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- (54) Title:** APPARATUS AND METHODS FOR DETECTION OF OBJECTS USING BROADBAND SIGNALS

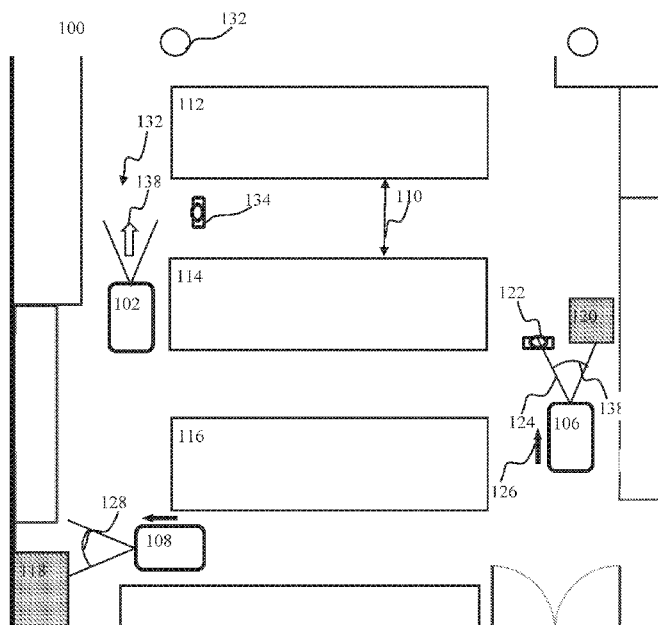


FIG. 1

(57) Abstract: Broadband signal transmissions may be used for object detection and/or ranging. Broadband transmissions may comprise a pseudo-random bit sequence or a bit sequence produced using, a random process. The sequence may be used to modulate transmissions of a given wave type. Various types of waves may be utilized, pressure, light, and radio waves. Waves reflected by objects within the sensing volume may be sampled. The received signal may be convolved with a time-reversed copy of the transmitted random sequence to produce a correlogram. The correlogram may be analyzed to determine range to objects. The analysis may comprise determination of one or more peaks/troughs in the correlogram. Range to an object may be determined based on a time lag of a respective peak.

APPARATUS AND METHODS FOR DETECTION OF OBJECTS USING BROADBAND SIGNALSPriority

This application claims the benefit of priority to U.S. Patent Application Serial No. 14/804,043 filed July 20, 2015 of the same title, the contents of which being incorporated herein by reference in its entirety.

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BACKGROUND OF THE DISCLOSURE***Field of the disclosure***

[0002] The present disclosure relates generally to remote detection of objects and more particularly in one exemplary aspect to computer apparatus and methods for detecting objects using reverse correlation ranging.

Description of Related Art

[0003] Object detection may be of use in a variety of applications including assisted vehicle navigation, autonomous robotic navigation, home automation, classification, and/or other applications. In some applications of robotic navigation it may be of benefit to detect objects remotely with a given margin of time in order to, e.g., execute a maneuver.

[0004] Some existing ranging technologies may be susceptible to interfere with one another. For example, two traditional sonars operating at the same time at in the same frequency band may not function correctly due to cross interference.

[0005] Additional deficiencies are that existing ranging technologies are often pulsed, as in not operated continuously in time, and as such detection of obstacles between pulses is not possible. For example, a sonar generates a chirp and then waits for the echo, depending on the strength of the chirp the amount of time between chirps can be 100 milliseconds (ms) or longer.

[0006] Further, existing technologies normally are narrow band, and as such some objects are not detectable at a specific frequency but would be detected using broad band transmissions.

[0007] Accordingly, there is a salient need for improved sensing apparatus and methods for detection of objects and/or ranges to objects.

SUMMARY OF THE DISCLOSURE

[0008] The present disclosure satisfies the foregoing needs by providing, *inter alia*, apparatus and methods for detecting objects using reverse correlation ranging.

[0009] In a first aspect of the present disclosure, an apparatus for determining range to an object is disclosed. In one embodiment, the apparatus includes: a transmitter component configured to transmit a broadband signal; a receiver component configured to sample a reflected signal comprised of a reflection of the broadband signal off the object, to produce a sampled signal; and a processing component. In one exemplary embodiment, the processing component is further configured to: determine a time-reversed instance of the transmitted signal; determine a correlogram, the correlogram comprising a convolution of the time reversed instance of the transmitted signal and the sampled signal at a plurality of lags; compare one or more correlogram values at the plurality of lags to a detection threshold; and based on a given correlogram value breaching the detection threshold, determine a range to the object corresponding to a given lag of the plurality of lags associated with the given correlogram value.

[0010] In a first variant, the broadband signal comprises a sequence of bits obtained based on a random or pseudo-random process, the sequence of bits characterized by a frequency invariant power spectral density.

[0011] In a second variant, the broadband signal comprises a sequence of bits obtained based on a process characterized by a power spectral density that increases with frequency.

[0012] In a third variant, the broadband signal comprises a sequence of bits obtained based on a process characterized by a power spectral density that decreases with frequency.

[0013] In a fourth variant, the broadband signal comprises a continuously valued sequence characterized by a random or pseudo-random distribution of values. In one such case, the random distribution comprises a Gaussian process.

[0014] In a fifth variant, the broadband signal comprises an electromagnetic wave transmission. In one such implementation, the broadband signal further comprises an acoustic wave transmission. In another such implementation, the receiver component is spatially spaced from the transmitter component. In still a third such implementations, the electromagnetic

wave is characterized by a frequency selected within a radio frequency band. For example, the transmitter component may comprise an acoustic transducer configured to radiate acoustic waves and a radio frequency antenna configured to radiate radio frequency waves in the radio frequency band. Still further, the receiver component may comprise an acoustic transducer configured to receive reflected acoustic waves and a radio frequency antenna configured to receive reflected radio frequency waves in the radio frequency band. In a fourth such implementation, the electromagnetic wave is characterized by a frequency selected within a visible light frequency band; the transmitter component comprises a light emitting element; and the receiver component comprises a photodetector. In one such case, the light element comprises an electrically pumped semiconductor laser element.

[0015] In a sixth variant, the plurality of lags exceeds 100 lags.

[0016] In a seventh variant, the detection threshold determination comprises determination of a mean value and a standard deviation value of the correlogram; and the detection threshold comprises a positive component configured greater than the mean value and a negative component configured smaller than a negative mean value having an absolute magnitude equal to the mean value. In one such variant, the positive component is configured based on a first number of standard deviation values above the mean value; and the negative component is configured based on a second number of standard deviation values below the negative mean value.

[0017] In a second aspect of the present disclosure, a non-transitory computer-readable storage medium having instructions embodied thereon is disclosed. In one embodiment, the instructions are executable by a processing apparatus to perform a method of detecting an object during navigation by a robotic apparatus, the method comprising: determining a pseudorandom sequence of bits; transmitting the pseudorandom sequence of bits using a wave type to produce a broadband signal, the broadband signal configured to irradiate a portion of an environment of the robotic apparatus; sampling reflections of the broadband signal from one or more objects in the environment; storing the sampled reflections of the broadband signal in a memory buffer for a time interval; convolving the stored sampled reflections with a time-reversed copy of the pseudorandom sequence of bits to produce a correlogram; determining at least one peak value based on an evaluation of the correlogram; and providing an indication of the one or more objects present within the environment to a controller of the robotic apparatus, the indication configured to cause an execution of action by the robotic apparatus.

[0018] In a first variant, the pseudorandom sequence of bits comprises a maximum length sequence comprising a number of bits; and the memory buffer is configured to store at least number of samples of the sampled reflections equal to the number of bits.

[0019] In a third aspect of the present disclosure, an apparatus for determining at least one positional attribute associated with an object is disclosed. In one embodiment, the apparatus includes: a transmitter component configured to transmit an oscillatory signal; a receiver component configured to sample a reflected signal comprised of a reflection of the oscillatory signal off the object, to produce a sampled signal; and computerized logic. In one embodiment, the computerized logic is configured to: obtain a modified instance of at least a portion of the transmitted oscillatory signal; perform a comparison of at least a portion of the modified instance to at least a portion of the sampled signal; evaluate one or more values obtained from the comparison to a detection criterion; and based on at least one of the one or more values meeting the detection criterion, determine the positional attribute associated with the object corresponding to a parameter associated with the at least one value.

[0020] In one variant, said positional attribute comprises a range; said oscillatory signal comprises either a broadband acoustic or broadband electromagnetic signal; said modified instance comprises a time-reversed instance of at least a portion of the transmitted oscillatory instance; said comparison comprises an autocorrelation performed at least at a plurality of time lags of each of the at least portion of modified instance and the at least portion of the sampled signal; said one or more values comprise respective one or more amplitudes; and said evaluation of said one or more values obtained from the comparison to a detection criterion comprises comparison to a predetermined detection threshold value stored in the apparatus.

[0021] In a second variant, the oscillatory signal further comprises a pseudorandom sequence that includes a plurality of bits of a given length selected using a random process; and a memory buffer is configured to store at least a number of samples of the sampled reflections greater than the given length.

[0022] Further features of the present disclosure, its nature and various advantages will be more apparent from the accompanying drawings and the following detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] FIG. 1 is block diagram illustrating operation of a robotic apparatus of the disclosure on premises of a retail store in accordance with one implementation.

