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(54) **REAL-TIME WAVE MONITORING AND SENSING METHODS AND SYSTEMS**

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See (63) Related U.S. Application Data.

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(60) Provisional application No. 62/658,542, filed on Apr. 16, 2018.

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B63B 22/04	(2006.01)
B63B 21/24	(2006.01)
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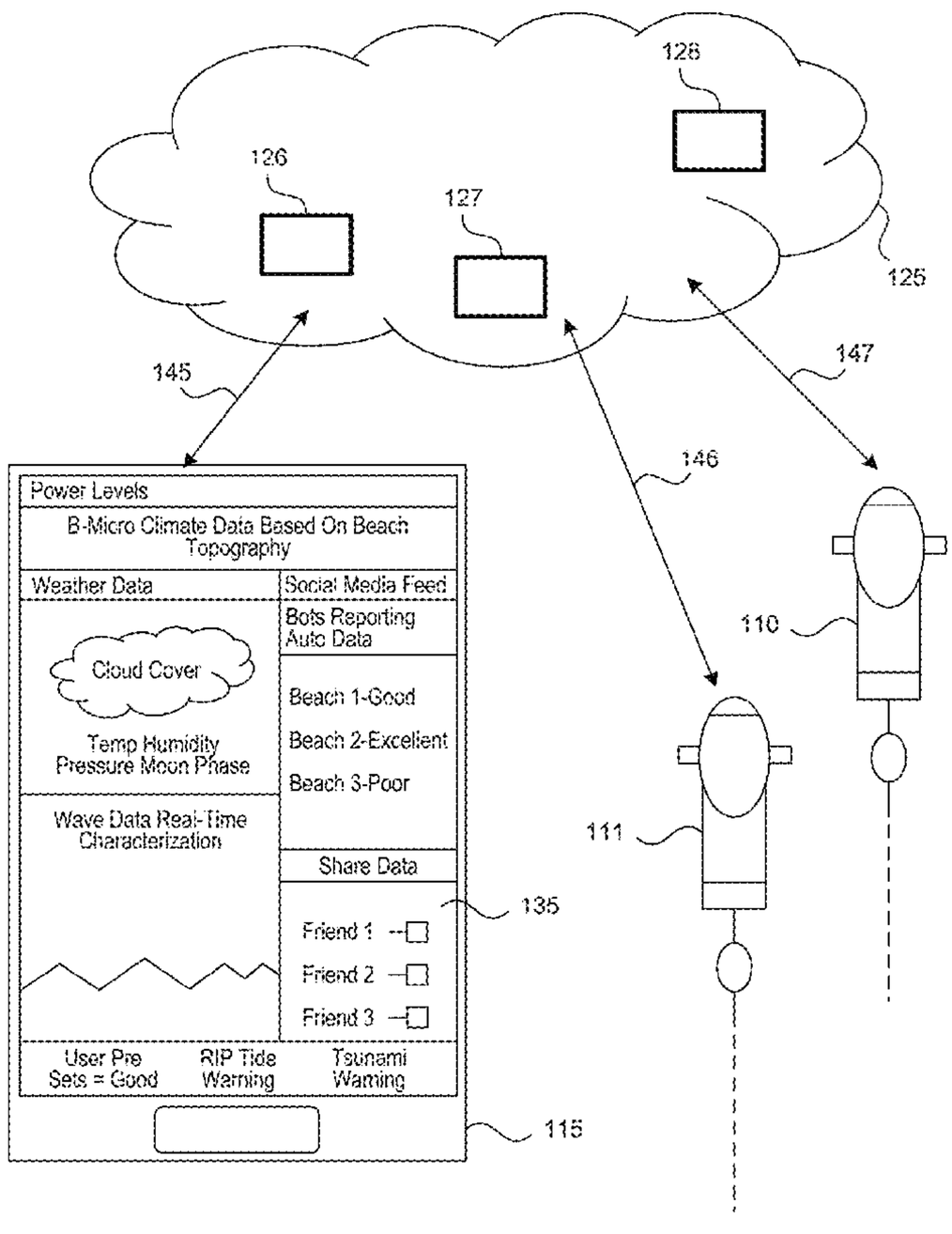
(57) **ABSTRACT**

Devices, systems and methods for real-time wave monitoring are described. One example system for real-time monitoring of wave conditions includes a plurality of buoys, wherein each of the plurality of buoys comprises a sensor array configured to continuously monitor one or more characteristics of the wave conditions, a transceiver configured to transmit, to a remote server, information corresponding to the one or more characteristics of the wave conditions over a wireless communication channel, and a tether that physically couples the buoy to an anchor, wherein the information from each of the plurality of buoys is combined with a user preference to provide a user with a message regarding the wave conditions in response to a user request, and wherein a duration between the user request and transmission of the information from each of the plurality of buoys is less than a predetermined value.



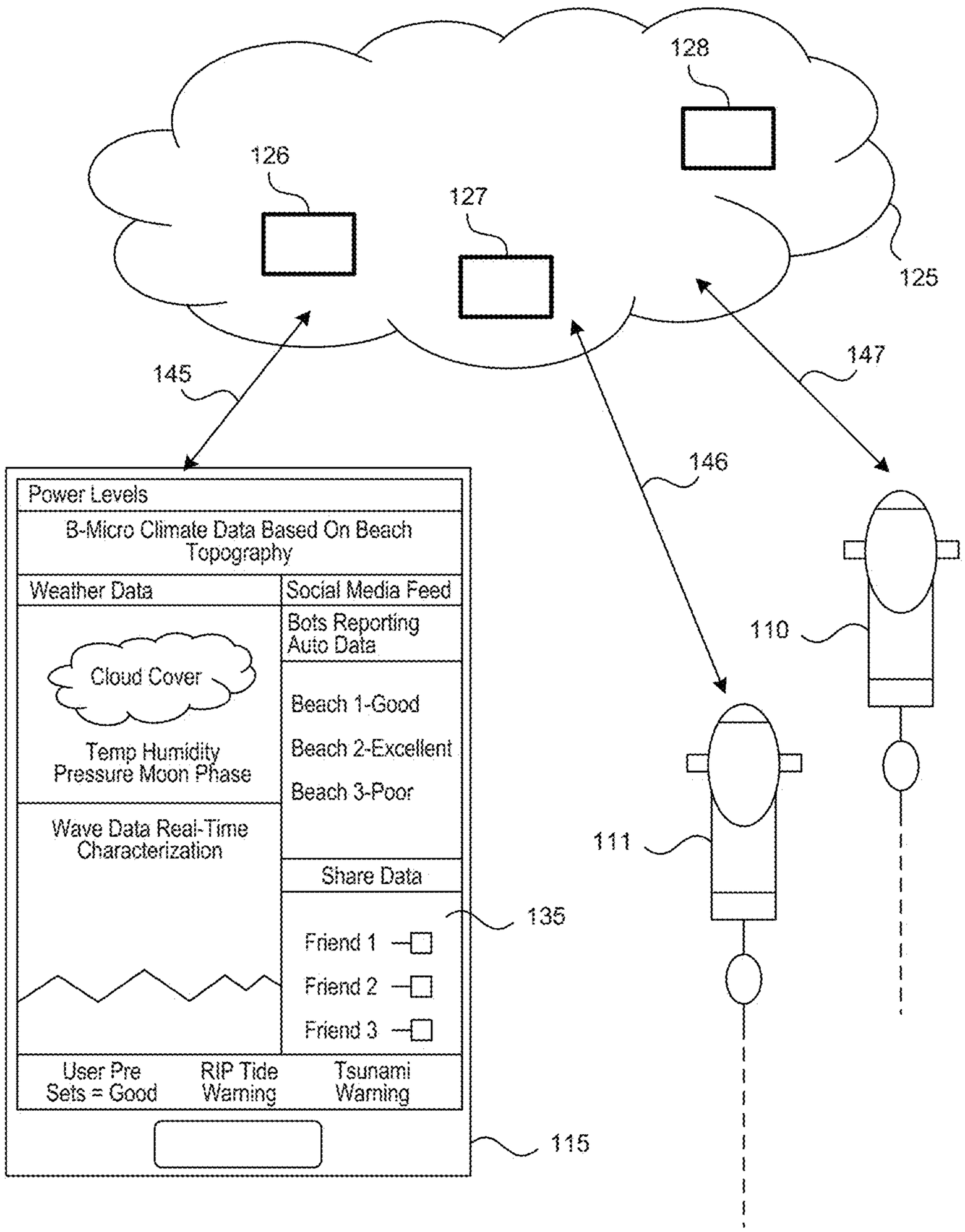

128
126
127
125
145
147
146
Power Levels
B-Micro Climate Data Based On Beach Topography
Weather Data
Social Media Feed
Bots Reporting Auto Data
Cloud Cover
Temp Humidity Pressure Moon Phase
Beach 1-Good
Beach 2-Excellent
Beach 3-Poor
Wave Data Real-Time Characterization
Share Data
135
Friend 1
Friend 2
Friend 3
User Pre Sets = Good
RIP Tide Warning
Tsunami Warning
115
110
111

