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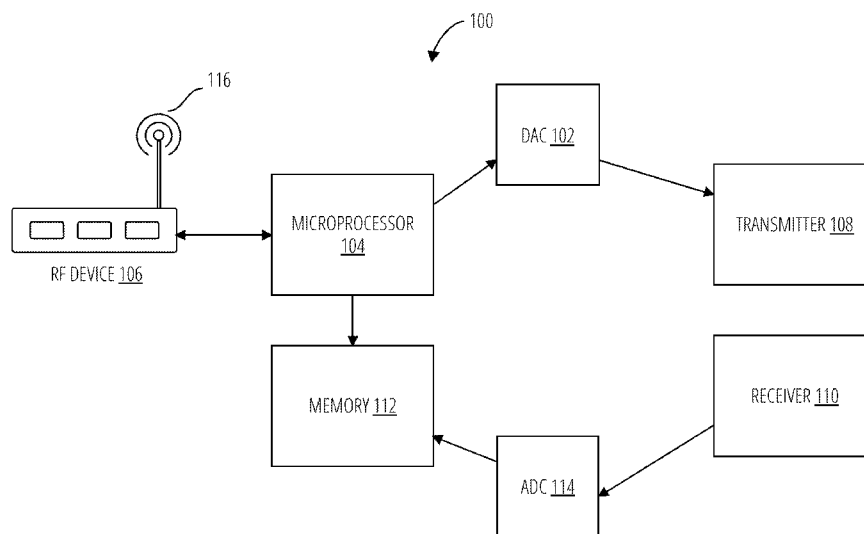


FIG. 1

(57) Abstract: There are provided a system and method for detecting motion or presence or an occupancy status. For example, there is provided a system that includes a processor and a memory including instructions that, when executed by the processor, cause the processor to perform certain operations. The operations include determining, based on a first signature, a second signature, and a third signature of a power spectrum of a sampled output signal of an ultrasonic receiver, whether motion has occurred in a range covered by the ultrasonic receiver. The first signature is a peak of a side lobe in the power spectrum, the second signature is a width of the side lobe, and the third signature is an asymmetry of the side lobe.



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SYSTEM AND METHOD FOR PRESENCE DETECTION

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present disclosure claims the benefit of U.S. provisional patent application no. 62/481,074, filed April 3, 2017, the contents of which are incorporated by reference herein in their entirety.

BACKGROUND

[0002] With the advent of the internet of things (IoT), many devices are being equipped with communication hardware to provide additional functionalities. For example, lighting systems can be activated remotely via a smart phone. While IoT devices are largely dominated by RF-based communication protocols such as Wi-Fi, BLUETOOTH®, and ZIGBEE®, to name a few, other communication and sensing modalities have been coupled with IoTs.

[0003] For example, infrared (IR) modules have been deployed in rooms to sense presence or changes within the vicinity of an IR photodetector. Such methods can be costly, and they may require specific hardware to be deployed to interface with existing systems. More importantly however, these sensors may not have the resolution and sensitivity to pick up small disturbances in their vicinity, as they can be line-of-sight sensors.

SUMMARY

[0004] One embodiment provides a system for determining presence in a room. The exemplary system includes a processor and a memory that includes instructions which, when executed by the processor, cause the processor to perform certain operations. The operations can include generating a power spectrum from the time-domain data, determining whether the power spectrum includes a side lobe, and in response to the power spectrum including the side lobe, comparing a width of the side lobe with a side lobe threshold. Further, in response to the width exceeding the side lobe threshold, the operations can include determining an asymmetry of a peak

of the side lobe with respect to an asymmetry threshold. And furthermore, in response to the asymmetry of the peak exceeding the asymmetry threshold, the operations can include indicating the time-domain data as including data indicating that motion has been detected proximate to the ultrasonic receiver.

[0005] Another exemplary embodiment provides a system that includes a processor and a memory including instructions that, when executed by the processor, cause the processor to perform certain operations. The operations include determining, based on a first signature, a second signature, and a third signature of a power spectrum of a sampled output signal of an ultrasonic receiver, whether motion has occurred in a range covered by the ultrasonic receiver. The first signature is a peak of a side lobe in the power spectrum, the second signature is a width of the side lobe, and the third signature is an asymmetry of the side lobe.

[0006] Another exemplary embodiment provides a method of sensing motion. The method includes emitting, by a system including an ultrasonic transceiver, a narrow-band ultrasonic signal. The method further includes generating by a processor of the system, a power spectrum of a measured signal from a receiver of the ultrasonic transceiver. The method further includes determining, based on a first signature, a second signature, and a third signature of the power spectrum, whether the motion has occurred in a range covered by the receiver. The first signature is a peak of a side lobe in the power spectrum, the second signature is a width of the side lobe, and the third signature is an asymmetry of the side lobe.

[0007] Additional features, modes of operations, advantages, and other aspects of various embodiments are described below with reference to the accompanying drawings. It is noted that the present disclosure is not limited to the specific embodiments described herein. These embodiments are presented for illustrative purposes. Additional embodiments, or modifications of the embodiments disclosed, will be readily apparent to persons skilled in the relevant art(s) based on the teachings provided.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Illustrative embodiments may take form in various components and arrangements of components. Illustrative embodiments are shown in the accompanying drawings, throughout which like reference numerals may indicate corresponding or similar parts in the various drawings. The drawings are only for purposes of illustrating the embodiments and are not to be construed as limiting the disclosure. Given the following enabling description of the drawings, the novel aspects of the present disclosure should become evident to a person of ordinary skill in the relevant art(s).

[0009] FIG. 1 illustrates a system in accordance with one or more embodiments.

[0010] FIG. 2 illustrates a method in accordance with the embodiments.

[0011] FIG. 3 illustrates a spectrum in accordance with the embodiments.

[0012] FIG. 4 illustrates spectra in accordance with the embodiments.

[0013] FIG. 5 illustrates a spectrum in accordance with the embodiments.

[0014] FIG. 6 illustrates a method in accordance with the embodiments.

[0015] FIG. 7 illustrates signals in accordance with the embodiments.

[0016] FIG. 8 illustrates signals in accordance with the embodiments.

[0017] FIG. 9 illustrates signals in accordance with the embodiments.

[0018] FIG. 10 illustrates time-domain data in accordance with the embodiments.

[0019] FIG. 11 illustrates a microprocessor in accordance with the embodiments.

DETAILED DESCRIPTION

[0020] While the illustrative embodiments are described herein for particular applications, it should be understood that the present disclosure is not limited thereto. Those skilled in the art and with access to the teachings provided herein will recognize additional applications,

modifications, and embodiments within the scope thereof and additional fields in which the present disclosure would be of significant utility.

[0021] The exemplary embodiments described herein provide several advantages over typical presence or occupancy characterization systems. For example, they allow non line-of-sight monitoring as sensors may be placed anywhere in a room, hidden from view, and still allow a slight change in the acoustic profile of the room to be picked up. Furthermore, embodiments of the present disclosures can be achieved at low costs relative to their infrared-based counter parts.

[0022] FIG. 1 shows the block diagram of a system 100 according to one exemplary embodiment. The system 100 includes a plurality of devices that cooperatively function to cause the system 100 to perform one or more tasks associated with ultrasonic sensing and/or persistent presence occupancy sensing. For example, the system 100 includes a radio frequency (RF) device 106 equipped with an antenna 116, a microprocessor 104, a memory 112, a digital to analog converter (DAC) 102, an analog to digital converter (ADC) 114, an ultrasonic transmitter 108, and an ultrasonic receiver 110.