[0024] FIG. 2 is a graphical illustration depicting a robotic vehicle comprising sensor apparatus of the disclosure, in accordance with one or more implementations.

[0025] FIG. 3 illustrates signal transmission and recording for use with the reverse correlation ranging methodology of the disclosure in accordance with one implementation.

[0026] FIGS. 4A-4B illustrate correlograms obtained using the reverse correlation methodology of the disclosure in accordance with one implementation.

[0027] FIG. 5 is a functional block diagram illustrating a computerized system configured to implement the bistatic sensing methodology of the disclosure, an adaptive predictor and/or a combiner components configured for operating, e.g., the robotic apparatus of FIG. 2, according to one or more implementations.

[0028] FIG. 6 is a logical flow diagram illustrating method of detection range to an object using of the approach of the disclosure, in accordance with one or more implementations.

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DETAILED DESCRIPTION

[0030] Embodiments of the present disclosure will now be described in detail with reference to the drawings, which are provided as illustrative examples so as to enable those skilled in the art to practice the disclosure. Notably, the figures and examples below are not meant to limit the scope of the present disclosure to a single embodiment, but other embodiments are possible by way of interchange of or combination with some or all of the described or illustrated elements. Wherever convenient, the same reference numbers will be used throughout the drawings to refer to same or like parts.

[0031] Where certain elements of these embodiments can be partially or fully implemented using known components, only those portions of such known components that are necessary for an understanding of the present disclosure will be described, and detailed descriptions of other portions of such known components will be omitted so as not to obscure the disclosure.

[0032] In the present specification, an embodiment showing a singular component should not be considered limiting; rather, the disclosure is intended to encompass other embodiments including a plurality of the same component, and vice-versa, unless explicitly stated otherwise herein.

[0033] Further, the present disclosure encompasses present and future known equivalents to the components referred to herein by way of illustration.

[0034] As used herein, the term “bus” is meant generally to denote all types of interconnection or communication architecture that is used to access the synaptic and neuron memory. The “bus” could be optical, wireless, infrared or another type of communication

medium. The exact topology of the bus could be for example standard “bus”, hierarchical bus, network-on-chip, address-event-representation (AER) connection, or other type of communication topology used for accessing, e.g., different memories in pulse-based system.

[0035] As used herein, the terms “computer”, “computing device”, and “computerized device”, include, but are not limited to, personal computers (PCs) and minicomputers, whether desktop, laptop, or otherwise, mainframe computers, workstations, servers, personal digital assistants (PDAs), handheld computers, embedded computers, programmable logic device, personal communicators, tablet computers, portable navigation aids, J2ME equipped devices, cellular telephones, smart phones, personal integrated communication or entertainment devices, or literally any other device capable of executing a set of instructions and processing an incoming data signal.

[0036] As used herein, the term “computer program” or “software” is meant to include any sequence or human or machine cognizable steps which perform a function. Such program may be rendered in virtually any programming language or environment including, for example, C/C++, C#, Fortran, COBOL, MATLAB™, PASCAL, Python, assembly language, markup languages (e.g., HTML, SGML, XML, VoXML), and the like, as well as object-oriented environments such as the Common Object Request Broker Architecture (CORBA), Java™ (including J2ME, Java Beans, etc.), Binary Runtime Environment (e.g., BREW), and the like.

[0037] As used herein, the terms “connection”, “link”, “transmission channel”, “delay line”, “wireless” means a causal link between any two or more entities (whether physical or logical/virtual), which enables information exchange between the entities.

[0038] As used herein, the term “memory” includes any type of integrated circuit or other storage device adapted for storing digital data including, without limitation, ROM, PROM, EEPROM, DRAM, Mobile DRAM, SDRAM, DDR/2 SDRAM, EDO/FPMS, RLDRAM, SRAM, “flash” memory (e.g., NAND/NOR), memristor memory, and PSRAM.

[0039] As used herein, the terms “microprocessor” and “digital processor” are meant generally to include all types of digital processing devices including, without limitation, digital signal processors (DSPs), reduced instruction set computers (RISC), general-purpose (CISC) processors, microprocessors, gate arrays (e.g., field programmable gate arrays (FPGAs)), PLDs, reconfigurable computer fabrics (RCFs), array processors, secure microprocessors, and application-specific integrated circuits (ASICs). Such digital processors may be contained on a single unitary IC die, or distributed across multiple components.

[0040] As used herein, the term “network interface” refers to any signal, data, or software interface with a component, network or process including, without limitation, those of the FireWire (e.g., FW400, FW800, etc.), USB (e.g., USB2), Ethernet (e.g., 10/100, 10/100/1000 (Gigabit Ethernet), 10-Gig-E, etc.), MoCA, Coaxsys (e.g., TVnet™), radio frequency tuner (e.g., in-band or OOB, cable modem, etc.), Wi-Fi (802.11), WiMAX (802.16), PAN (e.g., 802.15), cellular (e.g., 3G, LTE/LTE-A/TD-LTE, GSM, etc.) or IrDA families.

[0041] As used herein, the term “synaptic channel”, “connection”, “link”, “transmission channel”, “delay line”, and “communications channel” are meant generally to denote, without limitation, a link between any two or more entities (whether physical (wired or wireless), or logical/virtual) which enables information exchange between the entities, and is characterized by a one or more variables affecting the information exchange.

[0042] As used herein, the term “Wi-Fi” refers to, without limitation, any of the variants of IEEE-Std. 802.11 or related standards including 802.11 a/b/g/n/s/v.

[0043] As used herein, the term “wireless” means any wireless signal, data, communication, or other interface including without limitation Wi-Fi, Bluetooth, 3G (3GPP/3GPP2), HSDPA/HSUPA, TDMA, CDMA (e.g., IS-95A, WCDMA, etc.), FHSS, DSSS, GSM, PAN/802.15, WiMAX (802.16), 802.20, narrowband/FDMA, OFDM, PCS/DCS, LTE/LTE-A/TD-LTE, analog cellular, CDPD, RFID/NFC, satellite systems, millimeter wave or microwave systems, acoustic, and infrared (i.e., IrDA).

Detailed Description of Exemplary Embodiments

[0044] Implementations of the present technology will now be described in detail with reference to the drawings, which are provided as illustrative examples so as to enable those skilled in the art to practice the technology. Notably, the figures and examples below are not meant to limit the scope of the present disclosure to a single implementation, but other implementations are possible by way of interchange of, or combination with some or all of the described or illustrated elements. Wherever convenient, the same reference numbers will be used throughout the drawings to refer to same or like parts.

[0045] Where certain elements of these implementations can be partially or fully implemented using known components, only those portions of such known components that are necessary for an understanding of the present technology will be described, and detailed descriptions of other portions of such known components will be omitted so as not to obscure

the disclosure.

[0046] In the present specification, an implementation showing a singular component should not be considered limiting; rather, the disclosure is intended to encompass other implementations including a plurality of the same components, and vice-versa, unless explicitly stated otherwise herein.

[0047] Further, the present disclosure encompasses present and future known equivalents to the components referred to herein by way of illustration.

[0048] Robotic devices may be used for performing maintenance of residential and/or commercial premises (e.g., retail stores, warehouses, meeting halls, stadiums) and/or other applications. By way of an illustration, an autonomous robotic cleaning apparatus may be employed for cleaning floors in a retail store. Environment in the store premises may be modified on a daily/weekly basis, e.g., during restocking operations and/or by placement of promotional items for a given period of time at a given location. The presence of humans (e.g., customers and/or store personnel) may alter the environment.

[0049] During autonomous operations, robots may detect obstacles. The autonomous robotic device may comprise an object detection sensor apparatus configured to detect presence of objects in the environment. The sensor apparatus may comprise a transmitter component and a receiver component spaced from the transmitter component. Such configuration wherein the transmitter and the receiver sensor are not-collocated (e.g., displaced from one another) may be referred to as the bistatic sensor configuration.

[0050] The transmitter component may be configured to transmit a signal comprising a random sequence. The receiver component may be used to detect reflection of this random sequence. In some implementations, an existing computer sound card may be employed for audio transmissions, a high speed FPGA may be used for radio and/or light wave transmissions. The transmitted and received signals may be used to determine a correlation of the generated sequence and the received signal (which may contain a reflection/echo). Determining the correlation at different time lags, may enable determination of time delay between transmission and reflections from objects. Time delay may be used to determine distance away to object(s). In some implementations continuous transmission of random signal ("noise") may be used. Detection of objects may be only limited by signal to noise and thus by duration of time needed to average in order to reliably detect objects. In high signal to noise scenarios with high transmission frequencies (e.g., 100 KHz and above), objects may be readily detected in 1 ms time interval or less (100 samples or more).

[0051] FIG. 1 illustrates operation of a robotic apparatus comprising a sensing apparatus of the disclosure in an environment comprising objects and/or humans in accordance with one implementation. The layout 100 of FIG. 1 may correspond to a floor plan or a retail store, layout of a shopping mall, an exhibit hall and/or other premises. In some implementations, rectangles 112, 114, 116, 118 may denote one or more of a shelf, a rack, a cabinet, a pallet, a display, a stack, a bin, a container, a box, a pail, and/or other implements for displaying product in a store. One or more shelves (e.g., 112, 114) may be spaced by one or more isles (e.g., isle width denoted by arrow 110 in FIG. 1). The premises layout 100 may comprise one or more humans denoted by icons 134, 122 and corresponding to e.g., store personnel, vendors, shoppers, and/or other categories.