FIG. 1

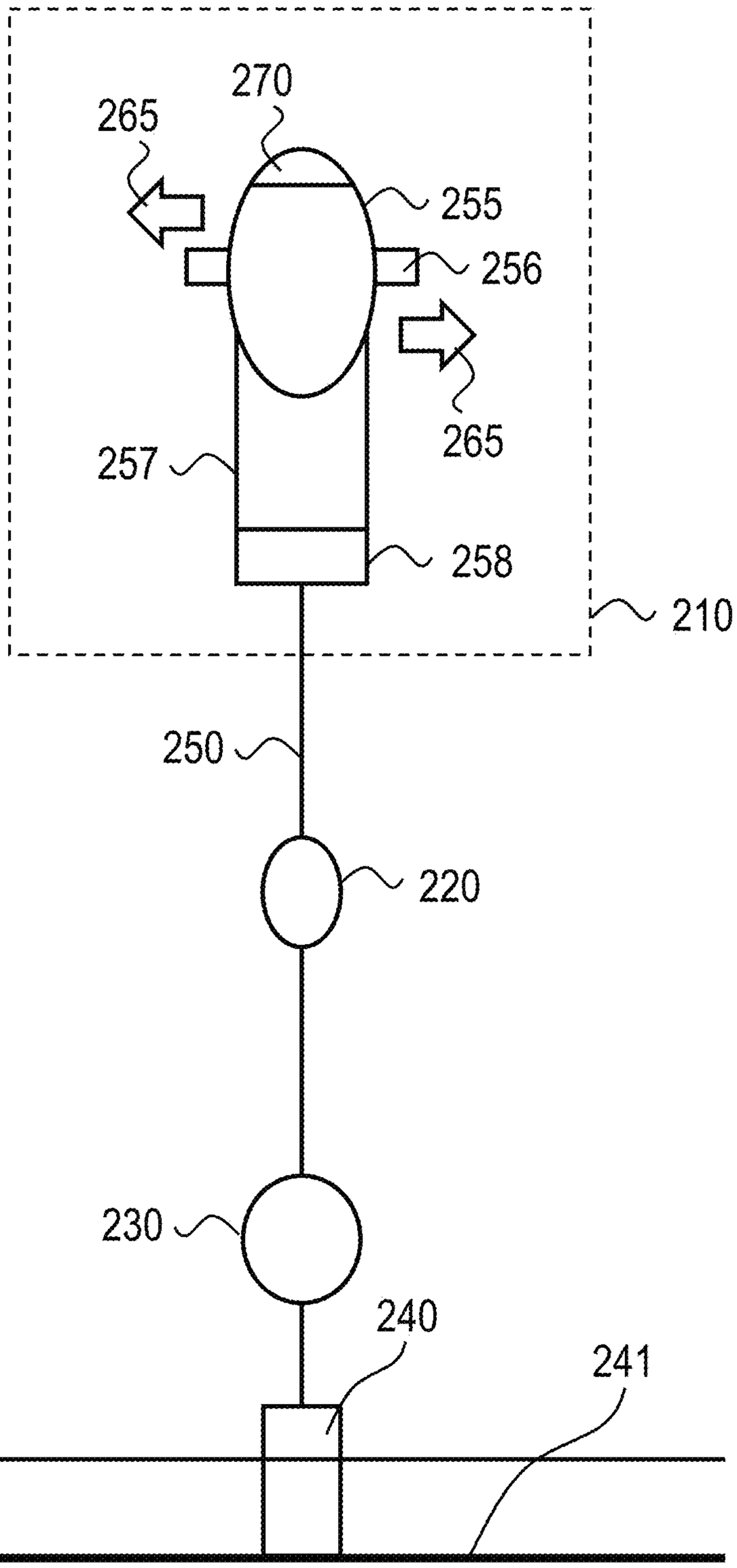


FIG. 2A

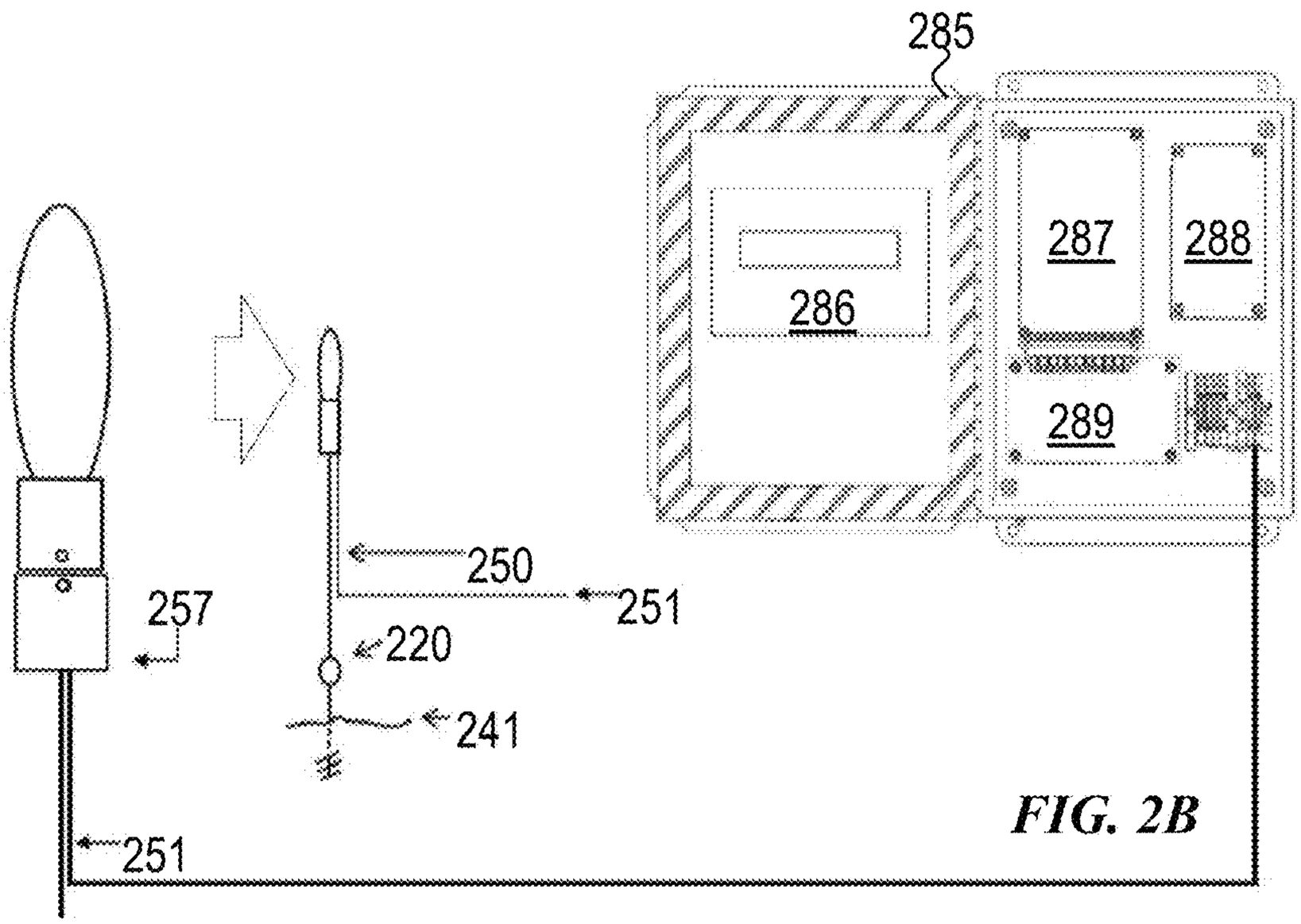

285
286
287
288
289
250
251
257
220
241
251

FIG. 2B

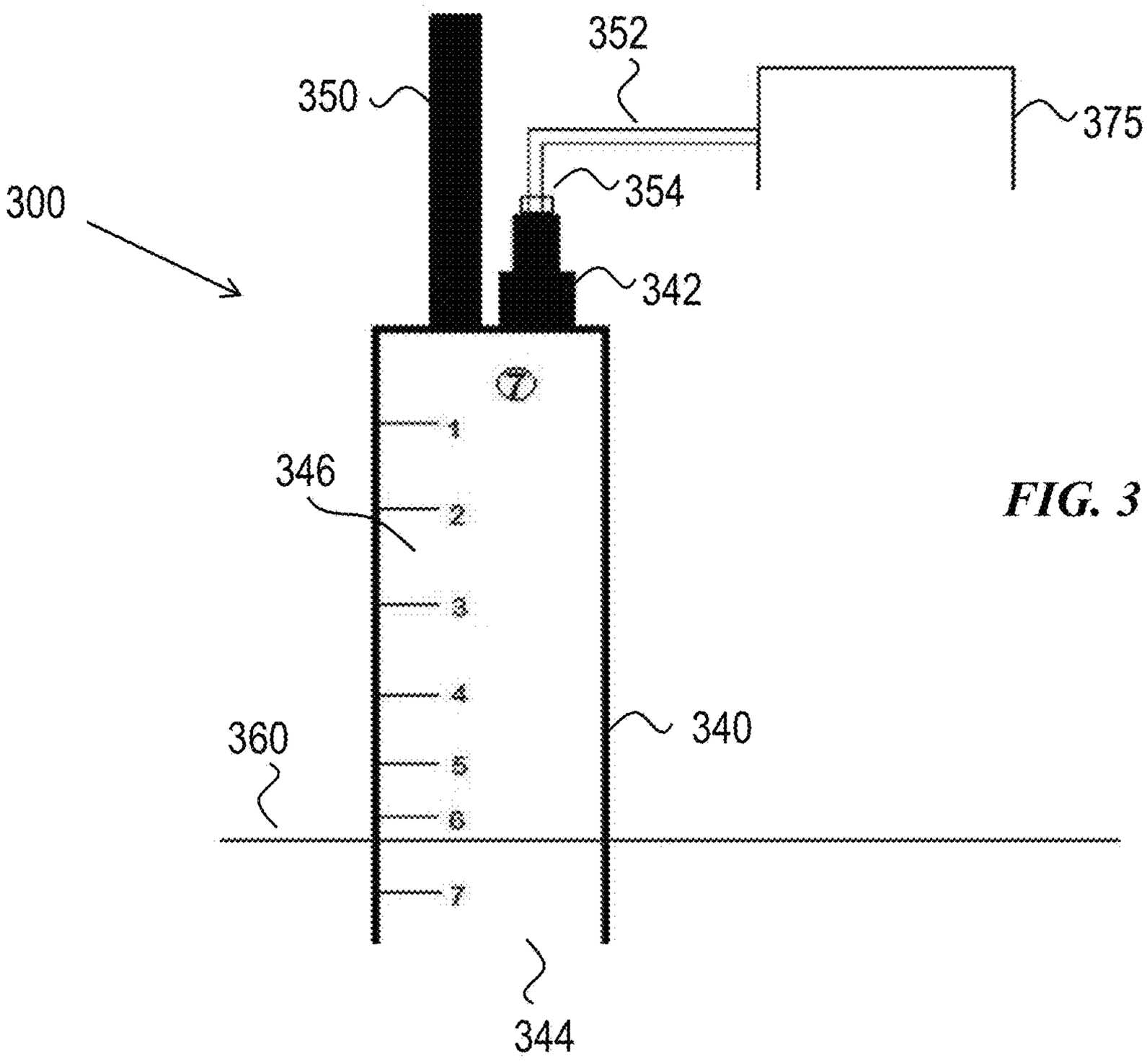
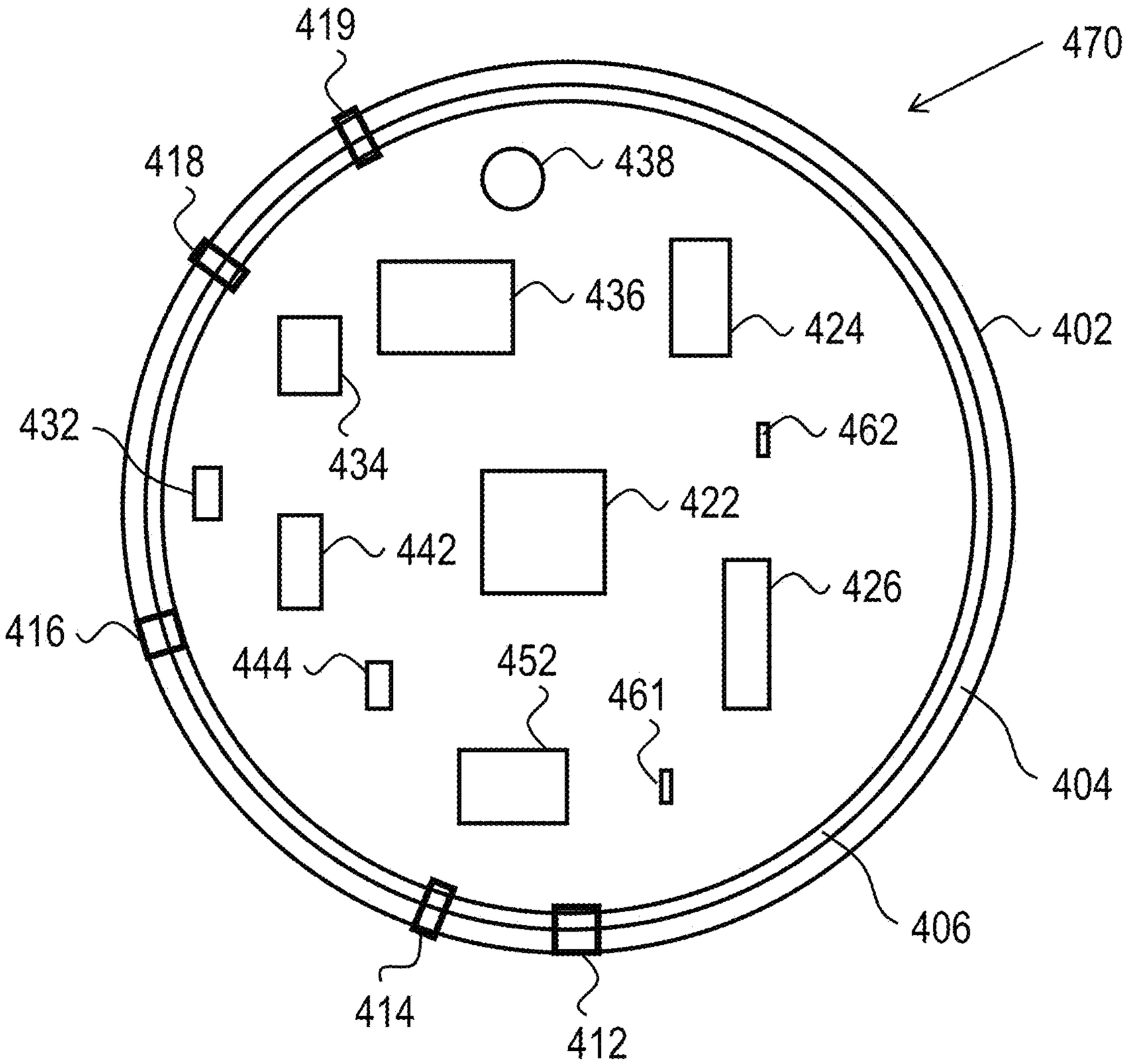

352
350
375
300
354
342
346
340
360
344

FIG. 3


419
470
418
438
436
424
402
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462
434
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442
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414
412