[0023] In one exemplary implementation, the RF device 106 can function according to a communication protocol configured to support Wi-Fi or Bluetooth applications. Nevertheless, generally, the RF device 106 can be a device that is configured to support an RF-based protocol to provide wireless connectivity between the system 100 and one or more remote devices. For example, the one or more remote devices can be a lighting system that is equipped with RF transceiving hardware and whose state (e.g., a light output intensity) can be queried remotely utilizing the system 100 and/or whose state can be altered upon receiving a command from the system 100.

[0024] The microprocessor 104 is an application-specific microprocessor or computing device that is programmed by the instructions included in a memory 112 to perform tasks specific to ultrasonic sensing and/or presence sensing. As shall be described below in the context of FIG.

11, the microprocessor 104 is an apparatus that is structured such that it can perform tasks related to ultrasonic sensing and or presence sensing that would not be otherwise possible with a routine or conventional computer.

[0025] The DAC 102 is configured to receive a digital command from the microprocessor 104 and output analog voltage that can then be used to transmit an ultrasonic pulse via the transmitter 108. Without limitation, but by example only, the DAC 102 can output a voltage at a fixed analog level corresponding to a unique digital input word, and the fixed analog level can correspondingly cause the transmitter 108 to output an ultrasonic tone having at an intensity corresponding only to the fixed analog level.

[0026] In the above-described exemplary configuration, the microprocessor 104 can modulate the ultrasonic output of the transmitter 108 by outputting a sequence of different digital words at one or more input terminals of the DAC 102. Furthermore, without limitation but by example, the DAC 102 can be any one of an R-2R ladder-based DAC, a resistor string DAC, a current steering DAC, a charge scaling DAC, a cyclic DAC, and a pipeline DAC. Generally, the system 100 is not limited to a particular DAC architecture, and one of ordinary skill in the art will readily recognize a suitable DAC architecture based on application-specific constraints.

[0027] The ADC 114 is configured to convert an analog output the ultrasonic receiver 110 into a digital word that can be saved in the memory 112. Again, similarly to the DAC 102, the ADC 114 is configured to provide a one-to-one correspondence between its input and output signals. Stated otherwise, the ADC 114 output digital word is unique to a specific analog voltage level at its input port. And in turn, the specific analog voltage level is unique to an intensity of an ultrasound signal transduced by the receiver 110.

[0028] As in the case of the DAC 102, the system 100 is not limited to a particular ADC architecture. For example, and not by limitation, the ADC 114 can be any one of a flash ADC, a

pipeline ADC, a single-slope ADC, a successive approximation ADC, and a charge redistribution successive approximation ADC, to name a few architectures that are possible.

[0029] The transmitter 108 may be an ultrasound emitting device that can be programmed to emit either a narrow band ultrasound at a predetermined frequency, or at wide-band ultrasound signal. Correspondingly, the receiver 110 may be an ultrasound sensor that is configured to pick up an ultrasound signal at a specific center frequency or in a wide band of ultrasonic frequencies. Furthermore, the receiver 110 may also be a wideband receiver configured to pick up audio frequencies as well as ultrasonic frequencies.

[0030] One of ordinary skill in the art will readily recognize that the various components show in in FIG. 1 can be implemented on a single circuit board, or they can be distributed over several boards that are either co-located in a single enclosure or on a single mother board, or that are dispersed but communicatively coupled via wired or a wireless connection.

[0031] Moreover, one of ordinary skill in the art will readily recognize that in an application a plurality of systems like the system 100 can be used in parallel, e.g. two or more systems like the system 100 can be deployed in a room to provide increased coverage of the room. In yet another implementation, the microprocessor 104 can be central to several pairs of ultrasound receivers and ultrasound transmitters, thereby allowing a distributed ultrasonic transceiver system to be implemented based on the system 100.

[0032] Having set forth the structure and functions of the system 100, a method 200 consistent with its operation is now described with respect to FIG. 2. The method 200 can be embodied in application-specific instructions that are saved into the memory 112 that cause the microprocessor 104 to execute the steps discussed below with respect to the flow chart shown in FIG. 2.

[0033] One of skill in the art will readily recognize that the method 200 (and any other method described herein) can be pre-loaded into the memory 112 at a production factory or it can be loaded into the memory 112 as firmware or software via a wireless link provided by the RF device

106 or by a direct-write mechanism, such as by loading via an input/output (I/O) port of the system 100 into the memory 112 from a hard drive.

[0034] In one exemplary use case, the system 100 is located in a room where its function is to assess a presence in the room. In this exemplary use case, the method 200 begins at step 202, either upon power up of the system 100 or upon the system 100 receiving a command to run via the RF device 106. The system 100 then samples the ultrasonic profile the room (step 206).

[0035] Specifically, the step 206 can include causing, by the microprocessor 104 from the instructions in the memory 112, the transmitter 108 to emit one or more ultrasonic pulses or a continuous signal utilizing the transmitter 108.

[0036] For example, and not by limitation, the transmitter 108 can output a narrow-band ultrasound signal centered at 40 kHz. The output pulse signal may have a predetermined amplitude, and as shall be described below, the output pulse can have specific spectral characteristics (e.g., a predetermined full-width half-max that gives it a particular spectral content that is the same every time the transmitter 108 transmits).

[0037] Still in the context of the step 206, in response to the transmitter 108 generating the above-described output signal, the receiver 110 picks up the ultrasonic energy and its output is digitized using the ADC 114, and the corresponding digital signal is saved in the memory 112. The ADC 114 can be configured to sample at a predetermined rate and for a predetermined a predetermined sampling period.

[0038] For example, and not by limitation, the ADC 114 can be configured to sample at a sampling rate of 96 kHz and for a time period that yields a total of 16 kilo-samples (kS). As can be understood, this sampling rate and number of samples is for illustration purposes and not limiting.

[0039] Once the digitized samples are saved in the memory 112, still under the step 206, the method 200 can include converting the digitized samples (which is a time-domain sequence) into

a frequency-domain sequence. In other words, a power spectrum of the digitized samples is generated. By example, and not by limitation, this can be achieved using known transform methods in the art (e.g., a fast-Fourier transform (FFT)). A program for performing the power spectrum generation can be fetched by the microprocessor 104 from the memory 112.

[0040] The method 200 continues to the step 208 from which the system 100 can determine characteristics based on the time-domain data and/or the generated power spectrum. For example, the system 100 can measure the noise floor of the received signal by comparing an amplitude of the time-domain data with a predetermined amplitude level corresponding to no ultrasonic pulse being generated by the transmitter 108.

[0041] Other signal metrics can be determined. For example, utilizing the generated power spectrum, sidelobe heights and widths can be measured and saved into the memory 112. Generally, the step 208 can include performing analytics on the sampled signals to infer certain signatures from which the system 100.

[0042] As shall be apparent to one of ordinary skill in the art, the analytics performed under the step 208 are by no means conventional as the system 100 can infer specific characteristics relating to motion and/or presence or occupancy of the room in which it is located. In other words, and generally, the system 100 can infer specific environmental changes as a result of specific signatures in the measured signal.