[0052] One or more autonomous robotic devices 102, 106, 108 may be operable within the premises 100. The autonomously operating robotic device may be used for a variety of tasks, e.g., floor cleaning (e.g., vacuuming, dusting, scrubbing, polishing, waxing, and/or other cleaning operation), survey (e.g., product count), and/or other operations. Dimensions of the robotic device (e.g., 102) may, for example, be configured in accordance with operational environment of the device (e.g., minimum isle width, available cleaning time, and/or other task parameter).

[0053] In some implementations, an autonomously operating robotic device (e.g., 106) may be used for assisting customers (e.g., 122) by e.g., identifying a customer in need of assistance and offering the customer assistance via a machine-human interface. In one or more implementations, the human-machine interface may be based on sound, light, display, gesture, and/or other interface component. Customer detection may comprise analysis of customer posture, movement, gestures, facial expression, speech, sounds, and/or other behavior characteristics provided via camera and/or audio sensor.

[0054] One or more autonomously operating robotic devices (e.g., 102, 106, 108) may be configured to navigate the premises 100 along a trajectory. In some implementations, the trajectory may comprise a pre-configured trajectory (e.g., pre-programmed, pre-trained) and/or adaptively learned trajectory. In some implementations, the trajectory configuration may be effectuated using a methodology of combining programming and training e.g., such as described in U.S. Patent Application Serial No. 14/613,237, entitled "APPARATUS AND METHODS FOR PROGRAMMING AND TRAINING OF ROBOTIC DEVICES", filed February 3, 2015, each of the foregoing being incorporated herein by reference in its entirety.

[0055] In some implementations, training of the trajectory may be accomplished using a plurality of training trials. An individual trial may comprise an instance of the trajectory

navigation. Training may be effectuated using supervised learning methodology, e.g., such as described in in U.S. Patent Application Serial Nos. 14/070,239 entitled “REDUCED DEGREE OF FREEDOM ROBOTIC CONTROLLER APPARATUS AND METHODS”, filed November 1, 2013, 14/070,269, entitled “APPARATUS AND METHODS FOR OPERATING ROBOTIC DEVICES USING SELECTIVE STATE SPACE TRAINING”, filed November 1, 2013, and/or 14/542,391 entitled “FEATURE DETECTION APPARATUS AND METHODS FOR TRAINING OF ROBOTIC NAVIGATION” filed November 14, 2014, each of the foregoing being incorporated herein by reference in its entirety.

[0056] During training, the premises environment (e.g., illustrated by the layout 100 in FIG. 1) may comprise a given number of objects (e.g., shelves, product displays, furniture, building elements (e.g., partitions, walls, doorways, doors, pillars e.g., 132 in FIG. 1, and/or other elements) infrastructure components (point of sale) and/or other components. During training, the robotic apparatus may be configured to explore the premises environment in order to, e.g., to produce a map or other informational element of or relating to the premises (e.g., such as shown in FIG. 1). The map of the environment may be stored in the non-transitory memory of the robot.

[0057] During operation, the layout map (e.g., obtained during training) may be accessed and utilized for navigating the premises. In some implementations, e.g., of nighttime cleanup operations, the layout map may provide an adequate amount of detail for successful navigation of the premises. In one or more implementations, the navigation success may be characterized by one or more of an absence of collisions with objects within the premises, area coverage, energy use, traverse time, and/or other performance characteristics associated with a given task.

[0058] In some implementations, e.g., daytime operations and/or nighttime cleanup during restocking), the layout map may become out of date as additional objects (e.g., a product display 118) may be added, displaced (e.g., product display 120) and/or some objects missing (removed). One or more humans (134) may be present on the premises. The robotic device may be configured for dynamic autonomous detection of objects within the elements. As used herein the term object may be used to describe a shelf, a doorway, a pillar, a wall, a human, a display, and/or another physical entity that may protrude above a surface (e.g., floor) being navigated by the robotic device and that may potentially interfere with the task being executed by the robotic device. In some embodiments, the robotic device may additionally differentiate between objects that are stationary (e.g., structural elements of the building, storage boxes, etc.) and objects that frequently move (e.g., humans, animals, shipping boxes, and/or other objects).

In some cases, the differentiation may be performed based on e.g., visual analysis (e.g., facial recognition, bar code reader,), historic recognition (e.g., the object has not moved for a period of time), and/or other approaches. Various other schemes will be appreciated by those of ordinary skill in the related art, given the contents of the present disclosure.

[0059] In some implementations, object detection by the robotic device may be effectuated using a broadband sensor apparatus, e.g., such as described below with respect to FIGS. 2-2B, 5. The sensor apparatus may illuminate and/or irradiate a sensing volume proximate the robotic device using one or more wave types. In one or more implementations, the wave type may comprise a mechanical wave type (e.g., acoustic waves) wherein signal propagation acts as the propagation of a disturbance through a material medium (e.g., air, water) due to the repeated periodic motion of the particles of the medium about their mean positions, the disturbance being handed over from one particle to the next, and/or an electromagnetic wave wherein signal is propagated due to varying electric and/or magnetic fields.

[0060] Various mechanical waves may employed, e.g., audible, ultrasonic, infrasonic. Examples of electromagnetic waves may comprise light waves (visible, IR, UV), radio waves, and/or other wave bands. In FIG. 1, the sensing volume is denoted by lines 124 and comprises a volume in front of the robotic device 106 that may be moving along direction indicated by the solid arrow 126. The sensing volume may be characterized by a horizontal extent (e.g., denoted by arc 138, 128 in FIG. 1) and/or vertical extent (e.g. denoted by arc 218 in FIG. 2).

[0061] The broadband sensor apparatus may project a given pattern into the sensing volume. In one or more implementations, the pattern may comprise a pseudo-random bit sequence (e.g., maximum length sequence (MLS), Barker code sequence) determined using a maximal linear feedback shift register. In some implementations, the pattern may comprise a random bit sequence produced using, e.g., a random process. Various random processes may be utilized, e.g., uniform, Poisson and/or other process. In some implementations, the pattern may comprise a plurality of bits of a given length (e.g., 1024-bit MLS). Bit values within the sequence may comprise a binary sequence (e.g., [0. 1], [-1 1] or another sequence characterized by two alternate states. In one or more implementations, the sequence magnitude values may be produced using a Gaussian distribution.

[0062] Reflected wave signals may be sampled by the sensor. An object being present within the sensing volume (e.g., human 122, product display 120, 118) may alter the sensed (reflected) pattern. Analysis of the sensed pattern may enable detection in real time of one or more objects being present in pathway of the robotic device thereby enabling autonomous

operation of the robotic device in presence of potential obstructions.

[0063] FIG. 2 illustrates operation of a robotic vehicle comprising a broadband sensor apparatus, in accordance with one or more implementations. The robotic vehicle 200 may comprise one of the autonomous robotic devices 102, 106, 108 described above with respect to FIG. 1. The autonomously operating robotic device 200 of FIG. 2 may be used for a variety of tasks, e.g., floor cleaning (e.g., vacuuming, dusting, scrubbing, polishing, waxing, and/or other cleaning operation), survey (e.g., product count), and/or other operations. In some implementations, the autonomously operating robotic device may be used for assisting customers by e.g., identifying a customer in need of assistance and offering the customer assistance via a machine-human interface. In one or more implementations, the human-machine interface may be based on sound, light, display, gesture, and/or other interface component. Customer detection may comprise analysis of customer posture, movement, gestures, facial expression, speech, sounds, and/or other behavior characteristics provided via camera and/or audio sensor.

[0064] Dimensions of the robotic device may be selected sufficient to support the sensor components 202, 204, e.g., greater than 0.1 m in height in some implementations. The robotic device may be configured to traverse the environment at a speed selected from the range between 0.05 m/s and 10 m/s. In some implementations, the device 200 may comprise a robotic floor cleaning device with the following dimensions: width of 0.8 m, length of 1.6 m and height of 1.14 m. The floor cleaning device may be configured to move during operation at a speed between 0.01 m/s and 3 m/s. The robotic device with above dimensions may be configured to operate within a premises characterized by isle dimensions (e.g., 110) between 1.2 m and 2.7 m.

[0065] The device 200 may comprise a broadband sensor apparatus configured to detect presence of objects and/or to determine range to objects in the environment. The sensor apparatus may comprise a transmitter component 202 and a receiver component 204. The transmitter and the receiver components may be disposed spaced from one from one another in a bistatic configuration. In one or more implementations, the transmitter may comprise a light source (e.g., visible, infrared (IR), ultraviolet (UV)), pressure wave (e.g., audio, ultrasonic) source, a radio wave source, and/or other wave type source. In some implementations of light waves, the transmitter 202 may comprise a light emitting diode (LED), electrically pumped semiconductor laser (e.g., a laser diode), and/or another source type; the receiver may comprise a photodetector (e.g., photodiode, and/or a phototransistors), and/or other sensors. In one or more implementations of radio wave transmissions and/or reception, the component 202 may

comprise a radio frequency antenna and a radio frequency transmitter; the component 204 may comprise a radio frequency antenna and a radio frequency receiver. The receiver component 204 of the sensor apparatus may comprise an acoustic transducer (e.g., a microphone), and/or other sensor configured to detect reflected waves corresponding to the modality of the transmitter 202.