FIG. 4

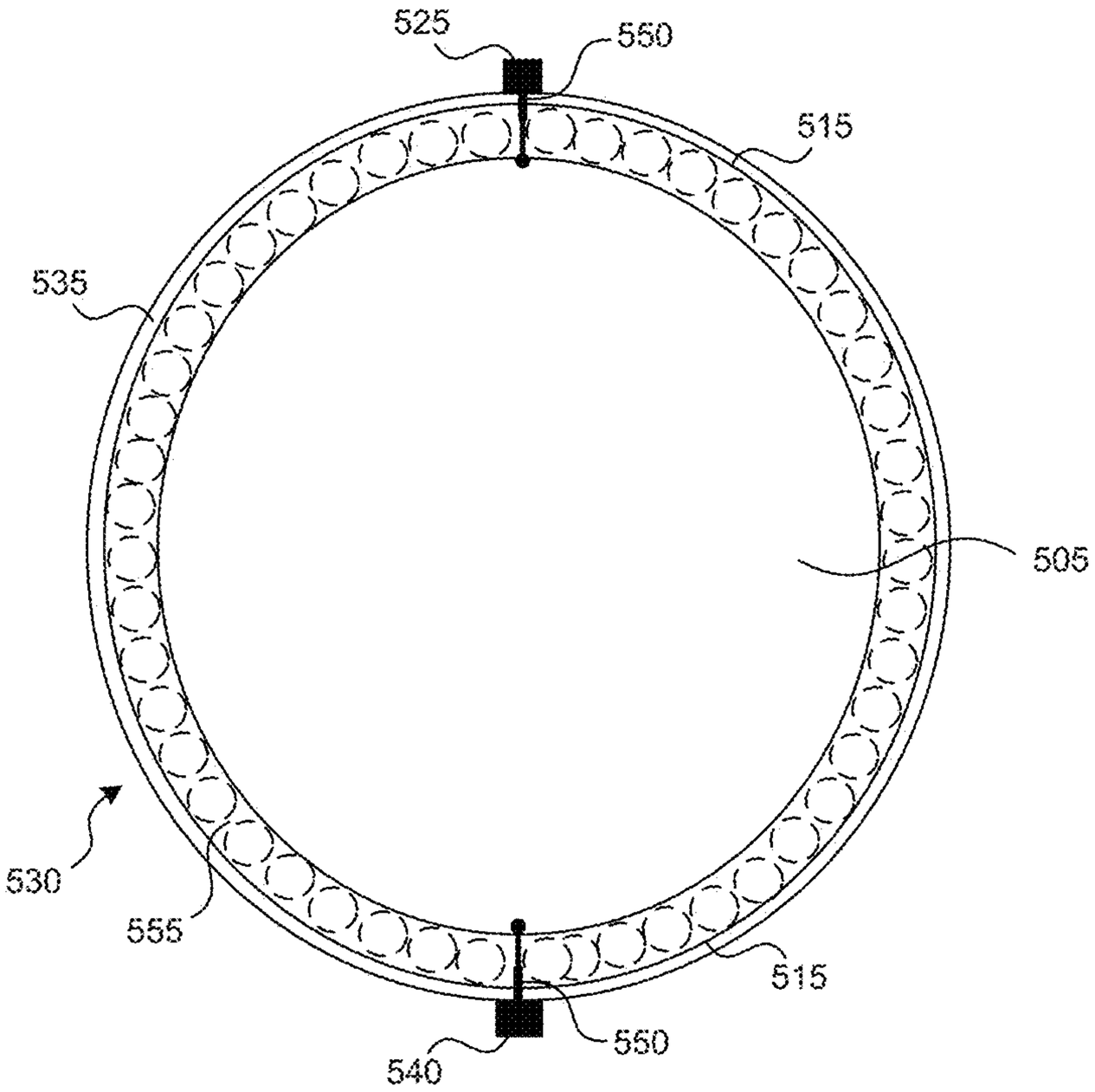
525
550
515
535
505
530
555
515
550
540

FIG. 5

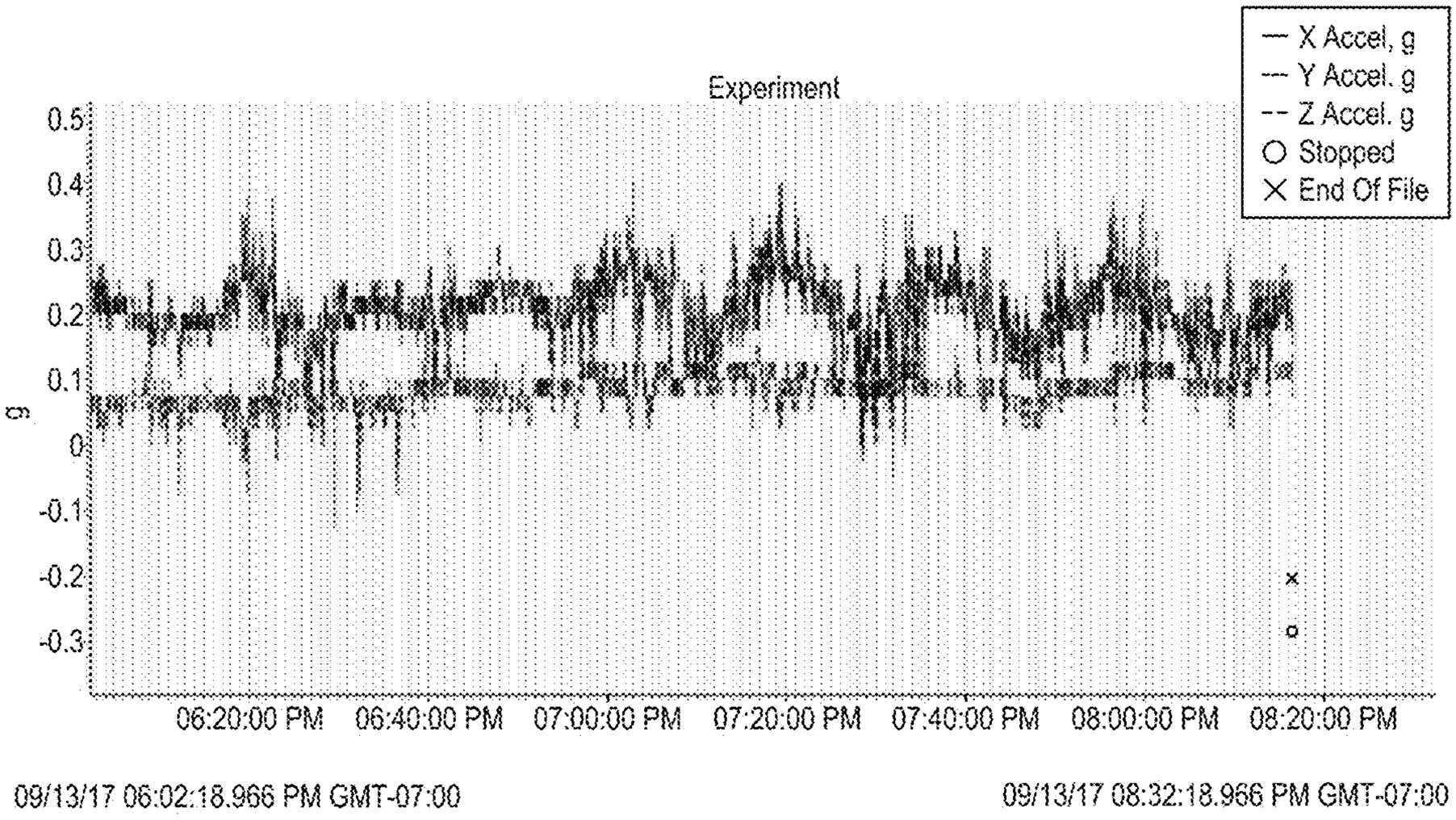
Experiment
X Accel, g
Y Accel. g
Z Accel. g
Stopped
End Of File
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
g
06:20:00 PM
06:40:00 PM
07:00:00 PM
07:20:00 PM
07:40:00 PM
08:00:00 PM
08:20:00 PM
09/13/17 06:02:18.966 PM GMT-07:00
09/13/17 08:32:18.966 PM GMT-07:00

FIG. 6

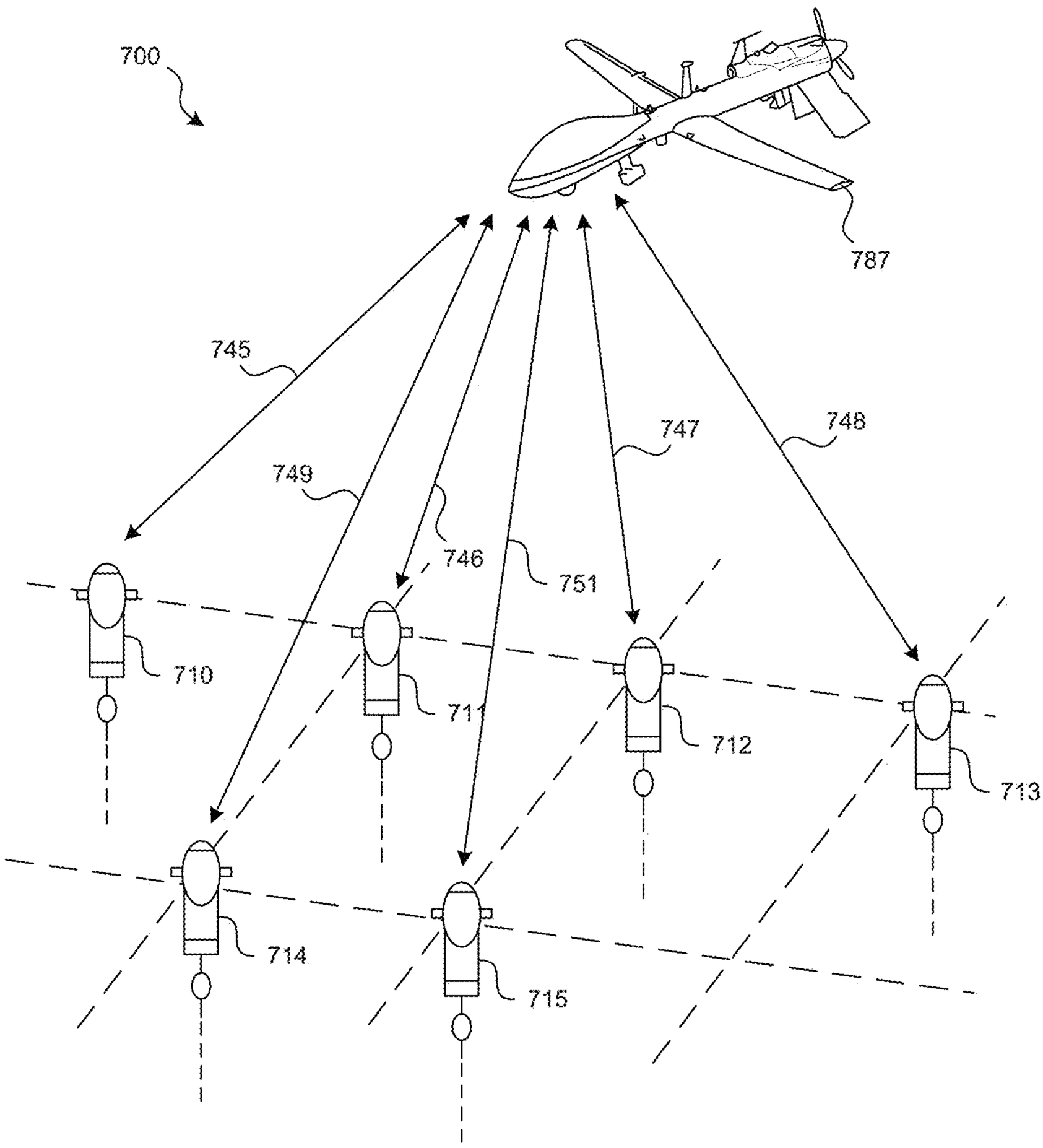

FIG. 7A

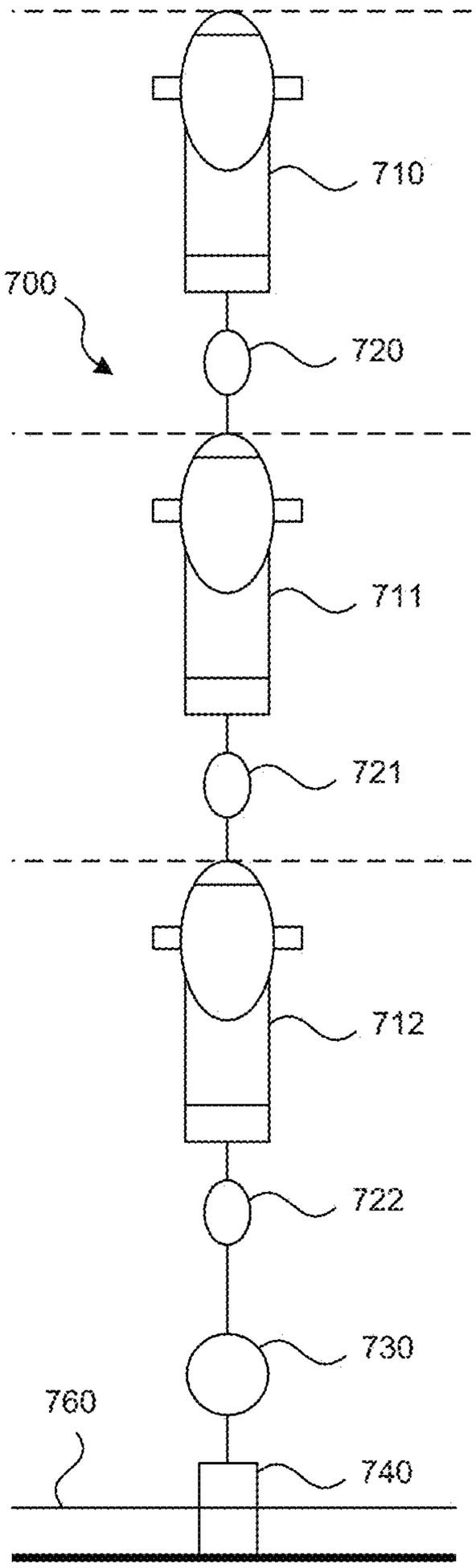
700
710
720
711
721
712
722
730
760
740

FIG. 7B

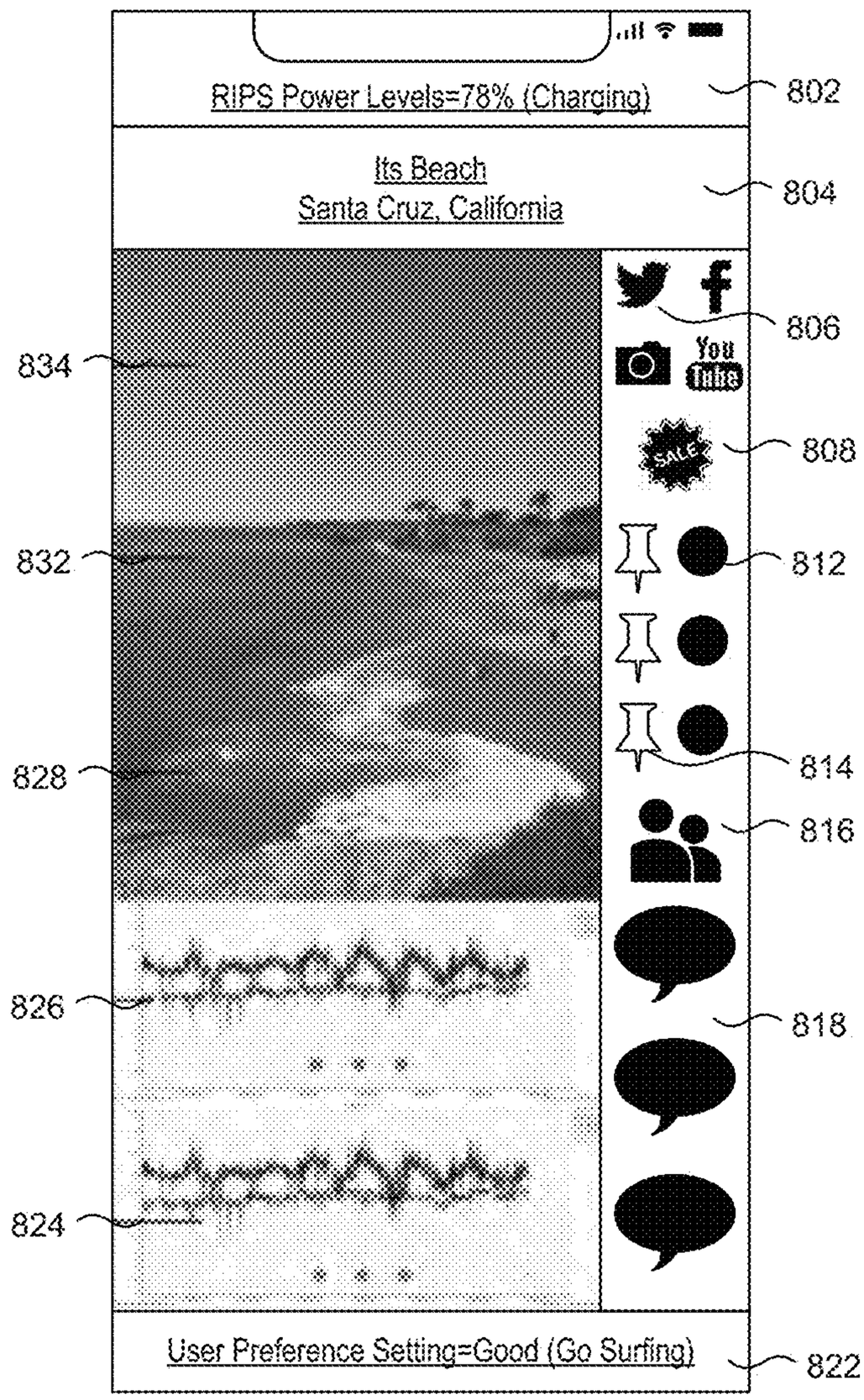
RIPS Power Levels=78% (Charging)
802
Its Beach
Santa Cruz, California
804
806
834
832
828
826
824
808
812
814
816
818
User Preference Setting=Good (Go Surfing)
822