[0043] The method 200 continues the decision block 210, where it is determined by the system 100 whether a sidelobe peak in the measured and sampled power spectrum is greater than the noise floor. If it is determined that the sidelobe peak is not greater than the noise floor (NO at decision block 210), the method 200 reverts back to the step 206, where another acquisition is performed. In other words, a NO at decision block 210 indicates that no change is detected, and as such there's no perceivable motion or perceivable change in occupancy in the room where the system 100 is located.

[0044] In the case of a YES at the decision block 210, the system 100 performs additional checks to ensure that there is indeed a change in the state of the room. As such, the method 200 moves to the decision block 212 where it is determined whether the width of a sidelobe is greater than a predetermined width threshold. In the case that the width of the sidelobe is not greater than (NO at the decision block 212), the method 200 reverts to the step 206, indicating that no motion or change in occupancy is detected. In contrast, when a YES is observed at the decision block 212, the system 100 conducts an additional test to determine whether there is motion or a change of occupancy or in presence in the room by moving to the decision block 214.

[0045] At that stage, the system 100 tests whether there is an asymmetry between a first side lobe and a second side lobe; the first and second side lobes are disposed on a first side and on a second side, respectively, of a central peak of the power spectrum (e.g., around 40 kHz). In one implementation, the asymmetry can be measured by taking a ratio of a peak of the first side lobe to a peak of the second side lobe, and the result can be compared with a predetermined asymmetry threshold ratio. If the measured asymmetry is not greater than the asymmetry threshold (NO at the decision block 214), the system 100 returns to the step 206. In contrast, if the measured asymmetry is greater than the asymmetry threshold, the system 100 determines that there is motion or a change in occupancy or presence in the room.

[0046] Or generally, if a YES is observed at the decision block 214, the system 100 determines that there is a change in state in its vicinity, at which point it can classify the motion or change observed at step return to the step 216. Classification of the change in state can depend on the side lobe peak height and integrated power. Such measures can identify the direction and the magnitude of the motion that is detected. In sum, in some embodiments, to estimate that a change has occurred, the system 100 must clear at least three checks based on various signatures of a measured ultrasonic signal. Further, the change can be classified by looking at further

characteristics of the measured signal, such as a side lobe peak height and/or an integral of the power spectrum.

[0047] From the step 216, the system 100 can move to the step 206 to perform another acquisition and continually probe the environment for other changes. Alternatively, or simultaneously, the system 100 can instruct one or more remote systems communicatively coupled to it (e.g., via the RF device 106) to perform an action based on the classified motion

[0048] For example, and not by limitation, the system 100 can instruct a lighting system to increase a light output in response to a change having been detected at the decision block 214 and the motion classified at step 216. In yet another example, the system 100 can report to a remote device that a change has occurred in its vicinity.

[0049] Without loss of generality, the above-mentioned thresholds can be determined by calibrating the system 100 and saving these thresholds in the memory 112. Calibration may be performed at commissioning of the system 100 or the memory 112 can include instructions that cause the system 100 to repeatedly or occasionally conduct a self-calibration procedure and update these thresholds. Furthermore, while the method 200 has been described in the context of only one system, two or more systems like the system 100 can be used to cooperatively determine whether a change has occurred.

[0050] The following figures show several traces corresponding to typical measurements and computations generated by the system 100 when executing the method 200. For example, FIG. 3 shows a power spectrum 300 of a signal sampled by the ADC 114 from the receiver 110. The spectrum includes low frequency components in the auditory range 304 of the human ear, i.e. up to 20 kHz. Above the range 304, i.e. at frequencies greater than 20 kHz, the spectrum 300 includes a single ultrasonic tone indicated by the peak 302, which is the center frequency of the narrow-band ultrasonic signal emitted by the transmitter 108. As previously mentioned, other

ultrasonic center frequencies can be used in the system 100, without departing from the scope of the present disclosure.

[0051] FIG. 4 shows spectra 400 that may be generated by the system 100 when executing an exemplary method like the method 200. The spectrum 402 is a detailed view of the ultrasonic tone centered around the peak 302. In contrast, the spectrum 404 is that of a measurement where a side lobe exists and is greater than the estimated noise floor, i.e. when a YES is observed at decision block 212. The side lobe can have a side lobe pick width 408 and a side lobe peak height 410 which can be measured and used in further computations and decision making as the method 200 is being executed. In the spectrum 404, a side lobe is shown on the right of the peak 302, whereas in the spectrum 406, the side lobe is shown on the left of the peak 302.

[0052] In some alternate embodiments of the method 200, specific frequencies in the spectrum 300 can be selected to serve as a reference for classifying motion or for detecting presence in a room in which the system 100 is located. For example, as shown in FIG. 5, a first reference frequency 502 and a second first second reference frequency 504, each being located around the peak 302 of the spectrum 500. These reference frequencies may be selected so as to form a predetermined frequency band around the peak 302. In one implementation, they may be chosen to be at the full-width half-max of the spectrum 500.

[0053] FIG. 6 illustrates an exemplary method 600 that makes use of the above-mentioned reference frequencies to sense presence or occupancy in a room. As in the method 200, the method 600 is embodied in the form of instructions in the memory 112 that the microprocessor 104 can fetch, decode, and execute to perform the various operations described in the flow chart depicted in FIG. 6.

[0054] The method 600 may begin at step 602, where tracking variables such as a no presence detected counter and a no-presence detected flag may be initialized. These tracking variables may be memory locations of the memory 112 that can be incremented (or reset) as the method 600 is

executed by the system 100. The method 600 then moves to the step 604 where data measured from the receiver 110 is sampled and saved in the memory 112. The sampling and saving occurs after an ultrasonic pulse having the spectrum shown in the spectrum 500 is emitted by the transmitter 108.

[0055] For example, and not by limitation, data from an output terminal of the receiver 110 may be sampled at 96 kHz and for a time period such that 16 kS are collected. The sampled data is subsequently converted to a power spectrum.

[0056] The method 600 further includes determining and logging a power ratio based on the aforementioned reference frequencies of the power spectrum generated from the sampled data (step 606). For example, the power ratio can be given by $P(f_{i-1})/P(f_{i+1})$, where f_{i-1} is the first reference frequency 502 and f_{i+1} is the second reference frequency 504 and f_i is the center frequency, i.e. the frequency at which the peak 302 occurs.

[0057] The method 600 then moves to step 608, where it utilizes a rolling window of a predetermined width (e.g. 256-samples wide) on the time-domain data obtained in step 606 to obtain a frequency domain power spectrum. The method 600 then moves to step 610 where the power in a specific frequency band of interest (f_0, f_1) is integrated to produce a sum.

[0058] The sum is checked at decision block 612 against a predetermined value of a no-presence threshold. If the sum is less than the no-presence threshold, a NO is observed at the decision block 612, and the no presence detected counter is reset (step 614), at which point the method 600 returns to the step 604. In other words, a presence was detected.

[0059] As such, at step 614 the method 600 can include instructing a remote device connected to the system 100 to perform an action, as in the case of the method 200. If a YES is observed at the decision block 612, i.e., if the sum is less than the no-presence threshold, then a no-presence detected counter is incremented at step 616. The value of the no-presence detected counter is then checked against a counter threshold at decision block 618.

[0060] If the no-presence detected counter value is greater than the counter threshold (YES), then a no presence flag is set at step 620, and the method 600 returns to step 604 where the system 100 performs another a sampling at the receiver 110. As such, at step 620 the method 600 can include instructing a remote device connected to the system 100 to perform an action, as in the case of the method 200. If the no-presence detected counter value is less than the counter threshold (i.e., NO at decision block 618), the method 600 returns to step 604.