[0066] Transmitter and/or receiver may be characterized by a directivity pattern (e.g., field of view denoted by arcs 218, 228 in FIG. 2 and/or 124 in FIG. 1). In some implementations of radio wave transmissions, radio frequency antennas may comprise dipole antennas characterized by directivity of a dipole. Antennas with an increased directivity (e.g., 3dB beam width of less than 180°) directional In some implementations of light transmissions, center axis of the transmitter 202 field of view 218 may be inclined with respect to the plane of operation of the apparatus 200 (e.g., the plane 212 in FIG. 2).

[0067] The transmitter component 202 may project (e.g., as illustrated by curves 306 in FIG. 3) a given pattern into sensing volume,. In one or more implementations, the pattern may comprise a pseudo-random bit sequence (e.g., maximum length sequence) determined using a maximal linear feedback shift register. Various random processes may be utilized, e.g., uniform, Gaussian, Poisson and/or other process. In some implementations, the pattern may comprise a plurality of bits of a given length (e.g., 1024-bit MLS). Bit values within the sequence may comprise a binary sequence (e.g., [0. 1], [-1 1] or another sequence characterized by two alternate states. In some implementations, the pattern may comprise a binary (bit) sequence produced using, a given process. In some implementations, the process used to determine the bit sequence may comprise a random distribution wherein the bit sequence may be referred to as “white noise”, i.e., a random signal with a constant (or near constant) in frequency (or frequency invariant) power spectral density and/or a discrete signal whose samples are regarded as a sequence of serially uncorrelated random variables with zero mean and finite variance. Biased distributions, (e.g., a pink noise process wherein the power spectral density (energy or power per Hz) is inversely proportional to the frequency of the signal, a “blue” or azure noise process wherein the power spectral density increases with the frequency of the signal) and/or other biased noise distributions may be utilized. The sequence may be configured as a zero-mean process in some implementations. In one or more implementations, magnitude of values within the transmitted sequence may be determined using a continuously valued random process (e.g. a Gaussian distribution).

[0068] The waves transmitted by the component 202 may be reflected by one or more elements within the environment, e.g., floor 212, wall 210, and/or object 208 in FIG. 2 and/or

310 in FIG. 3. In some implementations, the object 208 may comprise product display 120 of FIG. 1. Reflected waves (as shown by curves 308 in FIG. 3) may be detected by the receiver 204 to produce received pattern. The received pattern (e.g., as illustrated by waveform 314 in FIG. 3) may be sampled at the sampling rate of the sequence provided for the transmission. The received sampled pattern may be accumulated for a given time interval (e.g., selected between 1 ms and several hours, in some implementations, depending on *inter alia*, signal to noise, reaction time and/or tolerance of false positives of the application).

[0069] The received accumulated signal may be convolved with a time-reversed copy of the transmitted sequence (e.g., as illustrated by waveform 312 in FIG. 3) to produce a correlogram. The correlogram may be analyzed in order to determine presence of objects (e.g., the wall 210, the object 208 in FIG. 2 and/or 310 in FIG. 3) in the sampling volume. In some implementations, the analysis of the correlogram may comprise detecting one or more correlation peaks above a given threshold (significant peaks), e.g., such as described below with respect to FIGS. 3-4). The peak detection threshold may be selected from the range between 2 and 5 standard deviations (sigma σ) above zero. The standard deviation may be determined using the correlogram. Peaks in the correlogram which are significantly different from zero (e.g., greater than $5 \times \sigma$) may correspond to reflections of the transmitted signal from one or more objects. Occurrence of one or more peaks may indicate presence of objects. Location (e.g., time delay Δt) of individual significant peaks may be used to determine distance r to the detected object (which is echoing back the noise signal), as follows:

$$r = 0.5 C \Delta t, \quad (\text{Eqn. 1})$$

where r denotes range to object; C is speed of signal transmission in medium, Δt is the time delay.

[0070] In some implementations, the correlogram may be obtained using a filtered version of the received signal. In some implementations, the filter may comprise band-pass or a high pass filter configured to remove, e.g. low frequency signal component. For example, 50/60Hz line noise that may pollute recorded signals may be filtered out using a high pass filter with a corner frequency selected from the range between 100 Hz and 1000 Hz.

[0071] In some implementations, the correlogram may be filtered prior to peak detection process. The filter may comprise a band-pass or the low-pass filter.

[0072] Use of some signal modalities such as audio or radio may prove it difficult to completely isolate the receiver from the transmitter and thus the receiver may pick up the direct transmission of the pattern. In some implementations, signal component due a direct path from the transmitter to the receiver may be removed from the computed correlogram. The direct path signal may be removed by blanking out the correlogram for a time period corresponding to the direct path, subtracting a template of the expected direct path signal or high-pass filtering the sequence of correlograms as they are computed progressively over time.

[0073] FIGS. 4A-4B present data illustrating correlograms obtained using the reverse correlation methodology of the disclosure in accordance with one implementation. Broken lines 404, 406, 424, in FIGS. 4A, 4B denote event detection thresholds used for peak (positive threshold) and trough (negative threshold) detection. Thresholds in FIGS. 4A-4B are configured at $\pm 5\sigma$ from the mean value. In some implementations, the correlogram may be configured in accordance with a zero mean process.

[0074] X axis in FIGS. 4A-4B denotes time (in samples) from the onset of transmission (at 0 samples). Data presented in FIGS. 4A-4B were obtained using audio transmission/reception. Transmitted and received waveforms (such as shown by curves 312, 314 in FIG. 3) were obtained by sampling at 44100 samples per second. Accordingly, inter sample interval for data shown in FIG. 4A may correspond to 0.023 millisecond.

[0075] Curve 422 in FIG. 4B depicts correlogram data obtained in absence of objects in the sampling volume of the sensor. Curve 402 in FIG. 4 depicts correlogram data obtained in presence of one or more objects. One or more reflections (e.g., peak 408) may breach the threshold (e.g., 404). Peaks breaching a respective threshold may be associated with a given object in the sampling volume of the sensor (e.g., 310 in FIG. 3). Position of the peak with respect to the transmission onset (e.g., time interval 410 in FIG. 4A) may be used to determine range to the object using, e.g., Eqn. 1. The time interval 410 may be referred to as a time delay, lag, and/or peak position. By way of an illustration, peak 408 is positioned at 39 samples after the onset of the transmission. The corresponding time interval 410 may be determined as $39/44100 \sim 0.88$ milliseconds. Taking sound speed in air of 343 m/s, and using Eqn. 1, distance to an object corresponding to the peak 408 may be determined at 0.15 m.

[0076] In some implementations, the correlogram may comprise non-negative values determined based on an absolute value of the convolution operation. Object reflections may be determined based on locating one or more peaks using a positive threshold (e.g., 404 in FIG. 4A).

[077] FIG. 5 illustrates a computerized system configured to implement the sensing methodology of the disclosure, according to one or more implementations.

[078] The system 500 may comprise a learning configuration (robotic brain) component 512 for controlling a robotic apparatus (e.g., 200 of FIG. 2). The learning configuration component may be logically implemented within a processor that executes a computer program embodied as instructions stored in non-transitory computer readable media, and configured for execution by the processor. In some implementations, the robotic brain may be implemented as dedicated hardware, programmable logic (e.g., field programmable gate arrays (FPGAs), and/or other logical components), application specific integrated circuits (ASICs), and/or other machine implementations. Additional memory 514 and processing components 516 may be available for other hardware/firmware/software needs of the robotic device. In some embodiments, the learning logic may comprise a separate processor (FPGA, ASIC, neuromorphic processor) or a software process operable on a CPU.

[079] Sensor components 520 may enable the robotic device to accept stimulus from external entities. Input stimulus types may include, without limitation: video, audio, haptic, capacitive, radio, accelerometer, ultrasonic, infrared, thermal, radar, lidar, sonar, and/or other sensed inputs. In some implementations, the sensor components 520 may comprise a transmitter and a receiver components, e.g., such as described above with respect to FIG. 2 and/or FIG. 3. The sensor components 520 may be configured to produce waveforms 312, 314 described with respect to FIG3. The sensor components 520 may interface with the processing component 516.

[080] The processing component 516 may operate an object detection process of the disclosure. The detection process may comprise determination of a correlogram, e.g., such as described with respect to FIG. 4A and/or FIG. 6. After the correlogram is computed, and optionally the direct signal removed, the correlogram may be thresholded for positive and negative signals that exceed a given threshold. This threshold may be selected from a range between 3 and 9 standard deviations of the correlogram. In some implementations, the standard deviation may be computed using an off-line approach and/or an on-line approach by computing the distribution of correlation values for the recorded signal convolved with any pseudo and true random sequence not recently transmitted

[081] The processing component 516 may interface with the user interface (UI) components 518, sensor components 520, electro-mechanical components 522, power components 524, and communications (comms) component 526 via one or more driver interfaces and/or software abstraction layers. In one or more implementations, the power

components 524 may comprise one or more of a direct current, an alternating current source, a mechanical coupling, an energy accumulator (and/or a mechanical energy means (e.g., a flywheel, a wind-up apparatus), a wireless charger, a radioisotope thermoelectric generator, a piezo-generator, a dynamo generator, a fuel cell, an internal or external combustion engine, a pneumatic power source, a hydraulic power source, and/ or other power sources.