FIG. 8

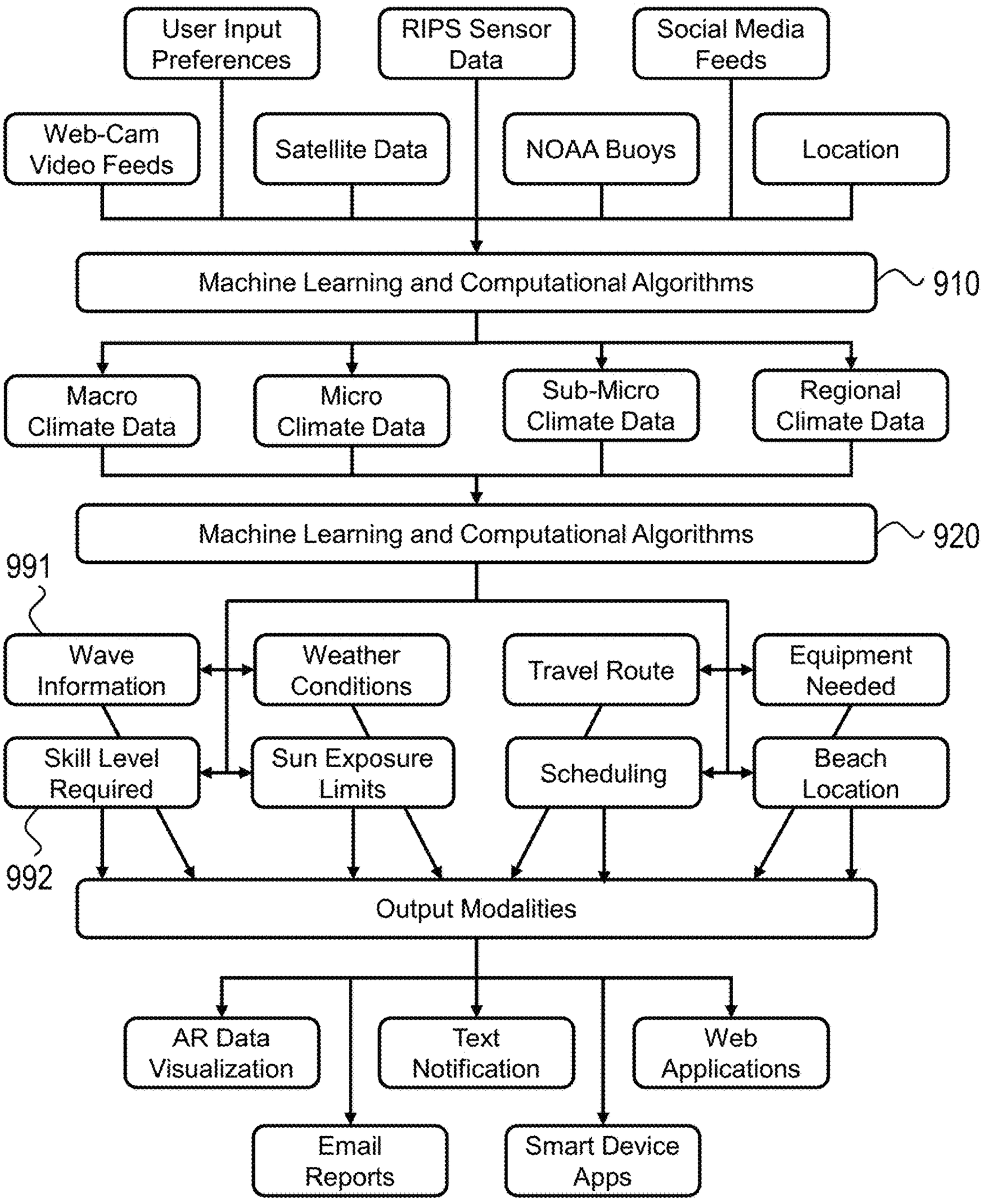
User Input Preferences
RIPS Sensor Data
Social Media Feeds
Web-Cam Video Feeds
Satellite Data
NOAA Buoys
Location
Machine Learning and Computational Algorithms
910
Macro Climate Data
Micro Climate Data
Sub-Micro Climate Data
Regional Climate Data
Machine Learning and Computational Algorithms
920
991
Wave Information
Weather Conditions
Travel Route
Equipment Needed
Skill Level Required
Sun Exposure Limits
Scheduling
Beach Location
992
Output Modalities
AR Data Visualization
Text Notification
Web Applications
Email Reports
Smart Device Apps

FIG. 9

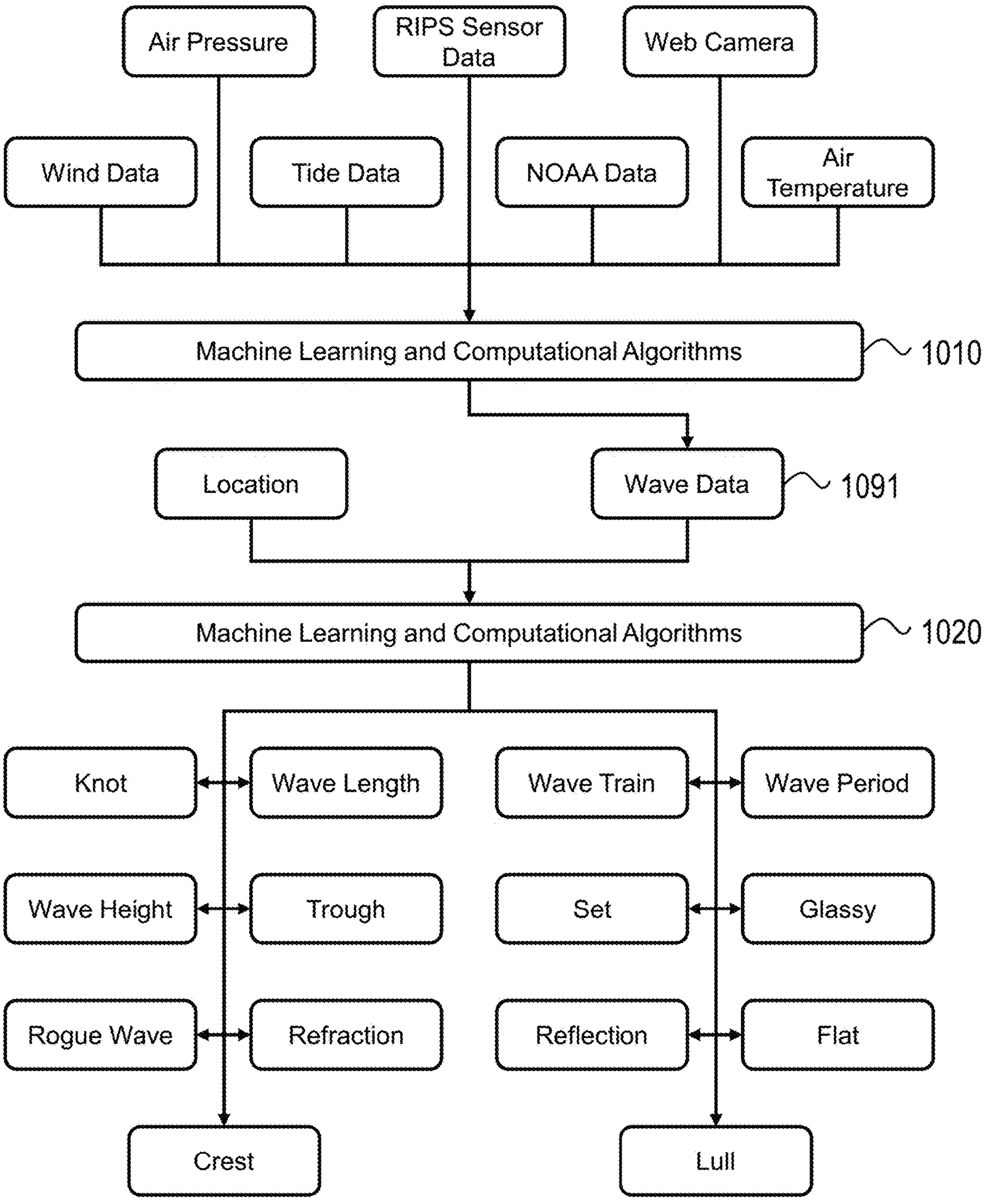
Air Pressure
RIPS Sensor Data
Web Camera
Wind Data
Tide Data
NOAA Data
Air Temperature
Machine Learning and Computational Algorithms
1010
Location
Wave Data
1091
Machine Learning and Computational Algorithms
1020
Knot
Wave Length
Wave Train
Wave Period
Wave Height
Trough
Set
Glassy
Rogue Wave
Refraction
Reflection
Flat
Crest
Lull

FIG. 10

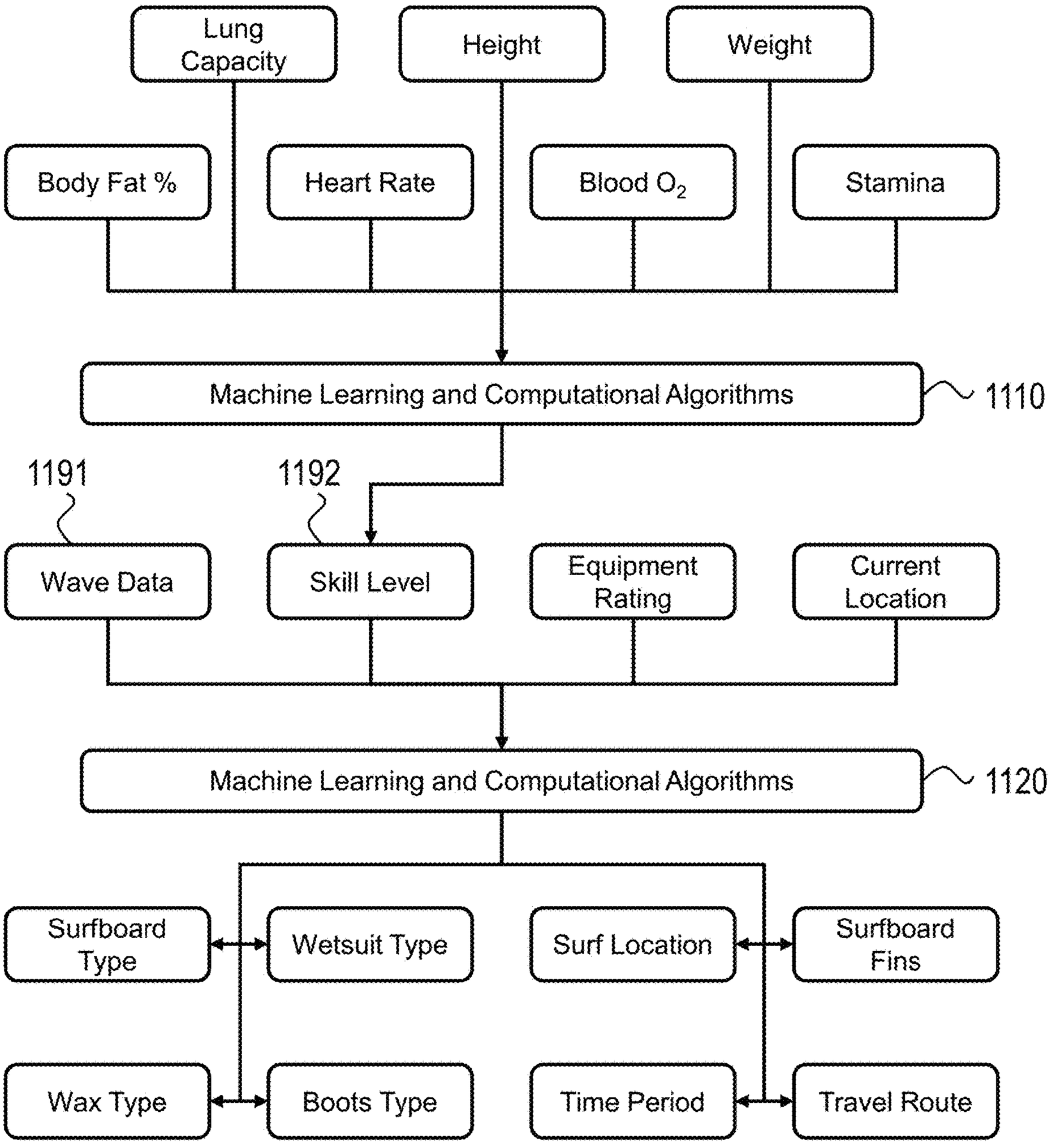
Lung Capacity
Height
Weight
Body Fat %
Heart Rate
Blood O_2
Stamina
Machine Learning and Computational Algorithms
1110
1191
1192
Wave Data
Skill Level
Equipment Rating
Current Location
Machine Learning and Computational Algorithms
1120
Surfboard Type
Wetsuit Type
Surf Location
Surfboard Fins
Wax Type
Boots Type
Time Period
Travel Route

FIG. 11

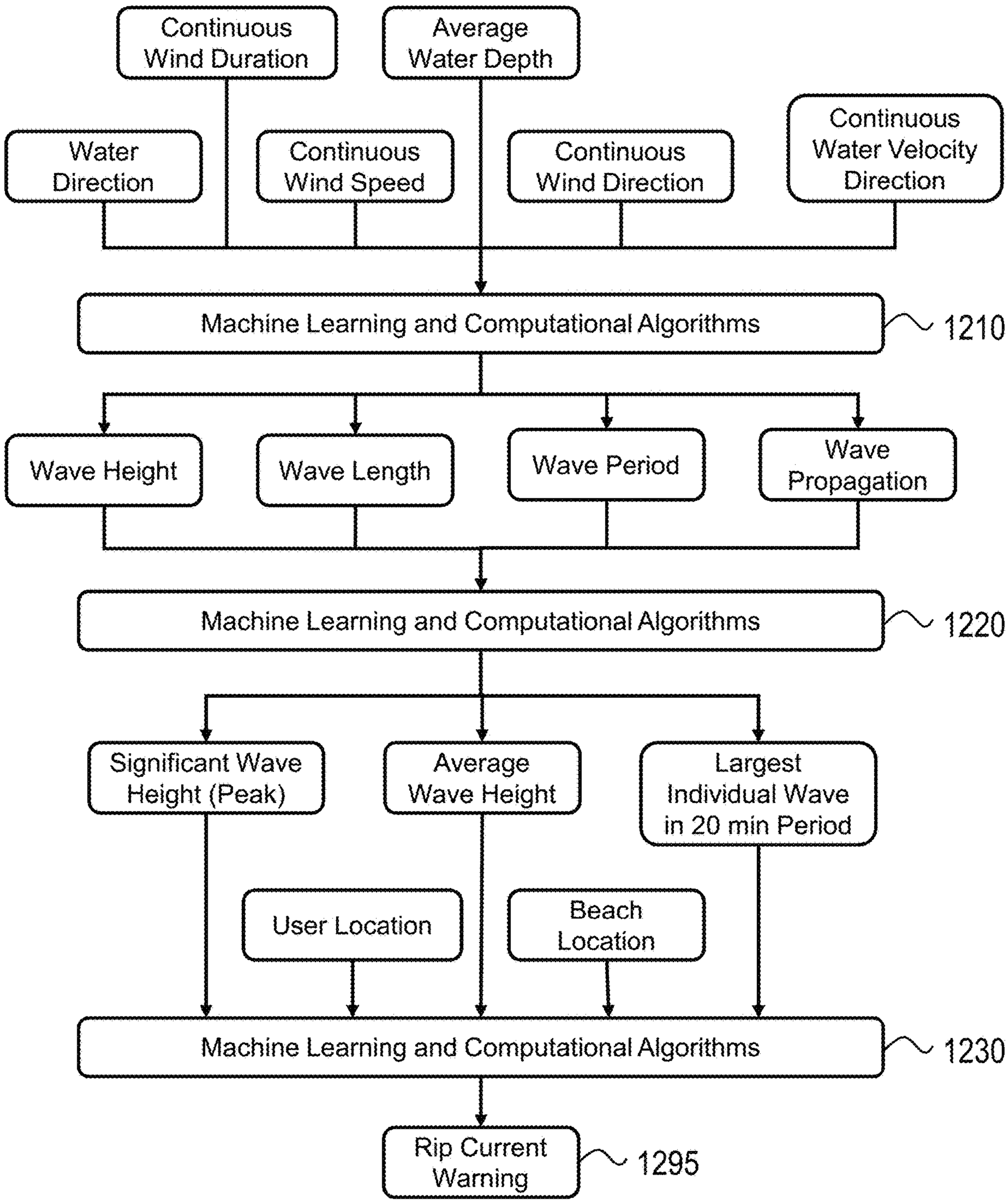
Continuous Wind Duration
Average Water Depth
Water Direction
Continuous Wind Speed
Continuous Wind Direction
Continuous Water Velocity Direction
Machine Learning and Computational Algorithms
1210
Wave Height
Wave Length
Wave Period
Wave Propagation
Machine Learning and Computational Algorithms
1220
Significant Wave Height (Peak)
Average Wave Height
Largest Individual Wave in 20 min Period
User Location
Beach Location
Machine Learning and Computational Algorithms
1230
Rip Current Warning
1295

