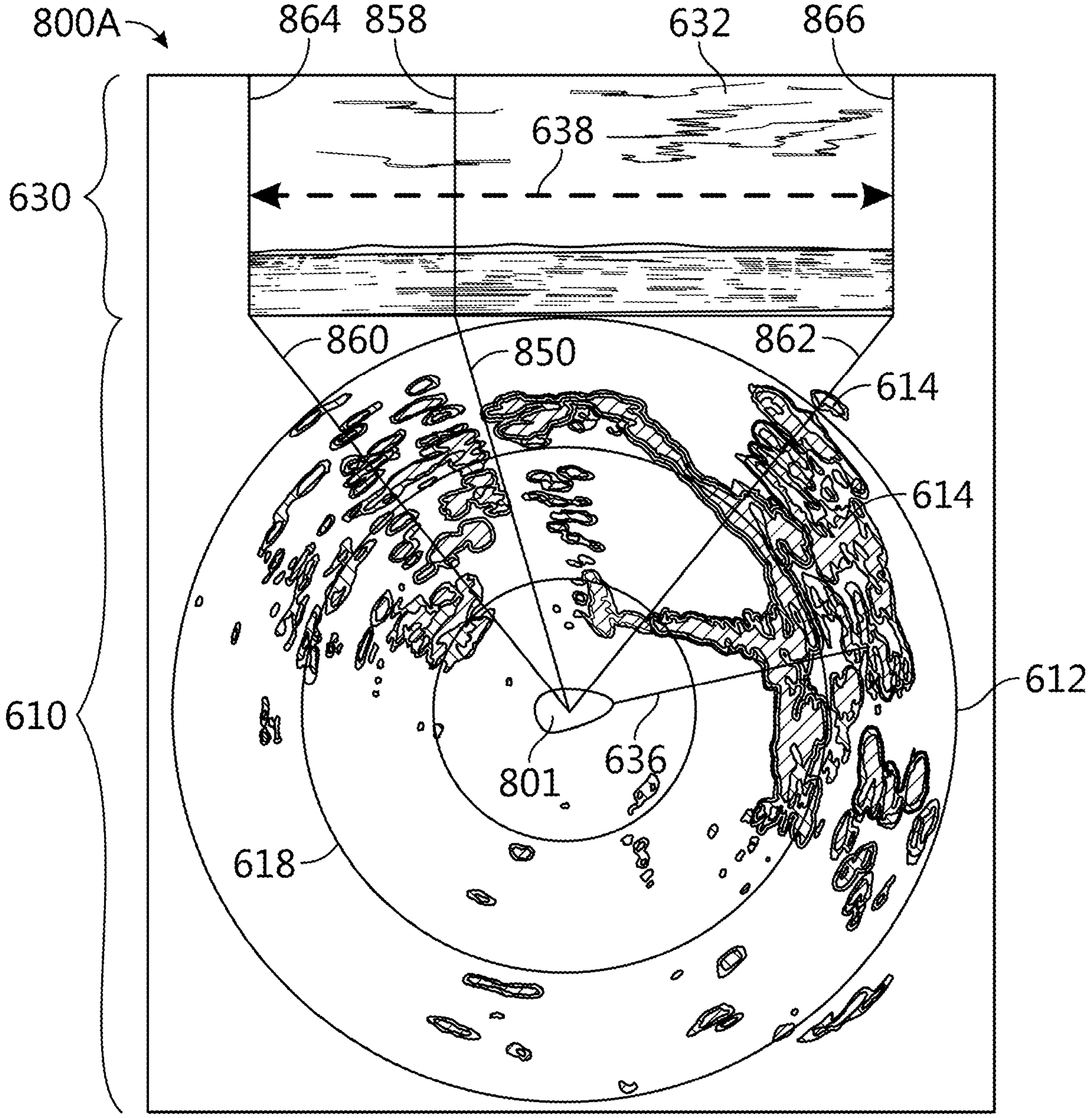
800A
864
858
632
866
638
630
860
850
862
614
614
612
610
801
636
618