[0061] The following figures illustrate one or more exemplary signals that may be generated as the system 100 is executing the method 600. For example, FIG. 7 shows signals 700, which include exemplary time-domain data 702 resulting from the data acquisition and subsequently recorded power ratio data. The power ratio is then computed for rolling a 256-samples window along the time-domain data 702. This produces the power spectrum 704. Furthermore, the time-domain data 704 is then integrated to yield the integrated power 706. In the case of the signals 700, no presence is detected as evidenced by the power spectrum 704 which is nearly devoid of energy in a specific frequency range of interest (e.g., $1 < f \text{ index} < 3$), and in view of the integrated power 706 being monotonically decreasing.

[0062] In contrast, FIG. 8 shows signals 800 for a case where presence is detected. The time-domain data 802 indicate features on the second half of the time frame that clearly indicate a disturbance from a baseline signal in the first half of the time frame. As such, the corresponding power spectrum 804 includes a feature in a specific frequency range of interest (e.g., $1 < f \text{ index} < 3$), consistent with a change having occurred in the vicinity of the receiver 110. The integrated power 806 shows a monotonically decreasing portion and an increasing portion; this change is consistent with a disturbance or a presence having been detected by the system 100.

[0063] FIG. 9 illustrates signals 900 where no-presence is detected and presence is detected in a subsequent execution of the method 600. As can be seen from the signals 900, the time-domain data 902 includes specific regions of increased activity and no-activity. Again, the power

spectrum 904 includes energy at a wide range of frequencies, and the integrated power 906 indicate clear time moment where there is more energy in the time-domain data 902, corresponding to a change, relative time indices where there's less energy in the time-domain data 902.

[0064] Given the sensitivity of the system 100, as shown by the signals 900, when the method 600 is executed continuously, very small disturbances in the air pressure level (i.e., acoustic and ultrasonic) profile of the room can be sensed, characterized, and classified. For example, in one embodiment, the system 100 can detect cardio-pulmonary changes of a person present in the room. This is shown in time-domain data 1000, as illustrated in FIG. 10. As shown from the trace, a first feature 1002 correspond to the person breathing normally.

[0065] The feature 1004 corresponds to the person holding her breath, and the feature 1006 corresponds to the person making a slight head movement. As such, while the system 100 can detect presence or absence in a room, it has suitable resolution and accuracy to characterize small changes in the air pressure level (i.e., acoustic and ultrasonic) profile when a person is present.

[0066] FIG. 11 presents a more detailed view of the microprocessor 104. As previously mentioned, the microprocessor 104 is an application-specific processor that is configured to perform tasks specific to ultrasonic sensing, presence or occupancy detection and characterization. The microprocessor 104 can include a processor 1114 that has a specific structure. The specific structure can be imparted to the processor 1114 by instructions stored in a memory 1102 included therein and/or by instructions 1118. The instructions 1118 can be fetched by the processor 1114 from a storage 1120, or from the memory 112. The storage 1120 may be co-located with the microprocessor 104, or it may be located elsewhere and be communicatively coupled to the microprocessor 104 via a communication interface 1116, for example.

[0067] The microprocessor 104 can be a stand-alone programmable system, or it can be a programmable module located in a much larger system. For example, the microprocessor 104 can be part of a distributed sensing network including several ultrasonic transceivers. The microprocessor 104 may include one or more hardware and/or software components configured to fetch, decode, execute, store, analyze, distribute, evaluate, and/or categorize information.

[0068] Furthermore, the microprocessor 104 can include an I/O module 1112 that can be configured to interface with the other components of the system 100. The processor 1114 may include one or more processing devices or cores (not shown). In some embodiments, the processor 1114 may be a plurality of processors, each having either one or more cores. The processor 1114 can be configured to execute instructions fetched from the memory 1102, i.e. from one of memory block 1104, memory block 1106, memory block 1108, and memory block 1110.

[0069] Without loss of generality, the storage 1120 and/or the memory 1102 may include a volatile or non-volatile, magnetic, semiconductor, tape, optical, removable, non-removable, read-only, random-access, or any type of non-transitory computer-readable computer medium. The storage 1120 and/or the memory 1102 may include programs and/or other information that may be used by the processor 1114. Furthermore, the storage 1120 may be configured to log data processed, recorded, or collected during the operation of microprocessor 104. The data may be time-stamped, location-stamped, cataloged, indexed, or organized in a variety of ways consistent with data storage practice.

[0070] In one embodiment, for example, the memory block 1106 may include instructions that, when executed by the processor 1114, cause the processor 1114 to perform certain operations consistent with either some or all of the steps of the method 200 or with some or all of the steps of the method 600.

[0071] Those skilled in the relevant art(s) will appreciate that various adaptations and modifications of the embodiments described above can be configured without departing from the

scope and spirit of the disclosure. For example, while exemplary embodiments have described in the context of presence in and occupancy of a room, embodiments of the present disclosure can be deployed in other settings like a car windshield in order to detect rain or snow, or at an outdoor light fixture to determine changes in the weather or nearby traffic patterns, or for in a store to determine patron traffic and store occupancy. Therefore, it is to be understood that, within the scope of the appended claims, the teachings featured herein may be practiced other than as specifically described herein.

CLAIMS

What is claimed is:

1. A system for determining presence in a room, the system comprising:
a processor;
a memory including instructions that, when executed by the processor, cause the processor to perform operations including:
sampling an output voltage of an ultrasonic receiver to obtain time-domain data;
generating a power spectrum from the time-domain data;
determining whether the power spectrum includes a side lobe;
in response to the power spectrum including the side lobe, comparing a width of the side lobe with a side lobe threshold;
in response to the width exceeding the side lobe threshold, determining an asymmetry of a peak of the side lobe with respect to an asymmetry threshold; and
in response to the asymmetry of the peak exceeding the asymmetry threshold, indicating the time-domain data as including data indicating that motion has been detected proximate to the ultrasonic receiver.
2. The system of claim 1, wherein the operations further include emitting a narrow-band ultrasonic signal centered around a peak frequency.
3. The system of claim 2, wherein the sampling is performed in response to emitting the narrow-band ultrasonic signal.
4. The system of claim 1, wherein the power spectrum is determined to include the side lobe based on a comparison of a region of the power spectrum with a noise floor of the power spectrum.

5. The system of claim 1, wherein the operations further include, in response to the power spectrum not containing the side lobe, indicating that the motion has not been detected.

6. The system of claim 1, wherein the operations further include, in response to the width not exciting the side lobe threshold, indicating that the motion has not been detected.

7. The system of claim 1, wherein the operations further include, in response to the asymmetry of the peak not exceeding the asymmetry threshold, indicating that the motion has not been detected.

8. The system of claim 1, further including, in response to the motion having been detected, instructing, by the processor, a remote device to perform an action.

9. The system of claim 1, further including, in response to the motion having been detected, classifying the motion based on the power spectrum.

10. The system of claim 9, wherein the classifying includes determining a magnitude and a direction.

11. The system of claim 10, wherein the classifying is based on a side lobe peak height and an integral of the power spectrum.

12. The system of claim 1, wherein the operations further include computing a power ratio based on a first reference frequency and a second reference frequency the power spectrum.