[082] Additional processing and memory capacity (not shown) may be used to support these processes. However, it will be appreciated that the aforementioned components (e.g., user interface components 518, sensor components 520, electro-mechanical components 522) may be fully controlled based on the operation of the learning configuration 512. Supplemental memory and processing capacity may also aid in management of the controller apparatus (e.g. loading executable code (e.g., a computational brain image), replacing the executable code, executing operations during startup, and/or other operations). As used herein, a “computational brain image” may comprise executable code (e.g., binary image files), object code, bytecode, an array of weights for an artificial neuron network (ANN), and/or other computer formats.

[083] Consistent with the present disclosure, the various components of the device may be remotely disposed from one another, and/or aggregated within one of more discrete components. For example, learning configuration software may be executed on a server apparatus, and control the mechanical components of a robot via a network or a radio connection. In another such example, multiple mechanical, sensory, and/or electrical units may be controlled by a single robotic brain via network/radio connectivity.

[084] The electro-mechanical components 522 include virtually any electrical, mechanical, and/or electro-mechanical component for sensing, interaction with, and/or manipulation of the external environment. These may include, without limitation: light/radiation generating components (e.g. light emitting diodes (LEDs), infrared (IR) sources, incandescent light sources, etc.), audio components, monitors/displays, switches, heating elements, cooling elements, ultrasound transducers, lasers, camera lenses, antenna arrays, and/or other components.

[085] The electro-mechanical components 522 may further include virtually any type of component capable of motion (e.g., to move the robotic apparatus 500, manipulate objects external to the robotic apparatus 500 and/or perform other actions) and/or configured to perform a desired function or task. These may include, without limitation: motors, servos, pumps, hydraulics, pneumatics, stepper motors, rotational plates, micro-electro-mechanical devices (MEMS), electro-active polymers, and/or other motive components. The components

interface with the learning configuration and enable physical interaction and manipulation of the device. In some implementations of robotic cleaning devices, the electro-mechanical components 522 may comprise one or more of a vacuum component, brush, pump, scrubbing/polishing wheel, and/or other components configured for cleaning/maintaining of premises. Such components enable a wide array of potential applications in industry, personal hobbyist, building management, medicine, military/intelligence, and other fields (as discussed below).

[086] The communications component 526 may include one or more connections configured to interact with external computerized devices to allow for, *inter alia*, management and/or control of the robotic device. The connections may include any of the wireless or wireline interfaces discussed above, and further may include customized or proprietary connections for specific applications.

[0087] The power system 524 may be configured to support various use scenarios of the device. For example, for a mobile robot, a wireless power solution (e.g. battery, solar cell, inductive (contactless) power source, rectification, and/or other mobile power source) may be appropriate. However, for fixed location applications which consume significant power (e.g., to move heavy loads, and/or other power intensive tasks), a wall power supply (or similar high capacity solution) may be a better fit. In addition, in some implementations, the power system and or power consumption may be configured with the training of a robotic apparatus (e.g., 200 of FIG. 2). Thus, the robot may improve its efficiency (e.g., to consider power consumption efficiency) through learned management techniques specifically tailored to the tasks performed by the robotic apparatus.

[088] FIG. 6 illustrates method for using the methodology of the disclosure for detection of objects during operation of robotic devices, in accordance with one or more implementations. The operations of methods 620 presented below are intended to be illustrative. In some implementations, methods 620 may be accomplished with one or more additional operations not described, and/or without one or more of the operations discussed. Additionally, the order in which the operations of method 620 are illustrated in FIG. 6 described below is not intended to be limiting.

[089] In some implementations, methods 620 may be implemented in one or more processing devices (e.g., a digital processor, an analog processor, a digital circuit designed to process information, an analog circuit designed to process information, a state machine, and/or other mechanisms for electronically processing information and/or execute computer program modules). The one or more processing devices may include one or more devices executing

some or all of the operations of methods 620 in response to instructions stored electronically on an electronic storage medium. The one or more processing devices may include one or more devices configured through hardware, firmware, and/or software to be specifically designed for execution of one or more of the operations of methods 620. The operations of methods 620 may be implemented by a bistatic sensor apparatus disposed on a robotic device (e.g., the device 200 in FIG. 2). In some implementations, the robotic device may comprise a cleaning device (e.g., 102 in FIG. 1) operating within a premises (e.g., 100 in FIG. 1)

[0090] At operation 622 of method 620, a pattern may be produced. In one or more implementations, the pattern may comprise a pseudo-random bit sequence (e.g., maximum length sequence (MLS)) determined using a maximal linear feedback shift register. In some implementations, the pattern may comprise a random bit sequence produced using, e.g., a random process. Various random processes may be utilized, e.g., uniform, Poisson and/or other process. In some implementations, the pattern may comprise a plurality of bits of a given length (e.g., 1024-bit MLS). Bit values within the sequence may comprise a binary sequence (e.g., [0, 1], [-1, 1] or another sequence characterized by two alternate states. In one or more implementations, the sequence magnitude values may be produced using a Gaussian distribution.

[0091] In some implementations, the pattern may comprise a randomly distributed sequence of values (e.g., white noise). Biased (e.g., a pink) noise process with a frequency spectrum such that the power spectral density (energy or power per Hz) is inversely proportional to the frequency of the signal or another biased noise distributions may be utilized. Sequence may be configured as a zero-mean process in some implementations.

[0092] At operation 624 the pattern may be transmitted. In one or more implementations, the pattern may be used to modulate signal generated by the transmitter. In some implementations of binary patterns, portions of the pattern comprising binary zero may cause the transmitter to be turned off, portions of the pattern comprising binary one may cause the transmitter to be turned on. In one or more implementations of binary patterns, the portions of the pattern comprising binary zero may cause the transmitter to transmit the most negative value, portions of the pattern comprising binary one may cause the transmitter to generate the most positive value. Various types of waves may be utilized, pressure waves (e.g., audio, ultrasonic), light (ultraviolet (UV), infrared (IR), and/or visible) waves produced using a light emitting diode (LED), electrically pumped semiconductor laser (e.g., a laser diode), radio waves, and/or a combination thereof.

[0093] At operation 626 the reflected signal may be sampled. In some implementations of acoustic wave type, operation 626 may comprise sensing of sound reverberation using a microphone. The sensed waveform may be sampled at a sampling rate matching time-resolution of the transmitted sequence. Duration of the sampled waveform may be selected in accordance with requirements of a given application. By way of an illustration of an audio signal ranging using a 44 kHz sampling frequency, strong echoed signals may be detected within 5 ms (corresponding to 220 samples/correlation vector length) at 5 standard deviations (corresponding to 1 in 10,000 measurements false positive rate). In some implementations, sampling operation may be performed continuously. Sampled waveform may be accumulated into a buffer. Upon reaching a given duration, the sampled waveform may be provided to a correlogram determination process described below.

[0094] At operation 628 a correlogram may be obtained. In some implementations, the correlogram may be obtained by convolving a time-reversed copy of the transmitted random/pseudo-random sequence with the received sampled signal; during convolution the mean value may be subtracted from at least one of the signals (transmit or receive) to produce zero-mean signal. The number of time-lags used in the correlogram may be configured based on the sampling rate and the distance range of detection relevant for the application; for example with audio sampled at 44 kHz with a maximum range estimate of 2 meters may correspond to a time-lag range between 0 ms and 6 ms and/or a correlogram of length 265. In some implementations, the received signal may be filtered (e.g., band-passed or low-passed) in order to reduce low and/or high frequency content of the correlogram. In some implementations, the correlogram may be filtered (e.g., band-passed or low-passed) in order to reduce low and/or high frequency content of the correlogram

[0095] At operation 630 the correlogram may be analyzed. In some implementations, the analysis may comprise filtering of the correlogram (e.g., band-pass or low-pass) in order to reduce low and/or high frequency content of the correlogram. The correlogram analysis may comprise determination of an object detection threshold (peak threshold, trough threshold), e.g., based on a number of standard deviations. The correlogram analysis may comprise determination of one or more peaks/troughs in the correlogram.

[0096] At operation 632, when one or more objects are identified the method proceeds to operation 434 where a range to the detected object is determined. In one embodiment, the one or more objects are identified when a peak or a trough breaches a peak/trough detection threshold. Responsive to a determination at operation 632 that the peak is above the peak detection threshold (e.g., 404 in FIG. 4A) or a trough is below the trough detection threshold

(e.g., 406 in FIG. 4A) the method may proceed to operation 434 where range to object corresponding to the given peak may be determined. In some implementations, the range to object may be determined using methodology described above with respect to FIG. 4A and/or Eqn. 1.

[0097] Object detection and/or object ranging methodology described herein may advantageously enable continuous estimation of range to objects and/or obstacles from robotic devices during autonomous operation. Continuous ranging may reduce time to impact and/or enable a robotic device to execute avoidance and/or an approach maneuver.

[0098] A ranging apparatus of the disclosure may utilize multiple transmitters and/or receivers in order to enable redundancy. In some implementations when operating contemporaneously with one another, individual transmitters may utilize unique random sequences (code division multiplexing) in order to avoid ambiguity. In one or more implementations individual transmitters may operate using alternate time slots (time division multiplexing) in order to avoid signal ambiguity. Other multiple access approaches may be utilized, e.g., frequency division multiplexing, polarization multiplexing, and/or other approaches.