FIG. 8A

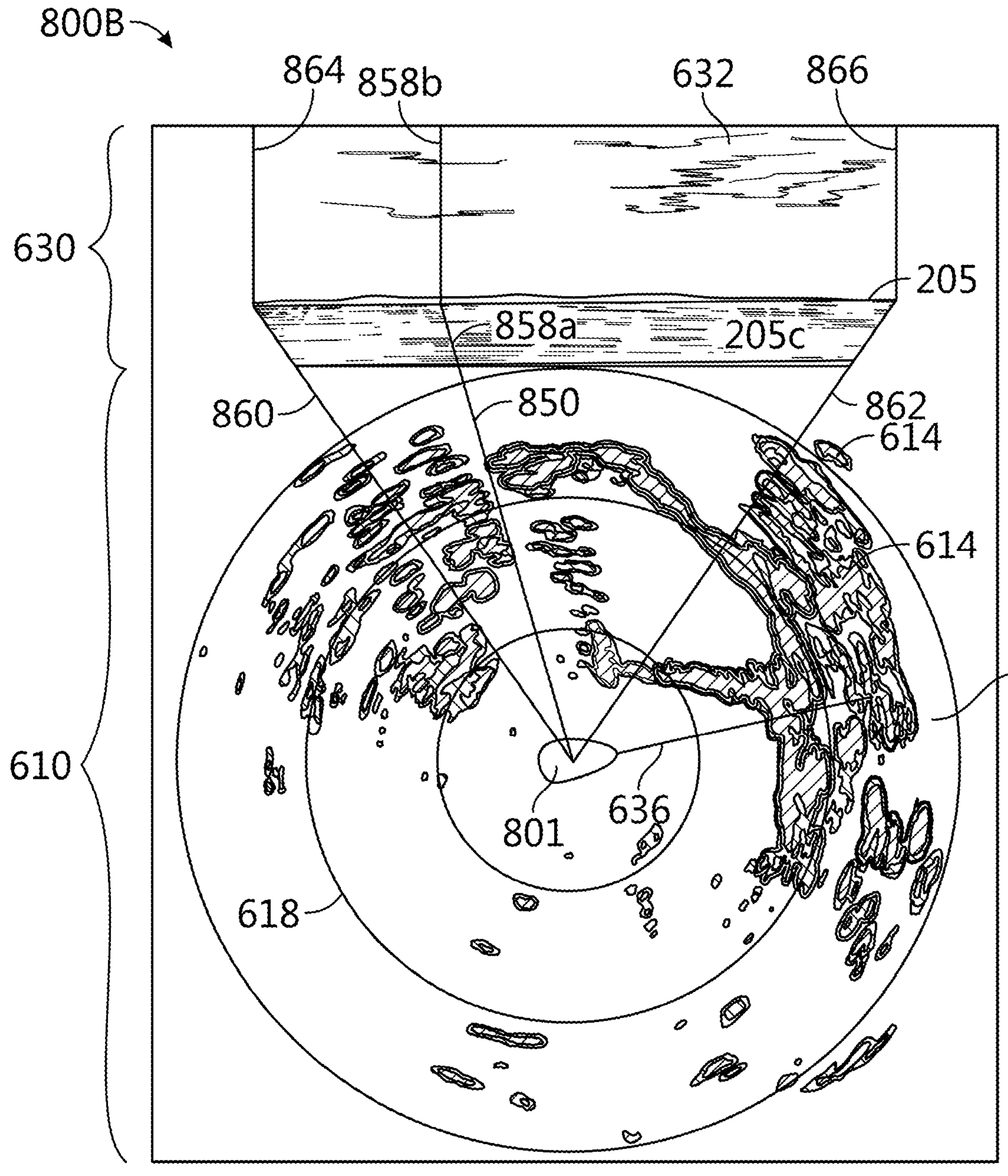
800B
864
858b
632
866
630
205
858a
205c
860
850
862
614
614
612
610
801
636
618