13. The system of claim 12, wherein the first reference frequency is located on a first side of a peak frequency and the second reference frequency is located on a second side of the peak frequency.

14. A system comprising:

a processor;

a memory including instructions that, when executed by the processor, cause the processor to perform operations including:

determining, based on a first signature, a second signature, and a third signature of a power spectrum of a sampled output signal of an ultrasonic receiver, whether motion has occurred in a range covered by the ultrasonic receiver;

wherein the first signature is a peak of a side lobe in the power spectrum;

wherein the second signature is a width of the side lobe; and

wherein the third signature is an asymmetry of the side lobe.

15. The system of claim 14, wherein the operations further including emitting a narrow-band ultrasonic signal and determining whether the motion has occurred in response to emitting the narrow-band ultrasonic signal.

16. The system of claim 15, wherein the narrow-band ultrasonic signal has a peak frequency at about 40 kHz.

17. The system of claim 15, wherein the narrow-band ultrasonic signal has a peak frequency greater than 20 kHz.

18. A method of sensing motion, the method comprising:

emitting, by a system including an ultrasonic transceiver, a narrow-band ultrasonic signal;

generating by a processor of the system, a power spectrum of a measured signal from a receiver of the ultrasonic transceiver;

determining, based on a first signature, a second signature, and a third signature of the power spectrum, whether the motion has occurred in a range covered by the receiver;

wherein the first signature is a peak of a side lobe in the power spectrum;

wherein the second signature is a width of the side lobe; and

wherein the third signature is an asymmetry of the side lobe.

19. The method of claim 18, further comprising classifying the motion based on a side lobe peak height and an integral of the power spectrum.