FIG. 12A

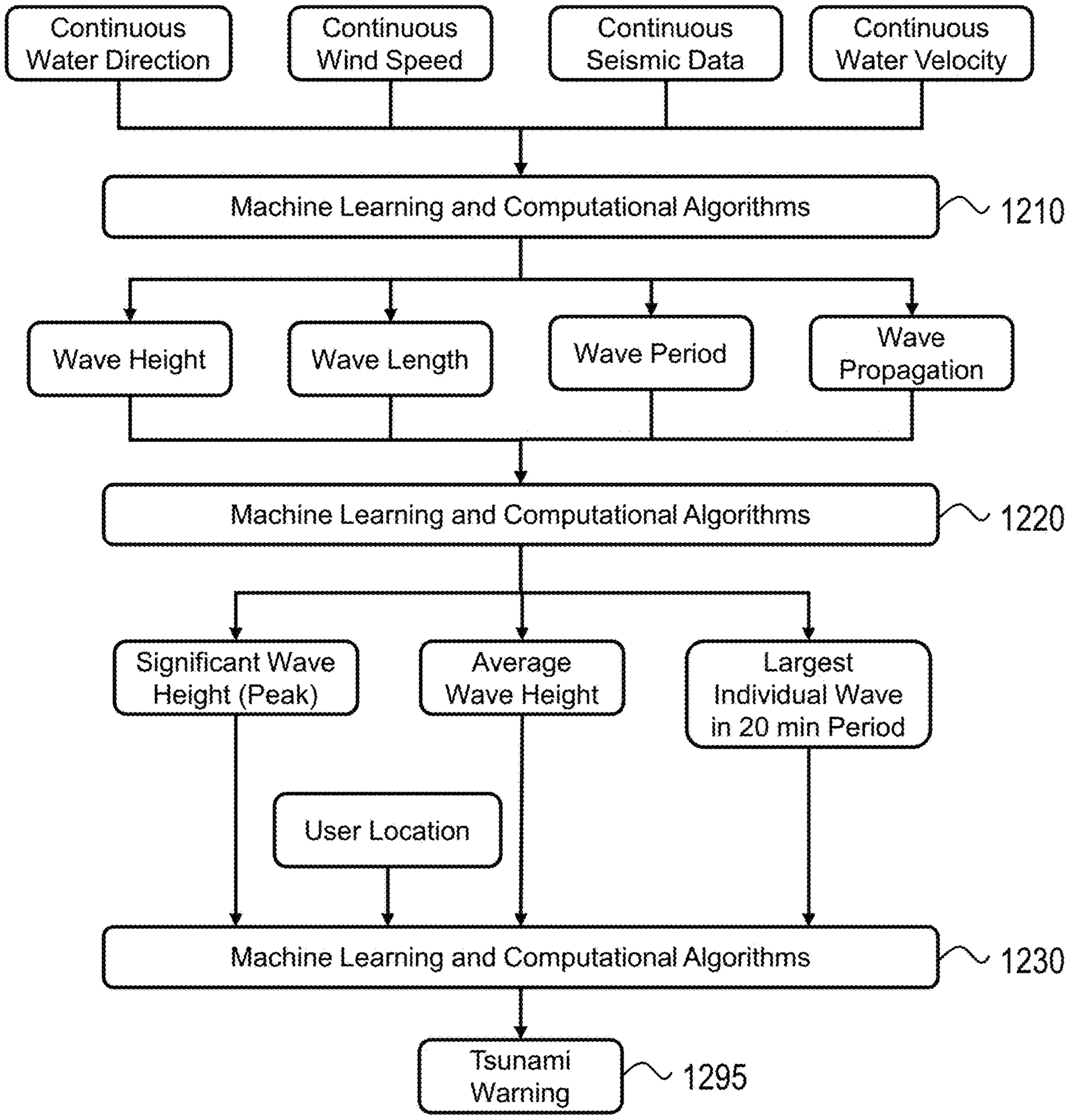
Continuous Water Direction
Continuous Wind Speed
Continuous Seismic Data
Continuous Water Velocity
Machine Learning and Computational Algorithms
1210
Wave Height
Wave Length
Wave Period
Wave Propagation
Machine Learning and Computational Algorithms
1220
Significant Wave Height (Peak)
Average Wave Height
Largest Individual Wave in 20 min Period
User Location
Machine Learning and Computational Algorithms
1230
Tsunami Warning
1295

FIG. 12B

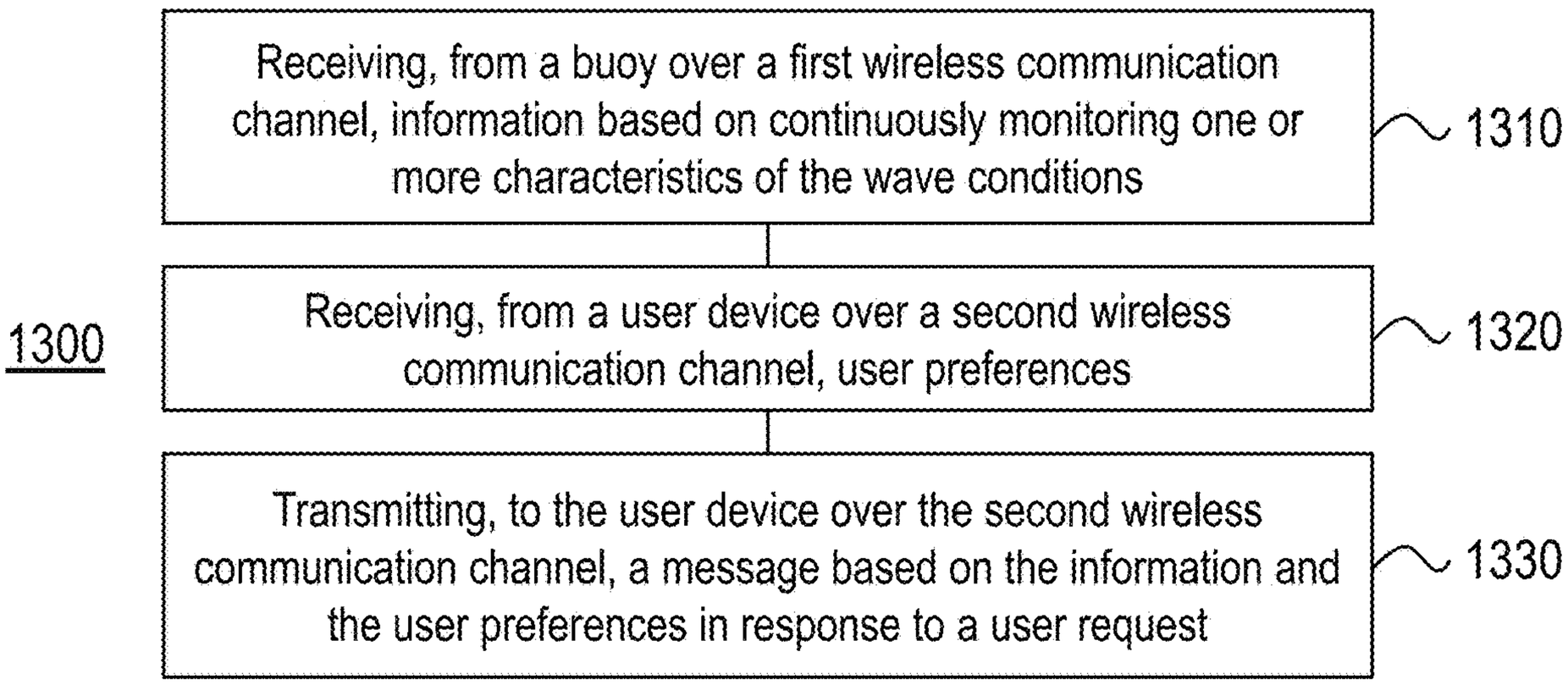

FIG. 13

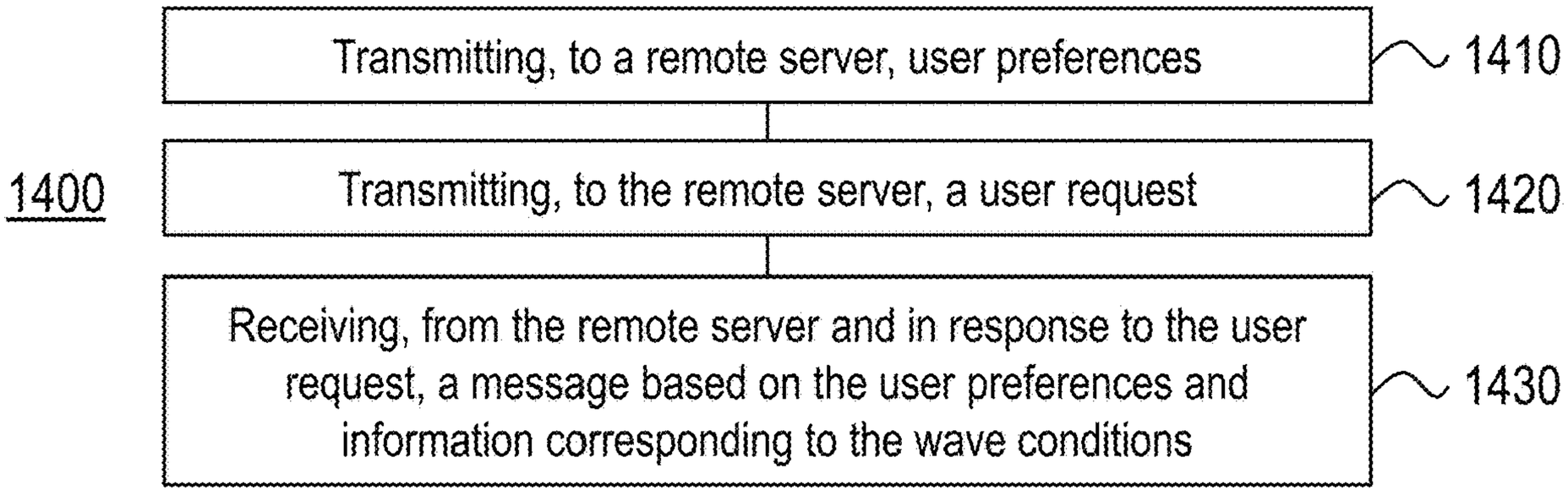

FIG. 14

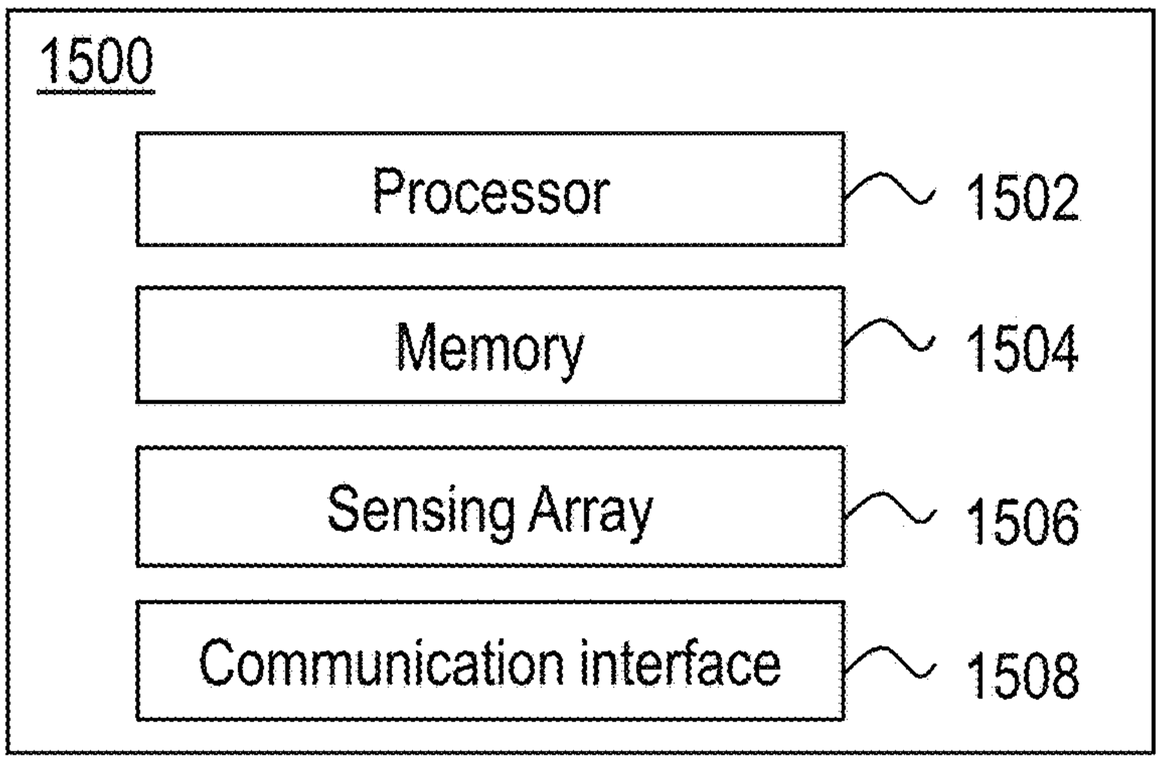

FIG. 15

REAL-TIME WAVE MONITORING AND SENSING METHODS AND SYSTEMS

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation of International Patent Application No. PCT/US2019/027644 entitled "Real-Time Wave Monitoring and Sensing Methods and Systems" and filed on Apr. 16, 2019, which claims the benefit of priority of U.S. patent application Ser. No. 15/974,570 entitled "Real-Time Wave Monitoring and Sensing Methods and Systems" and filed on 8 May 2018, as well as the benefit of priority of U.S. Provisional Patent 62/658,542 entitled "Remote Information Peak Sensing Methods and Systems" and filed on 16 Apr. 2018.