FIG. 8B

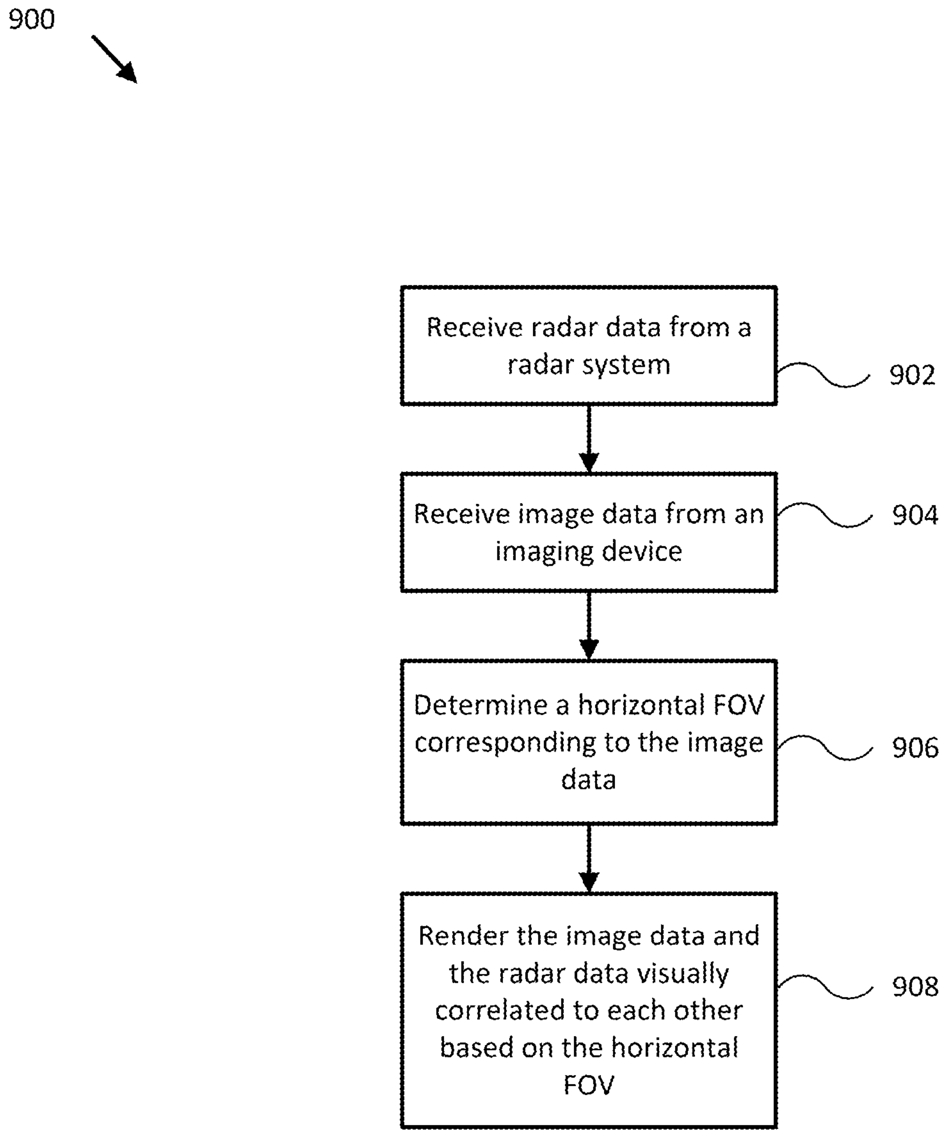
900
Receive radar data from a radar system
902
Receive image data from an imaging device
904
Determine a horizontal FOV corresponding to the image data
906
Render the image data and the radar data visually correlated to each other based on the horizontal FOV
908

FIG. 9

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2018/025297

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01S13/86 G01S7/12 B63B49/00 G01S7/16 G01S7/22
G01S7/24 G01S13/93
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01S B63B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2007 286725 A (IMAZU TOSHIMA; FURUNO ELECTRIC CO; JAPAN RADIO CO LTD; TOKIMEC INC; SH) 1 November 2007 (2007-11-01)	1-6,8, 11-16,18
Y	paragraph [0011] - paragraph [0013]	7,17
A	paragraph [0020] - paragraph [0022] figures 1, 2, 4-6 -----	9,10,19, 20
X	GB 2 428 151 A (FURUNO ELECTRIC IND COMPANY LT [JP]) 17 January 2007 (2007-01-17)	1-4,6,8, 11-14, 16,18
Y	page 1, line 1 - line 7	7,17
A	page 5, line 17 - line 21 page 7, line 6 - line 10 page 10, line 3 - page 13, line 1 figures 1, 2 -----	5,9,10, 15,19,20

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 June 2018	29/06/2018

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Köppe, Maro

1

Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2018/025297

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2015/126491 A1 (NICHOLS MARK EDWARD [NZ]; WALLACE GREGORY CRAIG [US]) 27 August 2015 (2015-08-27)	1-3, 9-13,19, 20
A	page 10, line 6 - line 26 page 13, line 1 - page 14, line 4 page 26, line 8 - line 25 figures 1B, 3-10	4-8, 14-18

Y	CN 104 215 963 A (INESA ELECTRON CO LTD) 17 December 2014 (2014-12-17)	7,17
A	figure 1	1-6, 8-16, 18-20

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2018/025297

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
JP 2007286725	A	01-11-2007	JP	4709684	B2	22-06-2011
			JP	2007286725	A	01-11-2007
GB 2428151	A	17-01-2007	GB	2428151	A	17-01-2007
			JP	4327000	B2	09-09-2009
			JP	2005289284	A	20-10-2005
			US	2009315756	A1	24-12-2009
			WO	2005095200	A1	13-10-2005
WO 2015126491	A1	27-08-2015	EP	3077845	A1	12-10-2016
			US	2016223647	A1	04-08-2016
			WO	2015126491	A1	27-08-2015
CN 104215963	A	17-12-2014	NONE			