[0099] Multiple signal types (modalities) may be employed contemporaneous with one another in order to provide multiple range estimates. Individual range estimates obtained using different physical wave types may be characterized by different performance characteristics, e.g., maximum detection range, range resolution, detection accuracy, energy use, and/or other performance characteristics. Given ranging sensor configuration may be selected based on parameters of a given application. By way of an illustration, a radio frequency sensor may be used to detect objects at greater distances (such from 0 m to 30 m) with poorer spatial resolution (e.g., 0.06 m, 2.4 GHz sampling rate). An acoustic sensor may be used to detect objects at closer distances (such as 0 m to 2 m) with higher spatial resolution (0.004 m, 44 kHz sampling rate) compared to the RF ranging.

[00100] Use of broadband signal transmissions enables object detection and/or ranging in varying environments, in the presence of noise (e.g., daylight, IR motion sensors, acoustic sensors in the same environment). Broadband signals may provide for detection of objects that may not be readily detectable by a single frequency (narrowband) signals, e.g., due to object geometry and/or object reflective properties.

[00101] Methodology of the disclosure may enable autonomous navigation by robotic devices in a variety of applications. The object detection approach disclosed herein a robotic

device to a variety of objects without object pre-selection and/or pre-of wiring and/or without requiring a trainer to record training dataset and analyze data offline. These improvements may be leveraged for constructing autonomous robotic vehicles characterized by a lower cost and/or increased autonomy and/or enable robotic devices to operate in more complex requirements (e.g., tracking multiple targets), navigate at higher speeds, and/or achieve higher performance (e.g., as characterized by a fewer collisions, shorter task execution time, increased runtime without recharging, greater spatial coverage, and/or other parameter).

[00102] Although the methodology of the disclosure is primarily described for robotic and vehicle navigation applications, the object detection and/or ranging technology may be used in a variety of applications where short range (e.g., between 1 m and 100 meters) ranging may be of use. By way of an illustration, the methodology of the disclosure may be utilized in human-robot interaction applications for example when determining how far away a hand is from the robot, in order to cause the robot to stop, move forward or backwards.

[00103] It will be recognized that while certain aspects of the disclosure are described in terms of a specific sequence of steps of a method, these descriptions are only illustrative of the broader methods of the disclosure, and may be modified as required by the particular application. Certain steps may be rendered unnecessary or optional under certain circumstances. Additionally, certain steps or functionality may be added to the disclosed implementations, or the order of performance of two or more steps permuted. All such variations are considered to be encompassed within the disclosure disclosed and claimed herein.

[00104] While the above detailed description has shown, described, and pointed out novel features of the disclosure as applied to various implementations, it will be understood that various omissions, substitutions, and changes in the form and details of the device or process illustrated may be made by those skilled in the art without departing from the disclosure. The foregoing description is of the best mode presently contemplated of carrying out the disclosure. This description is in no way meant to be limiting, but rather should be taken as illustrative of the general principles of the disclosure. The scope of the disclosure should be determined with reference to the claims.

WHAT IS CLAIMED:

1. An apparatus for determining range to an object, the apparatus comprising:
a transmitter component configured to transmit a broadband signal;
a receiver component configured to sample a reflected signal comprised of a reflection of the broadband signal off the object, to produce a sampled signal; and
a processing component configured to:
determine a time-reversed instance of the transmitted signal;
determine a correlogram, the correlogram comprising a convolution of the time reversed instance of the transmitted signal and the sampled signal at a plurality of lags;
compare one or more correlogram values at the plurality of lags to a detection threshold; and
based on a given correlogram value breaching the detection threshold,
determine a range to the object corresponding to a given lag of the plurality of lags associated with the given correlogram value.
2. The apparatus of Claim 1, wherein the broadband signal comprises a sequence of bits obtained based on a random or pseudo-random process, the sequence of bits characterized by a frequency invariant power spectral density.
3. The apparatus of Claim 1, wherein the broadband signal comprises a sequence of bits obtained based on a process characterized by a power spectral density that increases with frequency.
4. The apparatus of Claim 1, wherein the broadband signal comprises a sequence of bits obtained based on a process characterized by a power spectral density that decreases with frequency.
5. The apparatus of Claim 1, wherein the broadband signal comprises a continuously valued sequence characterized by a random or pseudo-random distribution of values.
6. The apparatus of Claim 5, wherein the random distribution comprises a Gaussian process.
7. The apparatus of Claim 1, wherein the broadband signal comprises an electromagnetic wave transmission.
8. The apparatus of Claim 7 wherein the broadband signal further comprises an acoustic wave transmission.
9. The apparatus of Claim 7, wherein the receiver component is spatially spaced from the transmitter component.

10. The apparatus of Claim 7, wherein: the electromagnetic wave is characterized by a frequency selected within a radio frequency band.

11. The apparatus of Claim 10, wherein:

the transmitter component comprises an acoustic transducer configured to radiate acoustic waves and a radio frequency antenna configured to radiate radio frequency waves in the radio frequency band.

12. The apparatus of Claim 11, wherein:

the receiver component further comprises an acoustic transducer configured to receive reflected acoustic waves and a radio frequency antenna configured to receive reflected radio frequency waves in the radio frequency band.

13. The apparatus of Claim 7, wherein:

the electromagnetic wave is characterized by a frequency selected within a visible light frequency band;

the transmitter component comprises a light emitting element; and

the receiver component comprises a photodetector.

14. The apparatus of Claim 13, wherein: the light element comprises an electrically pumped semiconductor laser element.

15. The apparatus of Claim 1, wherein the plurality of lags exceeds 100 lags.

16. The apparatus of Claim 1, wherein:

the detection threshold determination comprises determination of a mean value and a standard deviation value of the correlogram; and

the detection threshold comprises a positive component configured greater than the mean value and a negative component configured smaller than a negative mean value having an absolute magnitude equal to the mean value.

17. The apparatus of Claim 16, wherein:

the positive component is configured based on a first number of standard deviation values above the mean value; and

the negative component is configured based on a second number of standard deviation values below the negative mean value.

18. A non-transitory computer-readable storage medium having instructions embodied thereon, the instructions being executable by a processing apparatus to perform a method of detecting an object during navigation by a robotic apparatus, the method comprising:
determining a pseudorandom sequence of bits;
transmitting the pseudorandom sequence of bits using a wave type to produce a broadband signal, the broadband signal configured to irradiate a portion of an environment of the robotic apparatus;

sampling reflections of the broadband signal from one or more objects in the environment;

storing the sampled reflections of the broadband signal in a memory buffer for a time interval;

convolving the stored sampled reflections with a time-reversed copy of the pseudorandom sequence of bits to produce a correlogram;

determining at least one peak value based on an evaluation of the correlogram; and

providing an indication of the one or more objects present within the environment to a controller of the robotic apparatus, the indication configured to cause an execution of action by the robotic apparatus.

19. The non-transitory storage medium of Claim 18, wherein:

the pseudorandom sequence of bits comprises a maximum length sequence comprising a number of bits; and

the memory buffer is configured to store at least number of samples of the sampled reflections equal to the number of bits.

20. An apparatus for determining at least one positional attribute associated with an object, the apparatus comprising:

a transmitter component configured to transmit an oscillatory signal;

a receiver component configured to sample a reflected signal comprised of a reflection of the oscillatory signal off the object, to produce a sampled signal; and

computerized logic configured to:

obtain a modified instance of at least a portion of the transmitted oscillatory signal;

perform a comparison of at least a portion of the modified instance to at least a portion of the sampled signal;

evaluate one or more values obtained from the comparison to a detection criterion; and

based on at least one of the one or more values meeting the detection criterion, determine the positional attribute associated with the object corresponding to a parameter associated with the at least one value.

21. The apparatus of claim 20, wherein:

said positional attribute comprises a range;

said oscillatory signal comprises either a broadband acoustic or broadband electromagnetic signal;

said modified instance comprises a time-reversed instance of at least a portion of the transmitted oscillatory instance;

said comparison comprises an autocorrelation performed at least at a plurality of time lags of each of the at least portion of modified instance and the at least portion of the sampled signal;

said one or more values comprise respective one or more amplitudes; and

said evaluation of said one or more values obtained from the comparison to a detection criterion comprises comparison to a predetermined detection threshold value stored in the apparatus.

22. The apparatus of claim 20, wherein the oscillatory signal further comprises a pseudorandom sequence that includes a plurality of bits of a given length selected using a random process; and

a memory buffer is configured to store at least a number of samples of the sampled reflections greater than the given length.