20. The method of claim 19, wherein the classifying includes determining a magnitude and a direction of the motion.

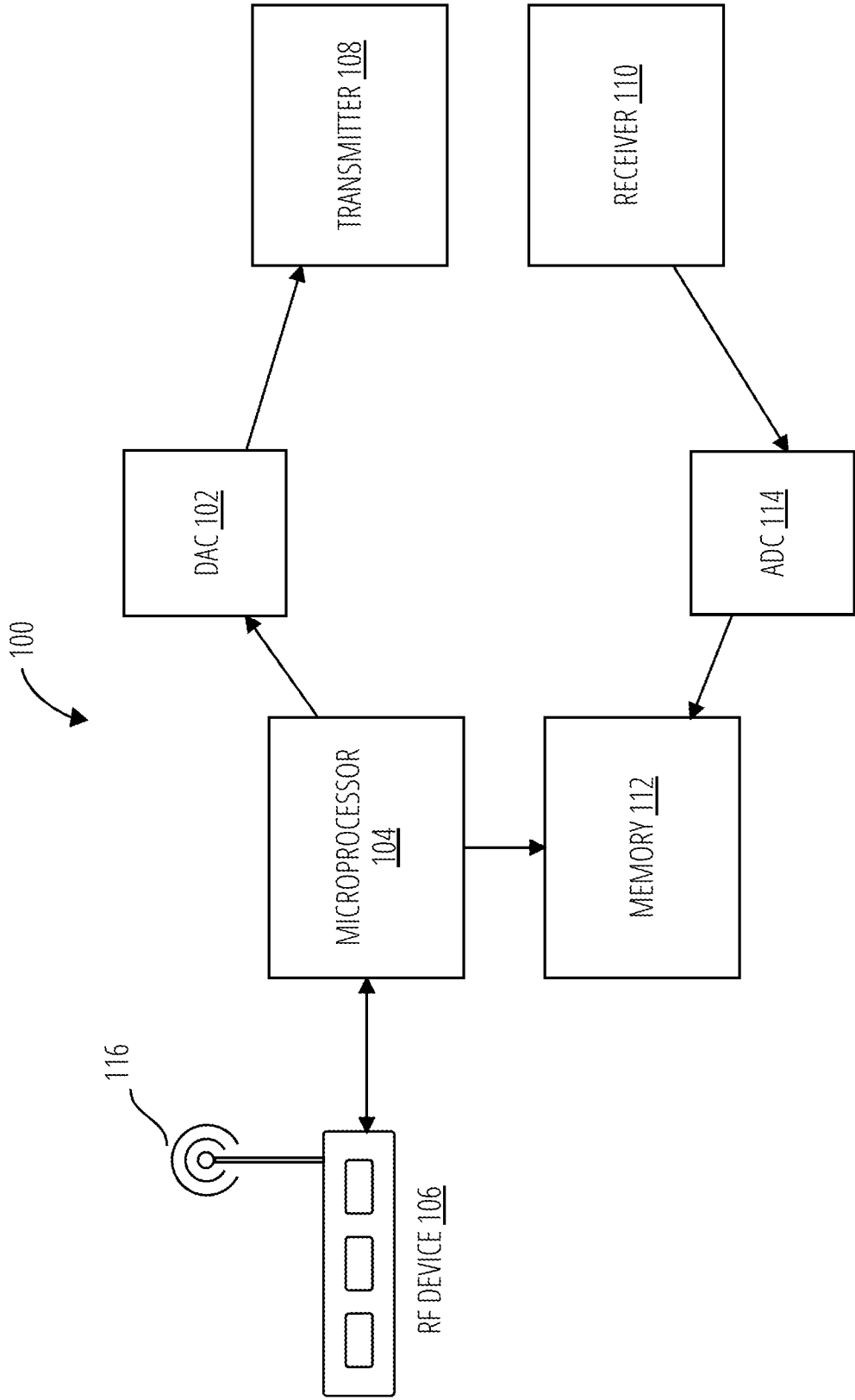


FIG. 1

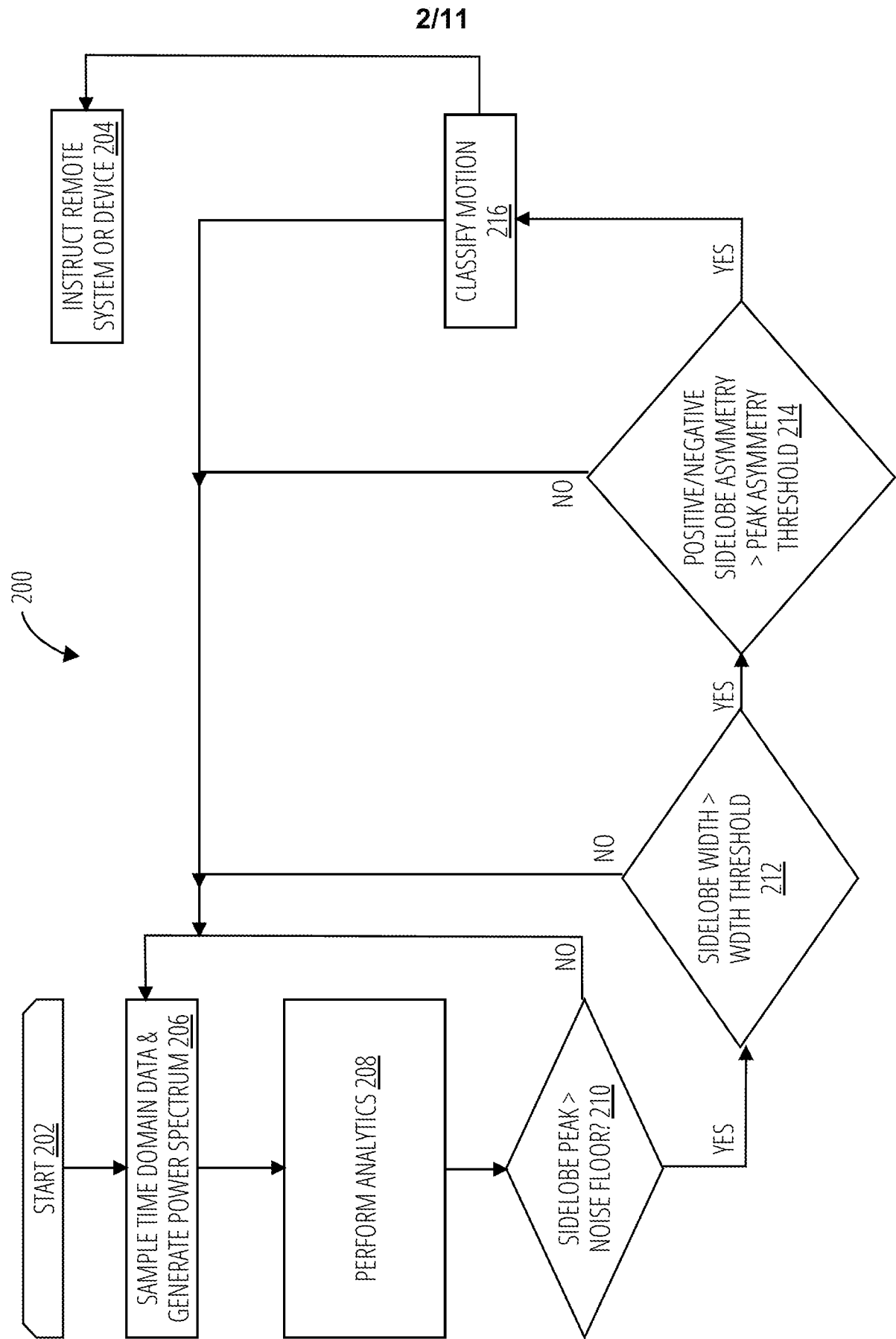


FIG. 2

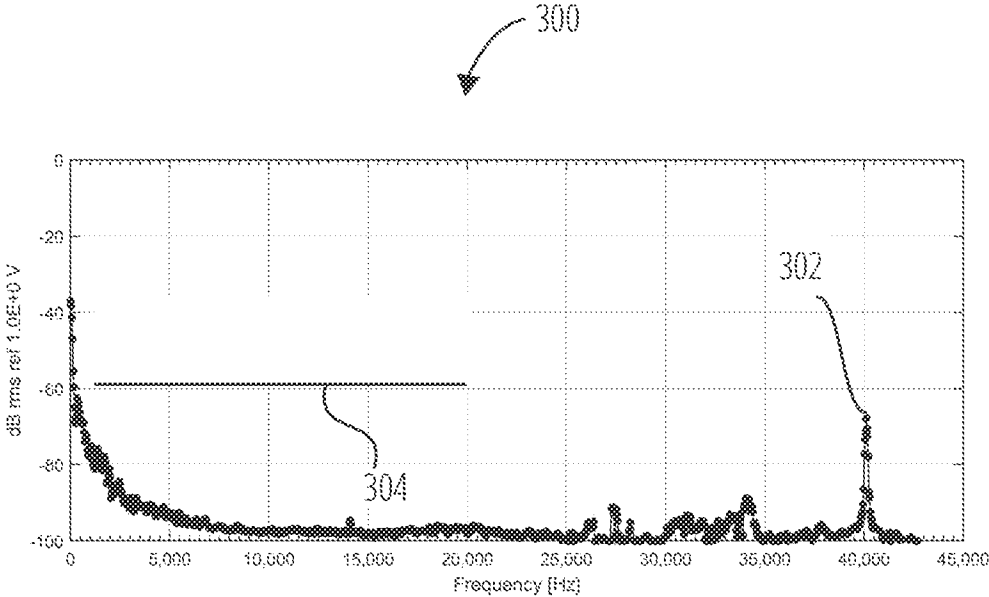