TECHNICAL FIELD

[0002] This document relates to methods and systems for real-time monitoring and sensing of wave characteristics, ocean currents, water velocity, and the like.

BACKGROUND

[0003] At the entrance of most beaches, there is a bulletin board with notices about water conditions: a faded sign warning about rip currents and a list of this week's tide tables. However, the bulletin board is typically of limited utility since the posted surf and water quality reports are produced by meteorologists using time-lapsed data, which may not be pertinent for that particular beach and for that particular time.

[0004] As such, existing systems do not provide real-time updates of wave conditions to users who wish to access the beach for leisure and sporting activities, and may not warn visitors to the presence of rip currents in the neighboring waters in real-time.

SUMMARY

[0005] Devices, systems and methods for real-time wave monitoring are described, and include the Remote Information Peak Sensing (RIPS) system. RIPS is a wave characterization, water signature identification, and wave sensing technology that provides real-time data solutions to surfers and anyone interested in ocean conditions, creating value by acquiring and aggregating wave data into a simplified user interface. In an example, this may be achieved by using buoys that include a sensor array and a transceiver to continuously monitor and sense wave conditions, transmit information to a remote server where the information may be further processed, and allow a user to access this data to determine when wave conditions may be optimal for leisure and sporting activities, or to alert the user to the presence of riptides.

[0006] In one aspect, the disclosed technology can be used to provide a method for real-time monitoring of wave conditions. This method includes receiving, from a plurality of buoys over a first wireless communication channel, information based on continuously monitoring one or more characteristics of the wave conditions, receiving, from a user device over a second wireless communication channel, user preferences, and transmitting, to the user device over the second wireless communication channel, a message based on the information and the user preferences in response to a user request, where a duration between the receiving the information and the receiving the user request is less than a predetermined value.

[0007] In yet another exemplary aspect, the above-described methods are embodied in the form of processor-executable code and stored in a computer-readable program medium.

[0008] In yet another exemplary aspect, a device that is configured or operable to perform the above-described methods is disclosed.

[0009] The above and other aspects and features of the disclosed technology are described in greater detail in the drawings, the description and the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] FIG. **1** shows a block diagram of an example system for real-time wave monitoring and sensing, according to embodiments of the disclosed technology.

[0011] FIGS. **2**A and **2**B show block diagrams of an example buoy deployments for real-time wave monitoring and sensing, according to embodiments of the disclosed technology.

[0012] FIG. **3** shows a block diagram of an example anchor of a buoy.

[0013] FIG. **4** shows a block diagram of an example sensing array of a buoy.

[0014] FIG. **5** shows a block diagram of an example power regeneration module of a buoy.

[0015] FIG. **6** shows an example of experimentally obtained wave data.

[0016] FIGS. **7**A and **7**B show examples of the deployment of multiple buoys for real-time wave monitoring and sensing, according to embodiments of the disclosed technology.

[0017] FIG. **8** shows an example screenshot of a mobile application interface that may be used to interact with embodiments of the disclosed technology.

[0018] FIG. **9** shows a flow diagram for real-time wave monitoring and sensing, according to embodiments of the disclosed technology.

[0019] FIG. **10** shows a flow diagram for wave data monitoring.

[0020] FIG. **11** shows a flow diagram for user skill and equipment determinations.

[0021] FIGS. **12**A and **12**B show flow diagrams for determination of rip current and tsunami warnings, according to embodiments of the disclosed technology.

[0022] FIG. **13** shows a flowchart of an example method of real-time monitoring and sensing of wave conditions, according to embodiments of the disclosed technology.

[0023] FIG. **14** shows a flowchart of another example method of real-time monitoring and sensing of wave conditions, according to embodiments of the disclosed technology.

[0024] FIG. **15** shows an example of a hardware platform that can implement some techniques described in the present document.

DETAILED DESCRIPTION

[0025] Coastal marine ecosystems are structured by physical processes. Wave energy, in particular, has important effects on the near-shore structure of coastlines and the productivity of communities. An example of the altering of

coastlines and communities may be seen in Santa Cruz, Calif. The Santa Cruz Harbor suffered ecological and economic damages from shoaling of the harbor mouth and boat slips. The ocean swells carried large amounts of sediment and sand that prevented commercial fishermen from exiting and entering the harbor due to shoaling problems. Measurement techniques used by the harbor master were time consuming and could not accurately measure the sediment build up in time for the dredging vessel to do preventative maintenance to the mouth of the harbor. Another example of the utility of monitoring wave energy is seen in the ability to be able to plan leisure and sporting activities along the hundreds of miles of California coast, such as surfing.

[0026] In some existing systems, air and sea surface temperature, as well as wind speed and direction may be monitored using a number of offshore buoys spaced several miles apart (e.g., the National Oceanic and Atmospheric Administration (NOAA) buoy and data collection network). However, the size and cost of the NOAA offshore buoys make them unsuitable for deployment near beaches and surfing environments. Alternatively, currently available buoys that may be deployed near the shore only include simple accelerometer loggers whose data needs to be manually accessed periodically (see, for example, the implementation in U.S. Patent Application Publication No. 2014/0137664, entitled "Inexpensive instrument for measuring wave exposure and water velocity").

[0027] Embodiments of the disclosed technology, described in detail in this document include the Remote Information Peak Sensing (RIPS) system that provides a low-cost and low-complexity solution for monitoring wave conditions and measuring wave exposure, and which can be deployed, for example, close to the beach and in surfing environments. The RIPS system is a real-time information system accessible by smart devices and/or web applications. Section headings are used in the present document to improve readability of the description and do not in any way limit the discussion or the embodiments to the respective sections only.

Introduction and Overview

[0028] Ocean waves deliver energy to coasts and mold the physical environments impacting the coastal communities. Measuring wave exposure at appropriate spatial scales is fundamental to understanding marine environments. This is a challenge because existing instruments are expensive, difficult to use, or are unable to measure at appropriate temporal scales. Approaches have been made using inexpensive devices designed to measure hydrodynamic force with small drogues and springs, or that measure average water flow through the dissolution of blocks of plaster or gypsum discs, or that use basic accelerometer logging.

[0029] Acoustic Doppler velocimeters (ADVs) and acoustic Doppler current profilers (ADCPs) are expensive (typically US$15K-25K) and logistically difficult to deploy, requiring the support of vessels with hydraulic hoists for deploying heavy instrument packages. These factors restrict the number of units that can be deployed concurrently, limiting the spatial coverage and resolution of measurements.

[0030] Embodiments of the disclosed technology provide a solution in the tradeoff between accuracy and the cost of measuring wave exposure. FIG. **1** shows a block diagram of an example system for real-time wave monitoring and sensing. As shown therein, RIPS buoys (**110**, **111**) are configured to continuously monitor wave conditions. In some embodiments, the RIPS buoy is a submerged float anchored just above the substrate by tether, which moves freely with water motion generated by waves. A sensor array is housed inside a protective housing connected to the float. In one example, records of the tilt of the float and its movement along with associated sensor data is distributed via a subsea data cable (not shown in FIG. **1**) connected to the underwater instrument, to a remote server **125** (or data system) that enables real-time data distribution via a wired or wireless internet connection.

[0031] In another example, and as shown in FIG. **1**, the RIPS buoys (**110**, **111**) can communicate wirelessly to a remote server **125** (e.g., remote data system, cloud computing system, software-as-a-service system). For example, the buoys may use communication links (**146**, **147**) that support protocols including Wi-Fi, LTE, Bluetooth and so on, and access either a cellular network access point **126**, a satellite access point **127**, or a fiber hybrid access point **128**. This remote server **125** may then connect to a user device **115** (e.g., personal computer, smartphone, tablet, smart watch) via a different communication link (**145**), and the real-time wave conditions may be accessed using a mobile application **135** or web program.

[0032] In an example, the RIPS system shown in FIG. **1** is an easy to deploy tool for accurately measuring bottom orbital velocities, thereby enabling the correlation of wave energy exposure to sediment and sand build-up, and providing the harbor master a cost effective real-time data characterization of the kinetic energy carrying sand and sediment causing shoaling to occur. In another example, the RIPS system creates real-time local immersive data visualizations, condition reports, and text notifications based on data sensed using sub microclimate data acquisition buoys. This information along with the users input preferences for optimal surfing conditions eliminates surfers waiting for optimal surfing conditions to enjoy the ocean. The data provides surfers with a greater range of insight into local sub-microclimates impacting surfing conditions effectively eliminating the need to use only inefficient time lapsed meteorology forecasts based on data collected offshore via offshore weather buoys and satellites in orbit.

Example Embodiment of a RIPS Buoy

[0033] FIG. **2**A shows a block diagram of an example of a deployed RIPS buoy that may be used for real-time wave monitoring and sensing, according to embodiments of the disclosed technology. As shown in FIG. **2**A, the buoy **210** includes an enclosure **255** that houses the sensing devices (or sensing/sensor array) **270** and communication radio **258**. In some embodiments, the sensor array and the communication capabilities in the buoy may be different components. In other embodiments, they may be part of the same hardware and/or software implementation. The sensor array **270** may measure various characteristics of the wave conditions, and the side panels **256** may be used to sense the direction of the ocean current. The buoy **210** may further include a charging base (or cradle) **257** that is configured to charge the sensing and communications devices via a connector. In some embodiments, the buoy may be constructed to be able to twist (as indicated by arrows **265**).

[0034] The buoy **210** is connected via an umbilical cord (or umbilical cable) **250** to additional components that are

necessary for the deployment of the buoy. In some embodiments, the umbilical cord **250** is an armored cable that contains a group of electrical conductors and fiber optics that carry electric power, video, and data signals. In some embodiments, a tether may be wrapped around the umbilical cord to strengthen it (and some embodiments of the disclosed technology may use "tether" to describe a strengthen umbilical cord with the aforementioned functionality). For example, single- or multi-mode fibers may be entwined with 2- or 3-layer steel wire to provide the required functional capabilities and be robust to undersea conditions.

[0035] As shown in FIG. **2**A, the buoy may be further connected to a recoil device **220**, which extends and shortens with tidal changes, and is able to strengthen communication signals for transmission. The tether further connects the recoil device **220** to a power regeneration device **230**, which provides power for the batteries by transforming ocean swell kinetics to electrical energy. The tether finally connects to an anchor **240**. In one example, the anchor **240** is a suction anchor that connects the deployment buoy to ocean floor **241** (below the mud line **260**) with suction vacuum. In some embodiments, the suction anchor may include a weight at the base of the unit to further support the anchoring.

[0036] FIG. **2**B shows additional elements of the deployment of a RIPS buoy. As such, it includes some components and features that are identical to those described in the context of FIG. **2**A, and which are not explicitly discussed in the context of this figure. In some embodiments, and as shown in FIG. **2**B, the tether **250** may be co-located with a data cable **251** that connects the buoy to a surface data acquisition and data distribution system **285**. In some embodiments, the surface data acquisition and data distribution system **285** may include a display **286**, a communication board/device **287**, a power supply **288** and a microcontroller **289**, as separate components as shown in FIG. **2**B. In other embodiments, the communication device **287** and the microcontroller **289** may be part of the same hardware and/or software component.

[0037] FIG. **3** shows a block diagram of an anchor (e.g., corresponding to anchor **240** shown in FIG. **2**) of a buoy. As shown in FIG. **3**, the deployed suction anchor **300** (also referred to as a suction pile or suction caisson) includes a metal cylinder **340** that is placed into the sand/mud line **360**. In some embodiments, the metal cylinder may be 12-foot long steel cylinder that includes a measurement ruler **346** for calibration during deployment and servicing. The operation of the suction anchor is based, in part, on creating (and dissipating) a vacuum in the water/sand displacement column **344**.

[0038] The metal cylinder **340** is connected to the tether (or umbilical cord) **350**, and is therefore able to secure the deployed RIPS buoy to the sea floor. The top of the metal cylinder **340** includes a two-way hydraulic check valve **342**, which is connected to a high pressure hose **352** using, for example, a ROV (remotely operated vehicle) quick connection **354**.

[0039] In some embodiments, the high pressure hose **352** connects the suction anchor to a hydraulic pump **375** on the surface, which is used to adjust the vacuum pressure in the suction anchor to securely anchor the RIPS buoy to the sea floor. For example, pumping fluid into the anchor raises it up, whereas pumping fluid out of the anchor creates a vacuum in the water/sand displacement column **344**, causing the anchor to sink.

[0040] FIG. **4** shows a block diagram of a sensing array (e.g., corresponding to sensor array **270** in FIG. **2**) of a buoy. In some embodiments, the sensing array **470** may include an outer shell **402**, which encloses internal insulation **404** and an innermost layer of foam insulation **406**. For example, the outer shell **402** may be a wooden shell that is made to insulate internal devices from sea water. For example, the foam insulation **406** may be made from biodegradable formulas such as shrimp shells, corn, etc. to provide insulation and buoyancy.

[0041] In some embodiments, the insulated shell may include a number of access ports, e.g., a port **412** for charging the device using a cradle, an antenna port **414** that allows communication of the buoy to one or more access points (of the same or different types), a data port **416** that allows divers or technicians to program or extract data from the device, a pressure port **418** that allows the unit to be pressurized for buoyancy, and a temperature port **419** that is a chamber the unit uses to measure differences of temperature points of the unit.

[0042] In some embodiments, the functionality of the sensing array **470** may be controlled by a microprocessor (or microcontroller) **422** and may include a data storage and/or memory **424** to serve as on board storage of data collected by microprocessor **422**, and a battery **426** to power the unit. The sensing array **470** may support different modalities, e.g. a pressure transducer **432** that converts ocean pressures into electrical currents for subsea pressure measurement, a vibration sensor **434** that measures the G-forces of the ocean current, a waterproof accelerometer **436**, a camera **438** that may be used to determine the water clarity for scuba divers, a temperature probe **442** that measures the temperature of the ocean, and a Global Positioning System (GPS) unit **444** that allows for location tracking of the instrument. In some embodiments, the camera may be configured to operate as a microscopic particle counter (e.g., to count sand particles in parts per million) to enable, in conjunction with wave kinetic measurements, the monitoring of sediment and shoaling and/or shoreline changes in real-time.