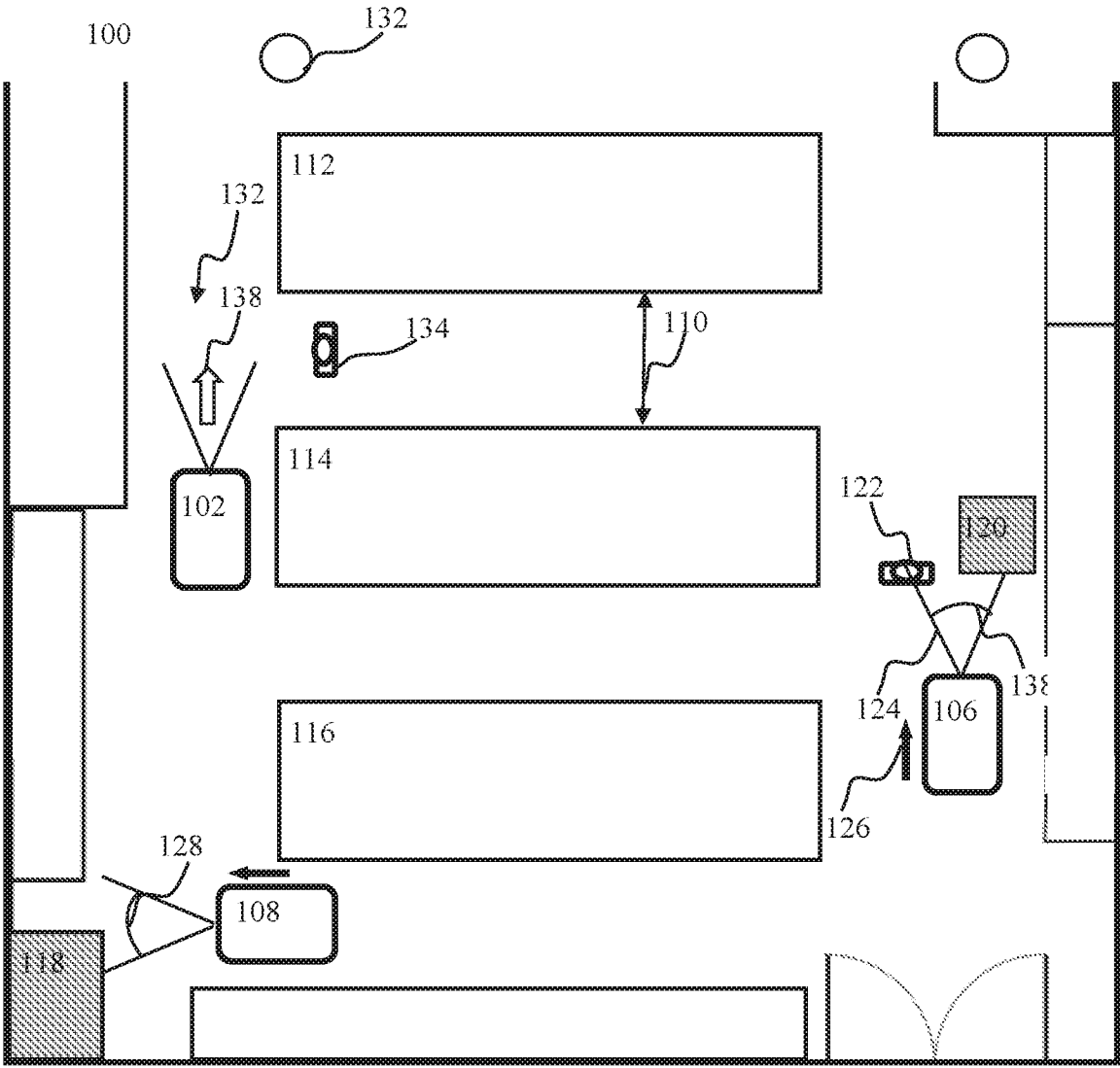


FIG. 1

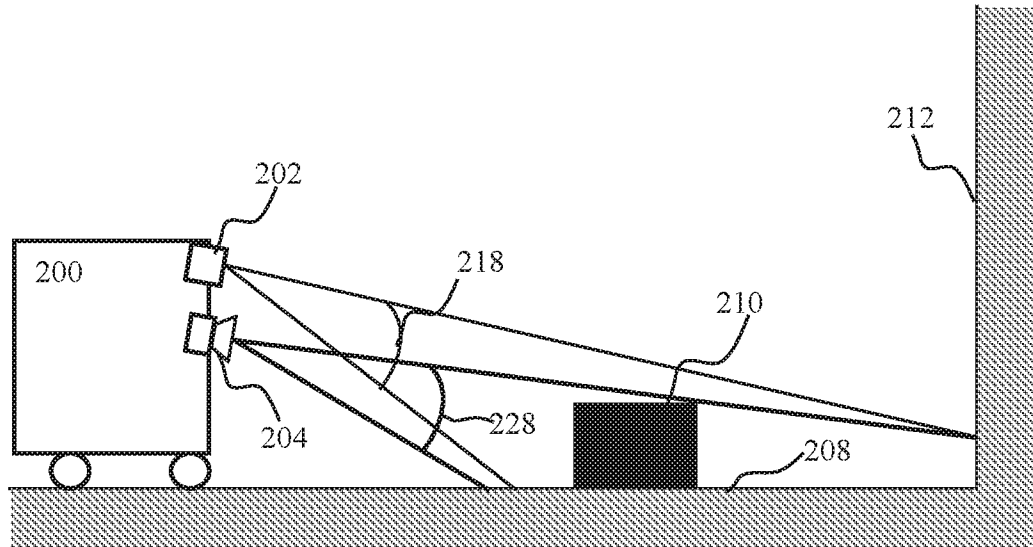


FIG. 2

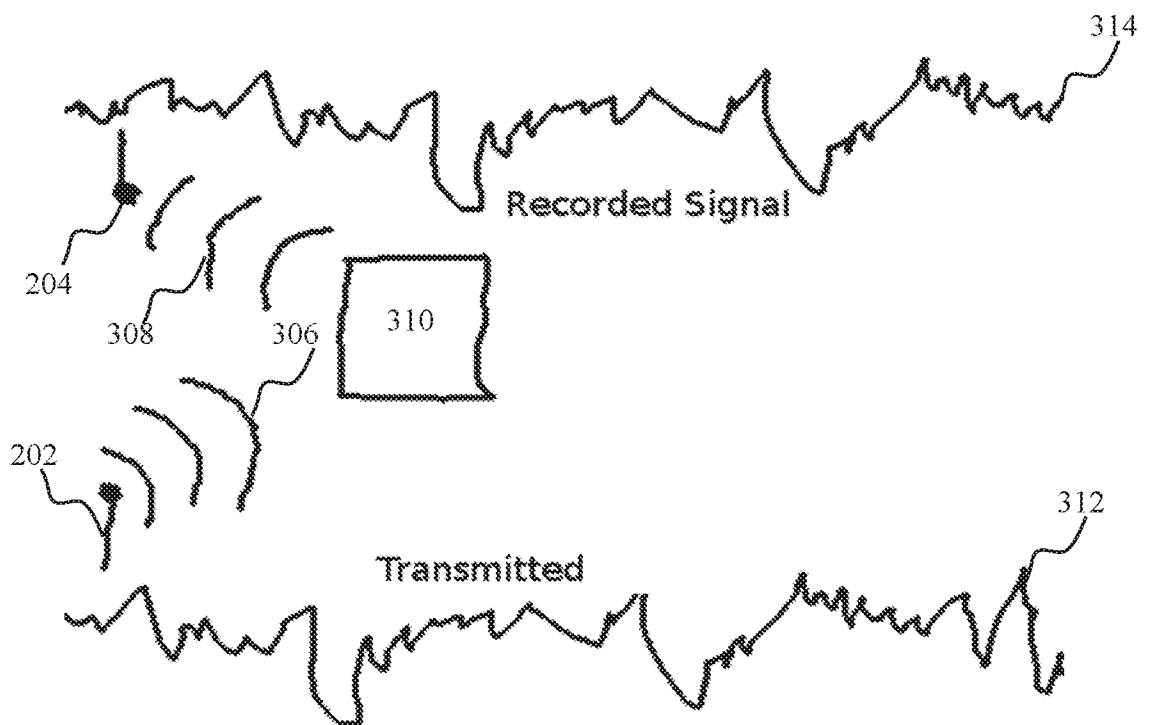


FIG. 3

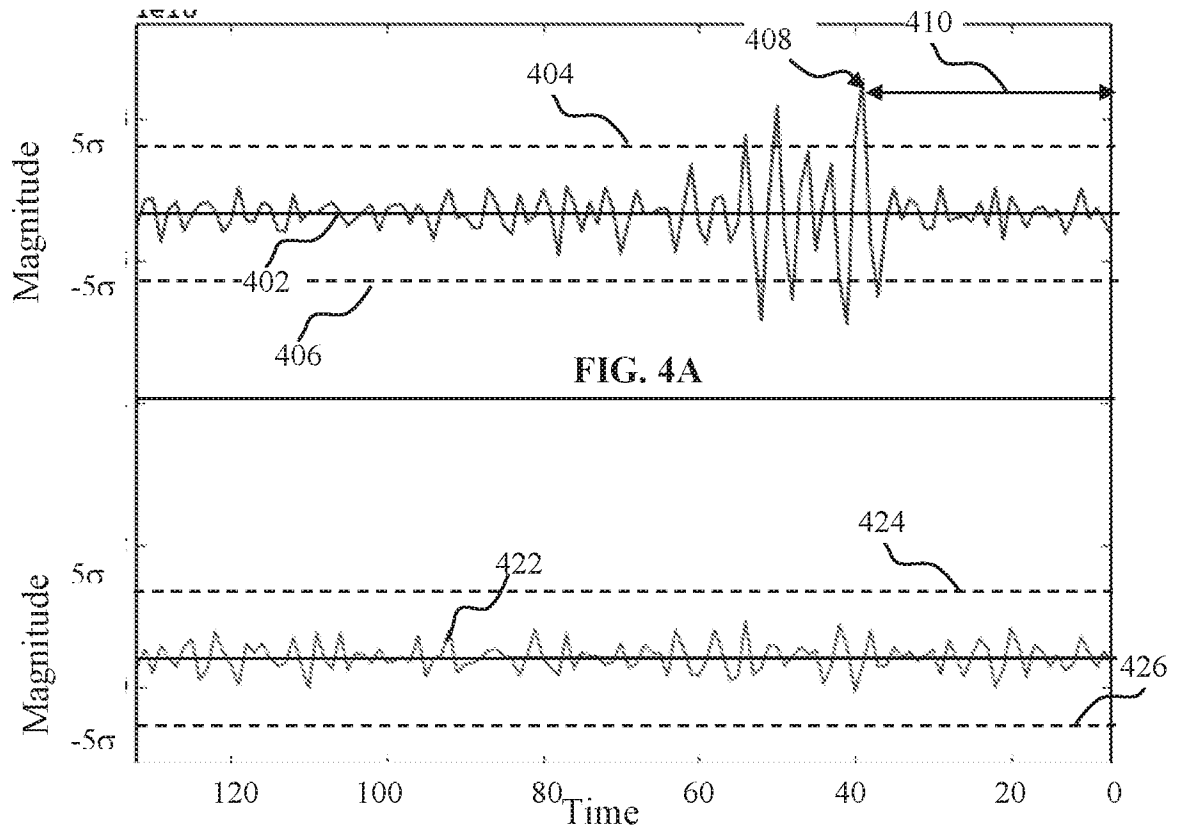


FIG. 4B

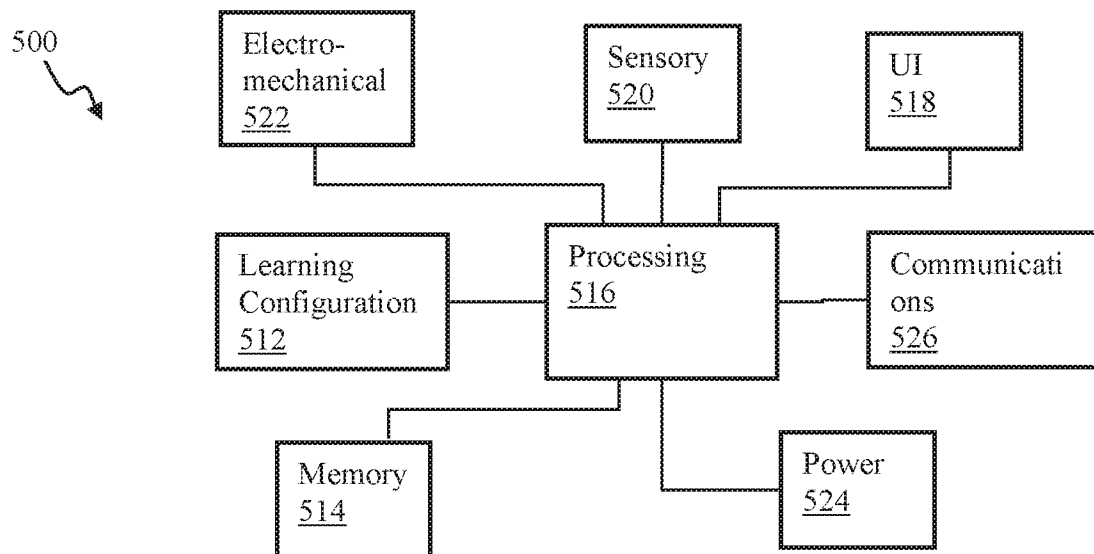


FIG. 5

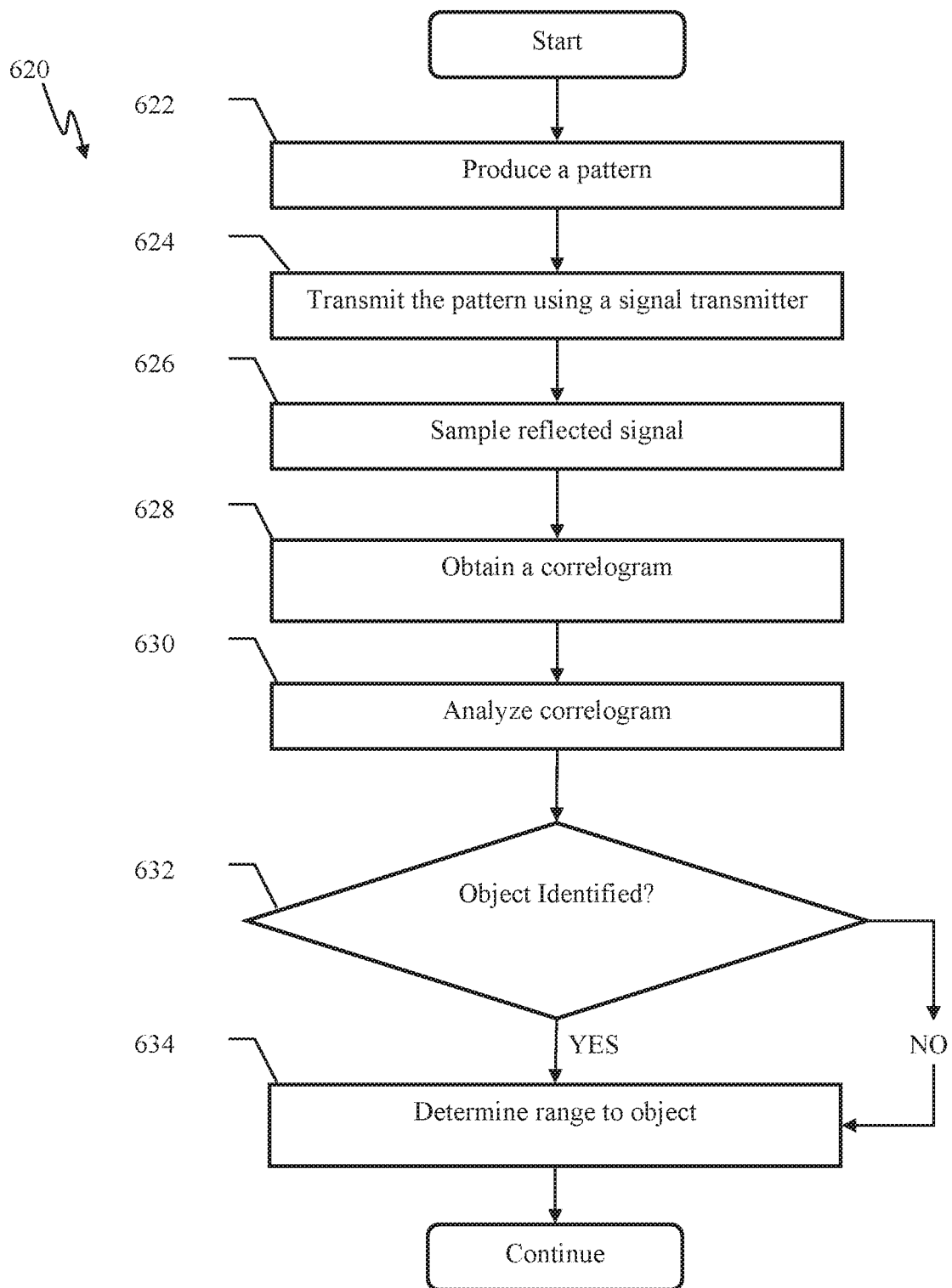


FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 16/42959

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - A61H 3/06, G01S 19/14 (2016.01)

CPC - G01C 21/20, A61H 2201/1604, A61H 3/061

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)

IPC(8): A61H 3/06, G01S 19/14 (2016.01)

CPC: G01C 21/20, A61H 2201/1604, A61H 3/061

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

IPC(8): A61H 3/06, G01S 19/14 (2016.01); CPC: G01C 21/20, A61H 2201/1604, A61H 3/061, G01S 19/14, A61H 2201/165, G01C 21/165, G01S 15/93; USPC: 367/93, 342/192, 342/28, 342/27, 367/136 (keyword limited, see terms below)

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

PatBase, Google Patents, Google Scholar. Search terms used: echo, reflect, sample, correlation, correlogram, autocorrelation, lag, time, delay, threshold, certainty, robot, automated, random, pseudorandom, electromagnetic, radio, apparatus, method, signal, psd, power, spectral, spectrum, density, Brain Corp, Eugono Izhikoviah, Micah Richert

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2011/0002191 A1 (DEMAIO et al.) 06 January 2011 (06.01.2011) entire document,	1, 2, 5, 7-12, 15-17, 18-22
---	especially: para [0001], [0029]-[0033], [0041], [0043], [0046], [0048], [0084], [0111], [0112],	-----
Y	[0116]	3, 4, 6, 13, 14
Y	US 2009/0106030 A1 (DEN BRINKER et al.) 23 April 2009 (23.04.2009) para [0013]-[0014]	3, 4
Y	US 2012/0072189 A1 (BULLEN et al.) 22 March 2012 (22.03.2012) par [0006]	6
Y	US 6,556,610 B1 (JIANG et al.) 29 April 2003 (29.04.2003) col 14, ln 27-35; col 17, ln 53-61	13, 14
Y,P	US 2016/0003946 A1 (GILLILAND et al.) 07 January 2016 (07.01.2016) entire document	1-22

☐ Further documents are listed in the continuation of Box C.

* 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

12 September 2016

Date of mailing of the international search report

06 OCT 2016

Name and mailing address of the ISA/US

Mail Stop PCT, Attn: ISA/US, Commissioner for Patents
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