FIG. 3

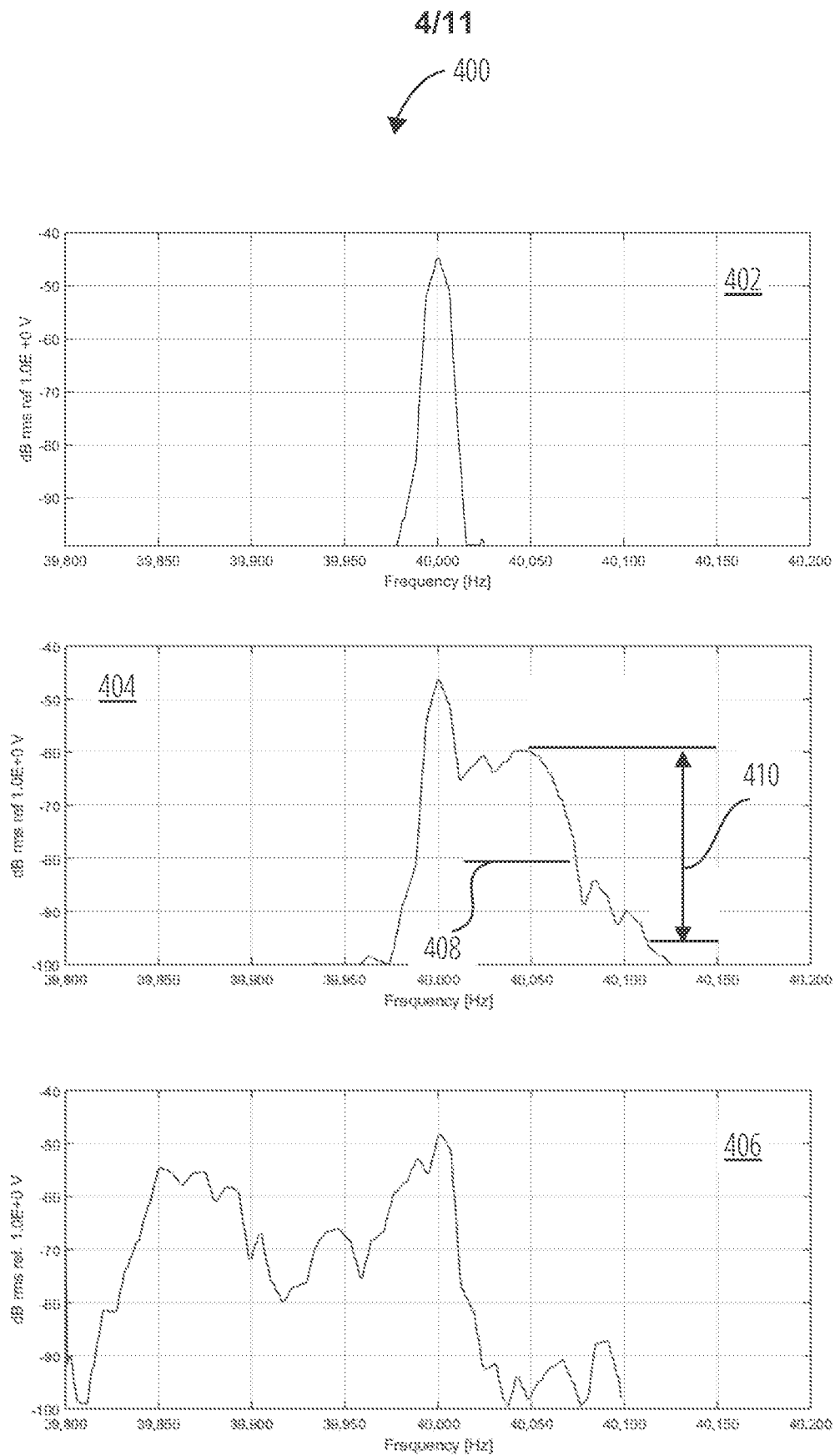


FIG. 4

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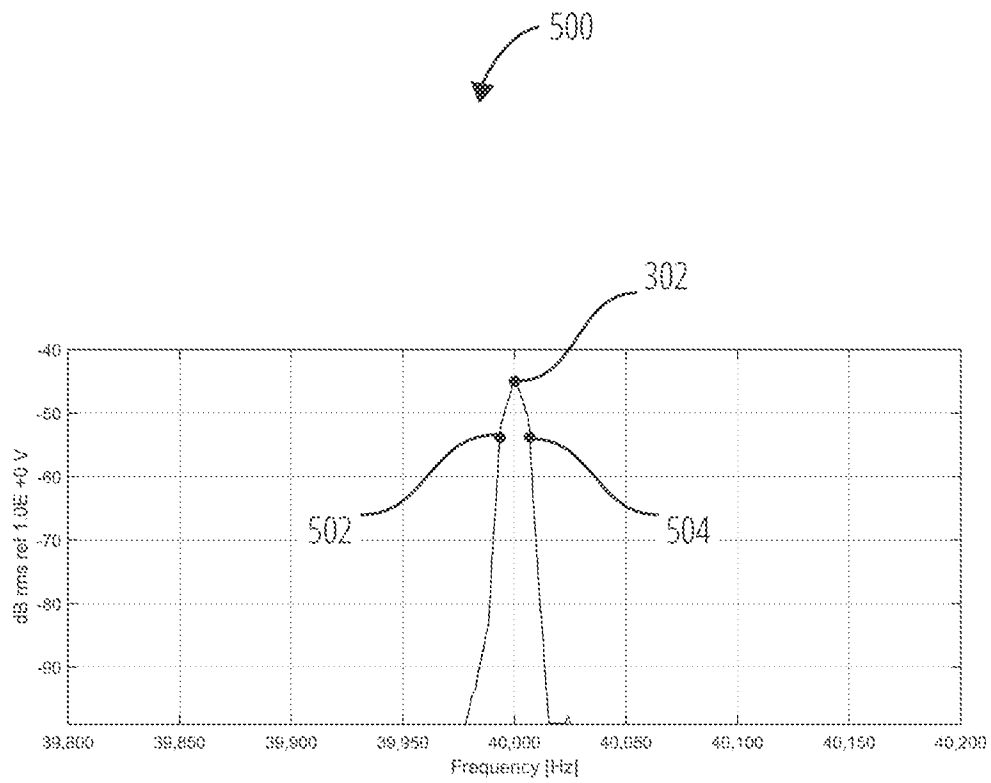


FIG. 5

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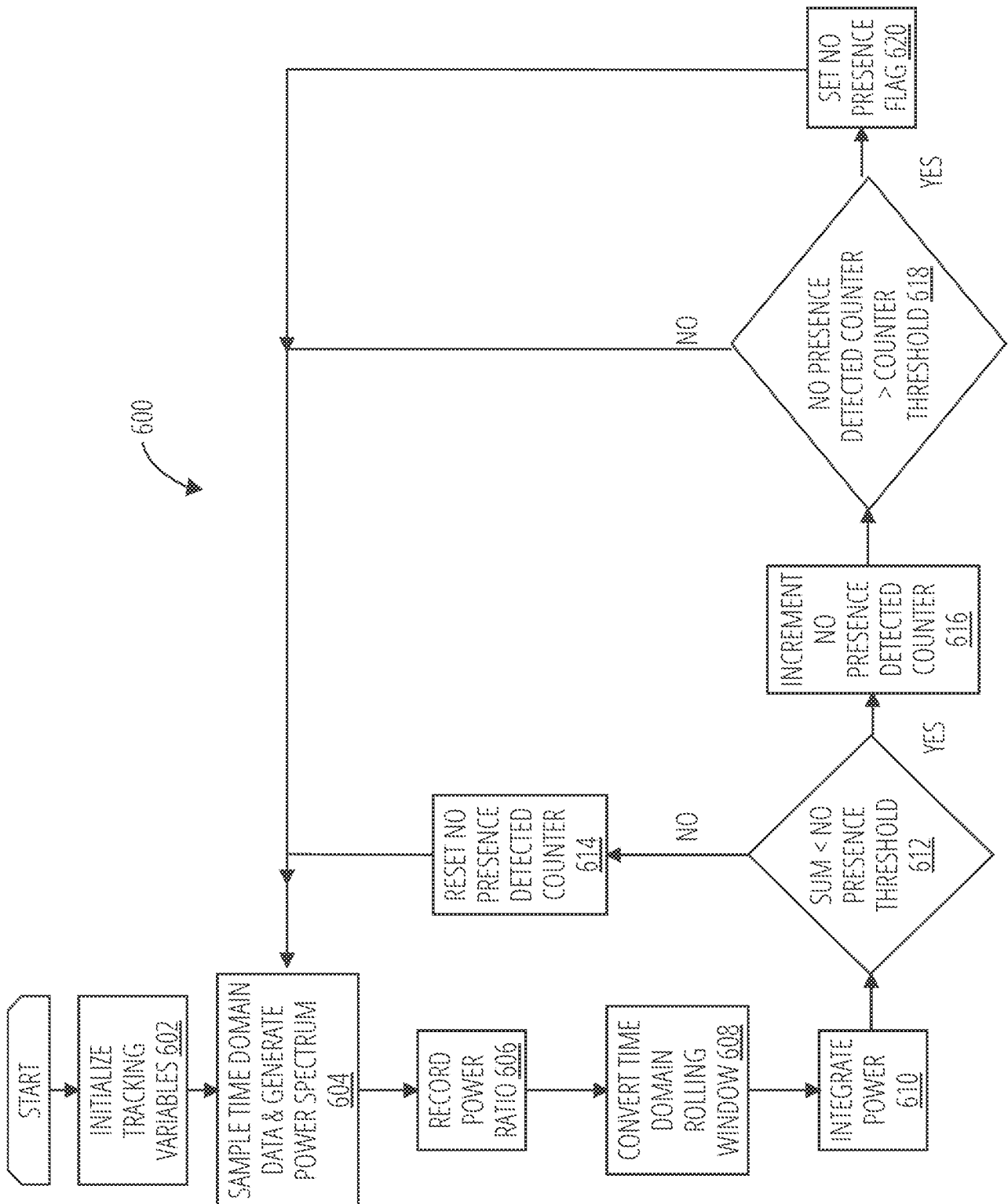