[0043] In some embodiments, the sensor array **470** may further include a network card **452** that may be configured to communicate data to one or more network access points at the surface, or to transmit the data to a diver or a drone (depending on the specific implementation). The unit may further include silica packets (**461**, **462**) to absorb moisture inside the unit from temperature changes that may occur.

[0044] FIG. **5** shows a block diagram of a power regeneration device (e.g., corresponding to power regeneration module **230** in FIG. **2**) of a buoy, which converts wave velocity kinetic energy into electricity for onboard power of sensors, communications, and battery charging.

[0045] As shown in FIG. **5**, the power regeneration device **530** is secured by the tether **550** to the anchor **540**, and includes a magnetic (e.g., iron) rotating/spinning core **505** encased in copper coils **555**, which is surrounded by an electrical conductor **515** and an outermost layer of non-conductive insulation **535**. Electricity is generated from wave kinetics by the buoy top rotation connected internally to the iron core **505** rotating inside the array of copper coils **555**. In some embodiments, excess electricity that is generated may be distributed to the land-based power grid or remote electric car charging terminals located near the beach via electrical cable connection.

[0046] FIG. **6** shows an example of experimental wave data. In some embodiments, and as shown in FIG. **6**, the data may be time stamped accelerometry data in the x-, y- and z-axis directions as function of time. Herein, the raw data from the waterproof accelerometer may be transmitted to the remote server, and then directly provided to the user. In other embodiments, the data may be processed on-board and then averaged (or aggregated, or processed) data from the accelerometer may be provided to the user. In yet other embodiments, the data from one or more of the sensors may be combined using machine learning or computational algorithms, and aggregated data or results sent to the remote server. Embodiments of the disclosed technology may employ any of the aforementioned techniques, based on how much power is available on-board the buoy, and trading off computational and communication costs.

Example Embodiments of RIPS System Deployments

[0047] Embodiments of the disclosed technology may be used to address problems in many disciplines from physical oceanography to freshwater and marine ecology, as well as supporting safety systems (e.g., rip current and tsunami warnings), and sporting and leisure water activities. In some embodiments, the tether length and buoyancy of RIPS buoys may be adjusted to accommodate different wave environments. They may also be used to measure unidirectional water flow and also, with development of a non-rotating tether, can measure flow direction. The RIPS system can easily integrate into NOAA's data network enabling a forecaster to compare offshore buoy data with near-shore data providing a high level of accuracy.

[0048] In some embodiments, the RIPS system offers a new and innovative wave monitoring technology. Customers are provided nearly instantaneous access to live sub-microclimate wave information, notifications, and visualization data. This information can be used to improve surfer efficiency, improve safety and lessen nonproductive time. Sensor data can be used to determine the optimal time to travel to an area by increasing accuracy of wave information, traffic, weather conditions, equipment needed such as surfboard, wetsuit, fins, leashes, boots. Safety increases by recommending skill level and lessening sun exposure.

[0049] In some embodiments, and as described in the context of FIGS. **1**, **2**A and **2**B, RIPS utilizes hybrid wireless communications to securely transmit data from equipment collecting data in the water to servers performing data aggregation and analysis. Mobile devices are fully supported, allowing a greater range of insight into minute-to-minute surf conditions. For example, remote sensing communication capabilities are realized by fiber to hybrid system infrastructure being installed locally making dead zones less of a burden when performing data acquisition wirelessly. The real-time reporting and notification system saves time and allows surfers to accurately schedule surf sessions without traveling to the beach or interpreting inaccurate reports of water conditions. For example, RIPS derives its value from saving surfers time and money. It provides surfers access to the technology necessary to consistently maintain safety, competitive advantage, and enjoyable surf experiences. Meteorologists typically produce inaccurate reports based on time-lapsed offshore buoy data not suitable for surfing sub-microclimates of the bay area and other similar topography. Embodiments of the disclosed technology advantageously overcome inaccurate reporting problems with the accurate sub-microclimate data enabling an exhilarating surfer experience. With visualizations in hand, consistent precision in catching an awesome wave may be achieved.

[0050] FIGS. **7**A and **7**B show examples of the deployment of multiple buoys for real-time wave monitoring and sensing, according to embodiments of the disclosed technology. As shown in the example in FIG. **7**A, multiple RIPS buoys (**710**, **711**, . . . , **715**) may be deployed in the form of a grid (e.g., a 100-yard square grid), and can be used to track the spatial and temporal variation of the waves and currents. In some embodiments, the information from the RIPS buoys (**710**, **711**, . . . , **715**) may be wirelessly collected by a drone **787** via communication links (**745**, **746**, . . . , **751**), respectively. In an example, the information from a grid of RIPS buoys may be integrated with NOAA data to provide a more accurate estimate of wave conditions. Using a grid of RIPS buoys may also provide detailed microclimate and sub-microclimate maps for any region in which they are deployed.

[0051] In another example, and as shown in FIG. **7**B, multiple RIPS buoys (**710**, **711**, **712**) may be deployed in a vertical manner so as to track waves and currents at different depths. In some embodiments, each of the buoys (**710**, **711**, **712**) may be deployed with their corresponding recoil devices (**720**, **721**, **722**), respectively, connected to a single power regeneration device **730**, and secured to the ocean floor (below the mud line **760**) using a suction anchor **740**.

[0052] In some embodiments, the frameworks shown in FIGS. **7**A and **7**B may be combined to provide accurate wave and current information through the entire water column and over a wide area. In an example, a series of RIPS buoys placed in the harbor may collect information about sand build-up. This information may then be transmitted in real-time to the surface and aggregated into software that produces a dynamic visualization of sand sediment build up for the harbor master. The dynamic visualization may then be used by the harbor master to plan and execute dredging operations safely.

[0053] In another example, the deployment of one or more RIPS buoys may be used as part of a dynamic positioning (DP) system, which assists in the stabilization of an offshore supply vessel when loading and unloading cargo without anchoring in deep water. The system takes time to stabilize the boat while the DP system performs wave force calculations using wind, roll, and pitch data to determine how to counter act these forces using its engine thrustors. The wave sensor data integrates into the dynamic positioning computer when performing calculations. This real-time data from the RIPS buoys decreases stabilization time and increases control of the vessel in rough seas lessening the down-time of a rig.

[0054] In yet another example, the deployment of one or more RIPS buoys may be used to provide knowledge of sub-microclimates for surfing (or watersport activities in general), since conditions in the water can change dramatically in short periods of time. Embodiments of the disclosed technology that provide the rapid detection of changing conditions enable a safe and more enjoyable way of learning to surf.

[0055] FIG. **8** shows an example screenshot of a mobile application interface that may be used to interact with embodiments of the disclosed technology when searching for the perfect surfing experience. As shown in FIG. **8**, the

mobile application interface comprises features and elements that assist in a safer and more enjoyable surfing experience, and may also provide diagnostic information regarding the deployed RIPS system (e.g. the power level of one or more RIPS buoys may be displayed (**802**)).

[0056] In the example shown in FIG. **8**, the interface may display the location of the sub-microclimate currently being displayed (**804**), and further provide the option to switch to other microclimate statuses (**812**). The application may be integrated with social media feeds (**806**), highlight relevant products for rent or sale (**808**, e.g., Craigslist), enable sharing data with friends and contacts (**816**, **818**), and display local locations that support a great surfing experience (**814**).

[0057] In some embodiments, the mobile application may provide the user with augmented reality (AR) weather visualizations (**834**), AR wave realizations (**832**), real-time wave data based on a location (**826**) either suggested by the application or selected by the user, predicted wave data analysis and characterization (**824**), and rip current and/or tsunami warnings (**828**).

[0058] In other words, embodiments of the disclosed technology enable:

[0059] (1) Surveillance, by monitoring the sub-microclimate conditions to detect developing optimal surfing opportunities;

[0060] (2) Diagnosis, based on the simplification of sub-microclimate weather reporting for determining a surf plan based on surfer location, skill level, equipment tolerance, and wave pattern characterization data with the assistance of machine learning technology; and

[0061] (3) Recommendations, by performing go-to action notifications based on pre-set user specifications and predictive machine learning recommendations giving the surfer a heads-up of the buildup of a great surf session.

Flow Diagrams and Methods for Example Embodiments

[0062] FIGS. **9-11**, **12**A and **12**B show flow diagrams for different aspects of real-time wave monitoring and sensing, according to embodiments of the disclosed technology. As shown in the flow diagrams, machine learning and computational algorithms are used to produce outputs based on inputs for different aspects of real-time wave monitoring and sensing.

[0063] FIG. **9** shows an example flow diagram of the machine learning analysis for the RIPS system. As shown therein, the initial set of inputs include one or more of user input preferences, RIPS sensor data (which is measured collected via the RIPS buoys are transmitted to the remote server, as shown in the context of FIG. **1**), social media feeds, web-camera video feeds, satellite data, information from NOAA buoys, and a user and/or beach location. In other words, the machine learning and computational algorithms **910** are able to combine a number of secondary sources of data with the RIPS sensor data to output climate data. In some embodiments, the output climate data may include one or more of macroclimate data, microclimate data (e.g., a local set of atmospheric conditions that differ from those in the surrounding areas, often with a slight difference but sometimes with a substantial one), sub-microclimate data, and regional climate data. In other words, because climate is statistical, which implies spatial and temporal variation of the mean values of the describing parameters, within a region there can occur and persist over time sets of statistically distinct conditions. Thus, the machine learning algorithms are able to combine the RIPS sensor data with secondary sources to generate climate conditions across differently sized spatial regions.

[0064] In a second step, the various climate data may be input into the machine learning and computational algorithms **920** to generate one or more outputs that a user may use to plan and execute an enjoyable and rewarding surfing experience. The various outputs that are available to the user include wave information, weather conditions, a user skill level, sun exposure limits, a travel route from the user's current location to the recommended surfing spot, equipment needed, scheduling information (e.g., when is the surfing spot open till, does the user have prior commitments, etc.) and beach locations.

[0065] In some embodiments, one or more of the various outputs may be delivered to the user using at least one of the enumerated output modalities. For example, the outputs may be provided to the user using an AR data visualization or an application for a smartphone (as described in the context of FIG. **8**), or via text or email notification and updates, or through a web application, and depending on the preference of the user.

[0066] In some embodiments, and in the context of FIG. **9**, some features of the disclosed technology include:

[0067] (1) Accuracy: delivering sub-microclimate reports for optimized local surfing;

[0068] (2) Predictive diagnosis: wave characterization used in developing a plan based on events predicted within an hour window using machine learning analysis giving the surfer a heads up on a potentially great experience;

[0069] (3) Notifications: action notifications based on pre-set user specifications and machine learning recommendations give surfers traffic recommendations, estimated travel times, equipment needed, and length of expected surf conditions. This reduces excess down time stuck in traffic, wrong turns to surf beaches, and excess equipment weight saving in fuel consumption that contributes to negatively impacting the coastal environments; and

[0070] (4) location: radius analysis notifies the surfer if response time is achievable based on current location and location of the beach being monitored by indicating a radius in which the surfer can travel in and would still be able to respond to waves if conditions present to be optimal for surfing at the beach being monitored by the RIPS system.

[0071] FIG. **10** shows an example flow diagram for the machine learning and computational analysis that generates wave data. As shown therein, the inputs to a first set of machine learning and computational algorithms **1010** may include air pressure data, wind data, tide data, RIPS sensor data, web-camera feeds, NOAA data, and/or air temperature data. As discussed earlier, the disclosed technology may use a combination of secondary sources with the RIPS sensor data, and in this example, generate wave data (**1091**). In an example, the wave information (**991**) shown in FIG. **9** may correspond to the generated wave data (**1091**).

[0072] The wave data (**1091**) may be used in conjunction with location data (e.g., location of the one or more RIPS buoys, the user location, etc.) to determine several wave characteristics that are enumerated in the following table (and a subset of which are shown in FIG. **10**).

TABLE 1

Wave Characteristics

Characteristic	Description
Knot	A unit of speed equal to one nautical mile per hour
Wave length	The distance between the crest of one wave to a crest of the next
Wave height	The difference between the elevations of a crest and a neighboring trough
Trough	The bottom of the wave, the opposite of a crest
Rogue wave	An open ocean wave bigger than the current sea condition
Refraction	The effect by which a swell moving along a point of land slows down where it feeds shallow water
Crest	The top and highest point of a wave
Wave train	A group of swells of similar wave lengths
Wave period	The time between two consecutive wave crests
Set	A group of waves
Glassy	A maritime condition when there is no wind to ripple the wave force
Reflection	When a wave strikes a hard object and bounces some of its energy off into another direction
Flat	With no waves or with no surf
Lull	Time between sets of wave with no waves breaking
Section	A part of the wave that breaks ahead of the curl line
Pit	The impact zone of the wave or the most hollow part of the tube
Peak	The spot in the ocean where the wave breaks for both sides
Lip	The curling part of a wave
Grounds wells	A swell that traveled thousands of miles through the ocean with a period of 15 seconds or more
Corduroy	The vision of a series of swells marching in from the horizon
Closeout	When a wave breaks all at once, with no shape or shoulder
Chop	Bumpy ocean and wave conditions that are rough due to strong winds or currents
Carve	A sharp turn on the wave face
Beach break	Waves that break over sandbars
Bathymetry	The measurement of depths of water in oceans and seas
Barrel	The tube, or the curl of the wave
Wedge	A steep wave
Backwash	When a wave sweeps up the beach and returns to the ocean, sometimes colliding with incoming waves

[0073] FIG. **11** shows an example flow diagram for the machine learning and computational analysis that generates user skill and equipment determinations. As shown therein, input to a first set of machine learning and computational algorithms **1110** may be a user's vital statistics, which include lung capacity (e.g., liters of air), height, weight, body fat %, heart rate (e.g., beats per minute), blood O_2 and stamina (e.g., average heart rate elevation over time). The vital statistics may be used to generate a user's surfing skill level (**1192**). In an example, the skill level required (**992**) shown in FIG. **9** may correspond to the generated skill level (**1192**).

[0074] The generated skill level (**1192**) may be used in conjunction with wave data (**1191**), equipment ratings and a user's current location as inputs to a second set of machine learning and computational algorithms **1120**, which may subsequently generate information that may be used by the user to plan and execute an enjoyable surfing experience. In some embodiments, this generated information may include a surfboard type, a wetsuit type, a surfboard wax type, a boot type, a surfing location, a surfboard fin type, a time window (or period) for surfing, a leash type, and a travel route from the user's current location to the recommended surfing location.

[0075] FIGS. **12**A and **12**B show example flow diagrams for the machine learning and computational analysis that generates rip current and tsunami warnings to alert users. As shown therein, a first set of inputs to the machine learning and computational algorithms **1210** may include water direction data, continuous wind duration data, continuous wind speed data, average water depth data, continuous wind direction data, and continuous water velocity direction data. These inputs, which may be ascertained based on the sensing arrays in one or more RIPS buoys, are used to generate wave characteristics that may include wave height, wave length, wave period, or wave propagation (or other characteristics tabulated above).

[0076] In some embodiments, the wave characteristics are used as inputs to a second set of machine learning and computational algorithms **1220** that generates aggregated wave characteristics that may include significant wave height (or peak), the average wave height and/or the largest individual wave in a fixed period (e.g., 20 minutes). These outputs are used in conjunction with a user location and a beach location as inputs to a third set of machine learning and computational algorithms **1230** that generates a rip current warning **1295**.

[0077] Similarly, FIG. **12**B shows the machine learning and computational analysis that generates tsunami warnings to alert users. In this scenario, the inputs to the first set of machine learning and computational algorithms **1210** may include continuous water direction data, continuous wind speed data, continuous seismic data, and continuous water velocity data. The second set of machine learning and computational algorithms **1220** is used in a manner similar to that described in the context of FIG. **12**A, and the aggregated wave characteristics are used in conjunction with a user location as inputs to a third set of machine learning and computational algorithms **1230** that generates a tsunami warning **1295**.

[0078] FIG. **13** shows a flowchart of an example method **1300** of real-time monitoring and sensing of wave conditions, which may be implemented at a remote server (e.g., cloud computing services **125** in FIG. **1**). The method **1300** includes, at step **1310**, receiving, from a buoy over a first wireless communication channel, information based on continuously monitoring one or more characteristics of the wave conditions. In some embodiments, and as discussed in the "Example Embodiment of a RIPS Buoy" section, the buoy may include a sensor array that includes at least one of a camera, an accelerometer, a vibration sensor, a temperature sensor, or a pressure transducer.

[0079] The method **1300** includes, at step **1320**, receiving, from a user device over a second wireless communication channel, user preferences. The method **1300** may further include the step of generating the message by combining the information and the user preferences based on a machine learning or computational algorithm, as discussed in the "Flow Diagrams and Methods for Example Embodiments" section. In some embodiments, the first and second communication channels may be part of the same infrastructure (e.g., the cellular LTE network). In other embodiments, the first channel may be a cellular LTE network communication link, whereas the second channel may be a Bluetooth or Wi-Fi link.

[0080] The method **1300** includes, at step **1330**, transmitting, to the user device over the second wireless communication channel, a message based on the information and the user preferences in response to a user request.

[0081] FIG. **14** shows a flowchart for another example method **1400** of real-time monitoring and sensing of wave conditions, which may be implemented at a user device (e.g., smartphone or tablet **115** in FIG. **1**). The method **1400** includes, at step **1410**, transmitting, to a remote server, user preferences.

[0082] The method **1400** includes, at step **1420**, transmitting, to the remote server, a user request. In some embodiments, the user preferences include a user surfing skill level, and transmitting the user request include accessing an application. For example, simply accessing the application may send a request to the remote server for an update on wave conditions associated with a pre-selected location by the user.

[0083] The method **1400** includes, at step **1430**, receiving, from the remote server and in response to the user request, a message based on the user preferences and information corresponding to the wave conditions. In some embodiments, the message may include a determination of whether the wave conditions at the monitoring location are compatible with the user surfing skill level. For example, and as discussed in section "Flow Diagrams and Methods for Example Embodiments", one or more sets of machine learning and computational algorithms may be used to determine the user skill level based on the user's vital statistics, and subsequently used to determine which surfing location has wave conditions that are suited for the user, and will provide an enjoyable surfing experience.

[0084] In some embodiments, and as discussed in the context of FIG. **8**, the application may include at least one of a social media feed, a local product for rent or sale, a graphical representation of a portion of the wave condition information (e.g., raw data from a sensor, or aggregated data that was processed on either the buoy or the remote server), or traffic data between a current user location and the monitoring location.

[0085] Embodiments of the disclosed technology further include, and in the context of FIGS. **2**A, **2**B, **3**, **4**, **5**, **7**A and **7**B, a system for real-time monitoring of wave conditions, comprising a plurality of buoys, wherein each of the plurality of buoys (e.g., FIG. **2**A and elements **71***x* in FIGS. **7**A and **7**B) comprises a sensor array configured to continuously monitor one or more characteristics of the wave conditions, a transceiver configured to transmit, to a remote server, information corresponding to the one or more characteristics of the wave conditions over a wireless communication channel, and a tether that physically couples the buoy to an anchor, wherein the information from each of the plurality of buoys is combined with a user preference to provide a user with a message regarding the wave conditions in response to a user request, and wherein a duration between the user request and transmission of the information from each of the plurality of buoys is less than a predetermined value.

[0086] Embodiments of the disclosed technology further include a method for real-time monitoring of wave conditions, comprising receiving, from a plurality of buoys (e.g., elements **71***x* in FIGS. **7**A and **7**B) over a first wireless communication channel (e.g., **74***x* in FIG. **7**A, **146** and **147** in FIG. **1**), information based on continuously monitoring one or more characteristics of the wave conditions, receiving, from a user device over a second wireless communication channel (e.g., **145** in FIG. **1**), user preferences, and transmitting, to the user device over the second wireless communication channel, a message based on the information and the user preferences in response to a user request, wherein a duration between the receiving the information and the receiving the user request is less than a predetermined value.

[0087] In some embodiments, each of the plurality of buoys (e.g., FIG. **2**A and elements **71***x* in FIGS. **7**A and **7**B) comprises a sensor array that includes at least one of a camera, an accelerometer, a vibration sensor, a temperature sensor, or a pressure transducer.

[0088] In some embodiments, the method further includes the step of generating the message by combining the information and the user preferences based on a machine learning or computational algorithm (e.g., FIGS. **9**, **10**, **11**, **12**A and **12**B).

[0089] In some embodiments, the plurality of buoys are arranged approximately linearly, or in a two-dimensional grid (e.g., FIG. **7**A). In other embodiments, the plurality of buoys comprises multiple buoys at different depths (e.g., FIG. **7**B).

[0090] FIG. **15** shows an example of a hardware platform **1500** that can be used to implement some of the techniques described in the present document. For example, the hardware platform **1500** may implement the methods **1300** or **1400**, or may implement the various modules described herein. The hardware platform **1500** may include a processor **1502** that can execute code to implement a method. The hardware platform **1500** may include a memory **1504** that may be used to store processor-executable code and/or store data. The hardware platform **1500** may further include a sensing array **1506** and a communication interface **1508**. For example, the sensing array **1506** may include a camera, various sensors (e.g., pressure, temperature, vibration) and/or an accelerometer. For example, the communication inter-

face **1508** may implement one or more of the communication protocols (LTE, Wi-Fi, and so on) described.

[0091] Implementations of the subject matter and the functional operations described in this patent document can be implemented in various systems, digital electronic circuitry, or in computer software, firmware, or hardware, including the structures disclosed in this specification and their structural equivalents, or in combinations of one or more of them. Implementations of the subject matter described in this specification can be implemented as one or more computer program products, e.g., one or more modules of computer program instructions encoded on a tangible and non-transitory computer readable medium for execution by, or to control the operation of, data processing apparatus. The computer readable medium can be a machine-readable storage device, a machine-readable storage substrate, a memory device, a composition of matter effecting a machine-readable propagated signal, or a combination of one or more of them. The term "data processing unit" or "data processing apparatus" encompasses all apparatus, devices, and machines for processing data, including by way of example a programmable processor, a computer, or multiple processors or computers. The apparatus can include, in addition to hardware, code that creates an execution environment for the computer program in question, e.g., code that constitutes processor firmware, a protocol stack, a database management system, an operating system, or a combination of one or more of them.

[0092] A computer program (also known as a program, software, software application, script, or code) can be written in any form of programming language, including compiled or interpreted languages, and it can be deployed in any form, including as a stand-alone program or as a module, component, subroutine, or other unit suitable for use in a computing environment. A computer program does not necessarily correspond to a file in a file system. A program can be stored in a portion of a file that holds other programs or data (e.g., one or more scripts stored in a markup language document), in a single file dedicated to the program in question, or in multiple coordinated files (e.g., files that store one or more modules, sub programs, or portions of code). A computer program can be deployed to be executed on one computer or on multiple computers that are located at one site or distributed across multiple sites and interconnected by a communication network.

[0093] The processes and logic flows described in this specification can be performed by one or more programmable processors executing one or more computer programs to perform functions by operating on input data and generating output. The processes and logic flows can also be performed by, and apparatus can also be implemented as, special purpose logic circuitry, e.g., an FPGA (field programmable gate array) or an ASIC (application specific integrated circuit).

[0094] Processors suitable for the execution of a computer program include, by way of example, both general and special purpose microprocessors, and any one or more processors of any kind of digital computer. Generally, a processor will receive instructions and data from a read only memory or a random access memory or both. The essential elements of a computer are a processor for performing instructions and one or more memory devices for storing instructions and data. Generally, a computer will also include, or be operatively coupled to receive data from or transfer data to, or both, one or more mass storage devices for storing data, e.g., magnetic, magneto optical disks, or optical disks. However, a computer need not have such devices. Computer readable media suitable for storing computer program instructions and data include all forms of nonvolatile memory, media and memory devices, including by way of example semiconductor memory devices, e.g., EPROM, EEPROM, and flash memory devices. The processor and the memory can be supplemented by, or incorporated in, special purpose logic circuitry.

[0095] It is intended that the specification, together with the drawings, be considered exemplary only, where exemplary means an example. As used herein, the singular forms "a", "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. Additionally, the use of "or" is intended to include "and/or", unless the context clearly indicates otherwise.

[0096] While this patent document contains many specifics, these should not be construed as limitations on the scope of any invention or of what may be claimed, but rather as descriptions of features that may be specific to particular embodiments of particular inventions. Certain features that are described in this patent document in the context of separate embodiments can also be implemented in combination in a single embodiment. Conversely, various features that are described in the context of a single embodiment can also be implemented in multiple embodiments separately or in any suitable subcombination. Moreover, although features may be described above as acting in certain combinations and even initially claimed as such, one or more features from a claimed combination can in some cases be excised from the combination, and the claimed combination may be directed to a subcombination or variation of a subcombination.

[0097] Similarly, while operations are depicted in the drawings in a particular order, this should not be understood as requiring that such operations be performed in the particular order shown or in sequential order, or that all illustrated operations be performed, to achieve desirable results. Moreover, the separation of various system components in the embodiments described in this patent document should not be understood as requiring such separation in all embodiments.

[0098] Only a few implementations and examples are described and other implementations, enhancements and variations can be made based on what is described and illustrated in this patent document.

What is claimed is:

1. A system for real-time monitoring of wave conditions, comprising:

a plurality of buoys,

wherein each of the plurality of buoys comprises:

a sensor array configured to continuously monitor one or more characteristics of the wave conditions;

a transceiver configured to transmit, to a remote server, information corresponding to the one or more characteristics of the wave conditions over a wireless communication channel; and

a tether that physically couples the buoy to an anchor,

wherein the information from at least one of the plurality of buoys is used to provide a user with a message regarding the wave conditions in response to a user request, and

wherein a duration between the user request and transmission of the information from the at least one of the plurality of buoys is less than a predetermined value.

2. The system of claim **1**, wherein the one or more characteristics comprises at least one of a wave height, a wave length, or a wave period.

3. The system of claim **1**, wherein each of the plurality of buoys further comprises:

a power regeneration device physically coupled to the buoy and the anchor via the tether, wherein the power regeneration device is configured to convert kinetic energy from movement of the buoy due to the wave conditions to electrical energy.

4. The system of claim **1**, wherein each of the plurality of buoys further comprises:

a recoil cable module physically coupled to the buoy and the anchor via the tether, wherein the recoil cable module is configured to adjust the height of the buoy from the anchor.

5. The system of claim **1**, wherein the user request comprises accessing an application, and wherein the message comprises a recommendation for surfing at a location near the buoy that is received through the application.

6. The system of claim **1**, wherein the user request comprises a location, wherein the message comprises a microclimate information associated with the location, and wherein the microclimate information is generated using a machine learning or computational algorithm and wave energy information from the at least one of the plurality of buoys.

7. The system of claim **1**, wherein the user request comprises a stabilization request from an offshore supply vessel, and wherein the message comprises output calculations from a dynamic positioning computer.

8. The system of claim **7**, wherein the dynamic positioning computer is configured to receive wind, roll, or pitch data from the offshore supply vessel and wave energy information from the at least one of the plurality of buoys, and generate the output calculations by using a machine learning or computational algorithm.

9. The system of claim **1**, wherein the message comprises a tsunami warning or a rip current warning.

10. The system of claim **1**, wherein the sensor array comprises at least one of a camera, an accelerometer, a vibration sensor, a temperature sensor, or a pressure transducer.

11. The system of claim **1**, wherein generating the message is based on combining, using a machine learning or computational algorithm, the information from the at least one of the plurality of buoys with a user preference.

12. The system of claim **1**, wherein the plurality of buoys are arranged approximately linearly, or in a two-dimensional grid.

13. The system of claim **1**, wherein the plurality of buoys comprises multiple buoys at different depths.

14. A method for real-time monitoring of wave conditions, comprising:

receiving, from at least one of a plurality of buoys over a first wireless communication channel, information based on continuously monitoring one or more characteristics of the wave conditions,

receiving, from a user device over a second wireless communication channel, user preferences; and

transmitting, to the user device over the second wireless communication channel, a message based on the information and the user preferences in response to a user request,

wherein a duration between the receiving the information and the receiving the user request is less than a predetermined value.

15. The method of claim **14**, wherein each of the plurality of buoys comprises a sensor array that includes at least one of a camera, an accelerometer, a vibration sensor, a temperature sensor, or a pressure transducer.

16. The method of claim **14**, wherein each of the plurality of buoys comprises a suction anchor coupled to a hydraulic pump at a remote location, and wherein the hydraulic pump is configured to pump fluid out of the suction anchor to adjust a vacuum pressure therein and securely anchor each of the plurality of buoys to a sea floor.

17. The method of claim **14**, wherein the one or more characteristics of the wave conditions comprises at least one of continuous wind speed, continuous water velocity or continuous water direction, and wherein the message comprises a tsunami warning or a rip current warning.

18. The method of claim **14**, wherein the plurality of buoys are arranged approximately linearly, or in a two-dimensional grid.

19. The method of claim **14**, wherein the plurality of buoys comprises multiple buoys at different depths.

20. The method of claim **14**, wherein the first communication channel comprises a relay, and wherein the relay is a satellite or a drone.

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