FIG. 6

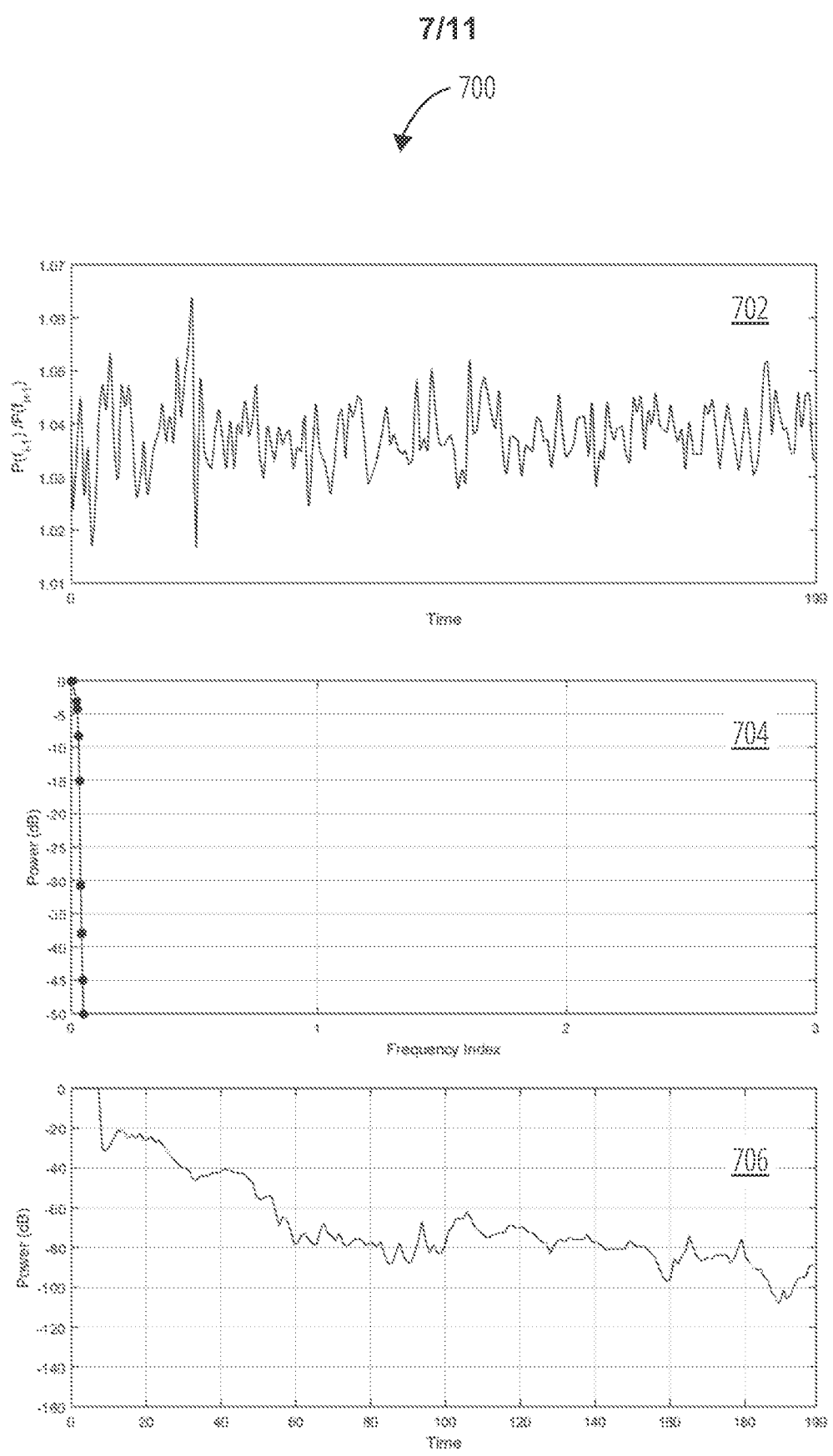


FIG. 7

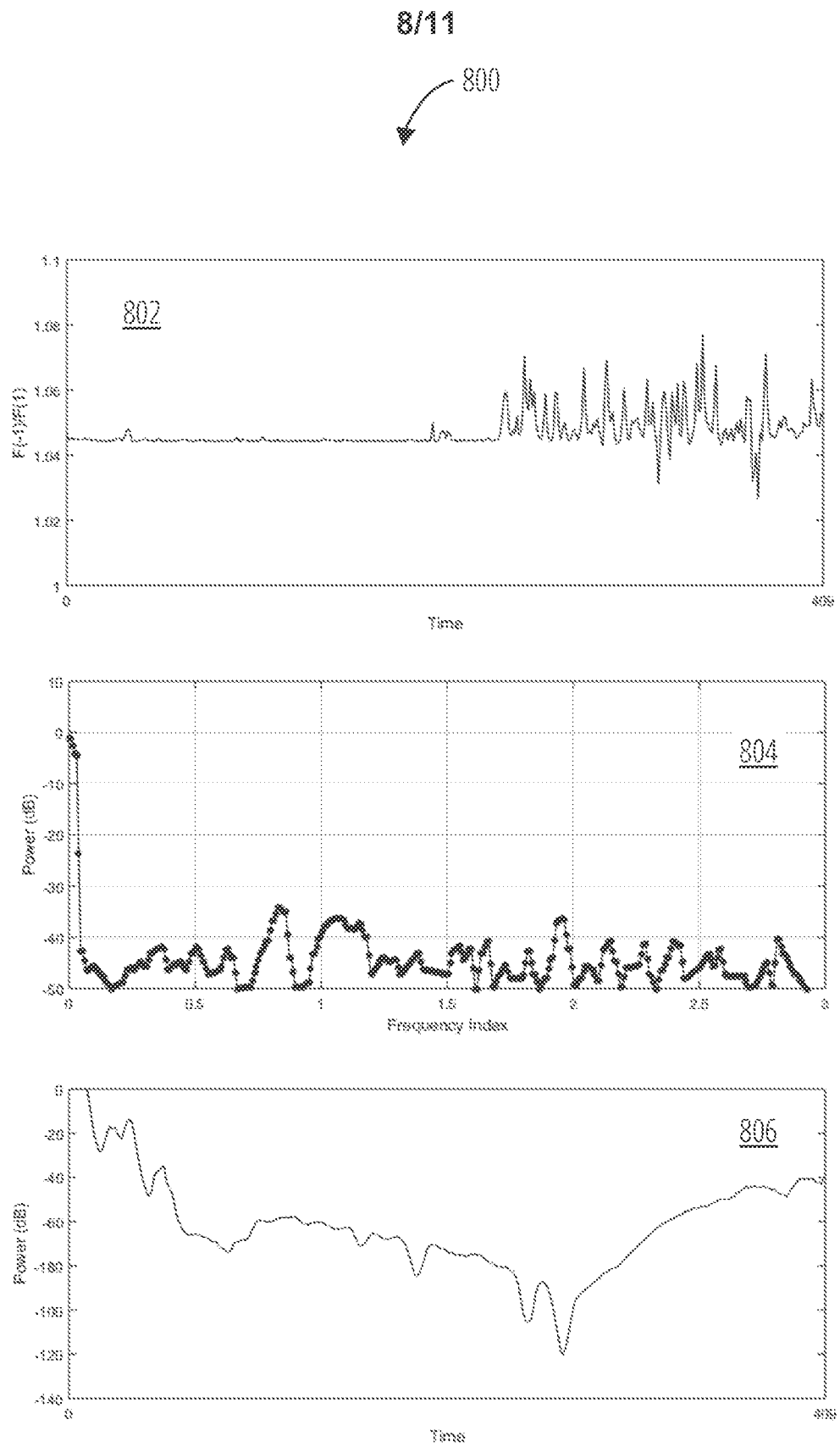


FIG. 8

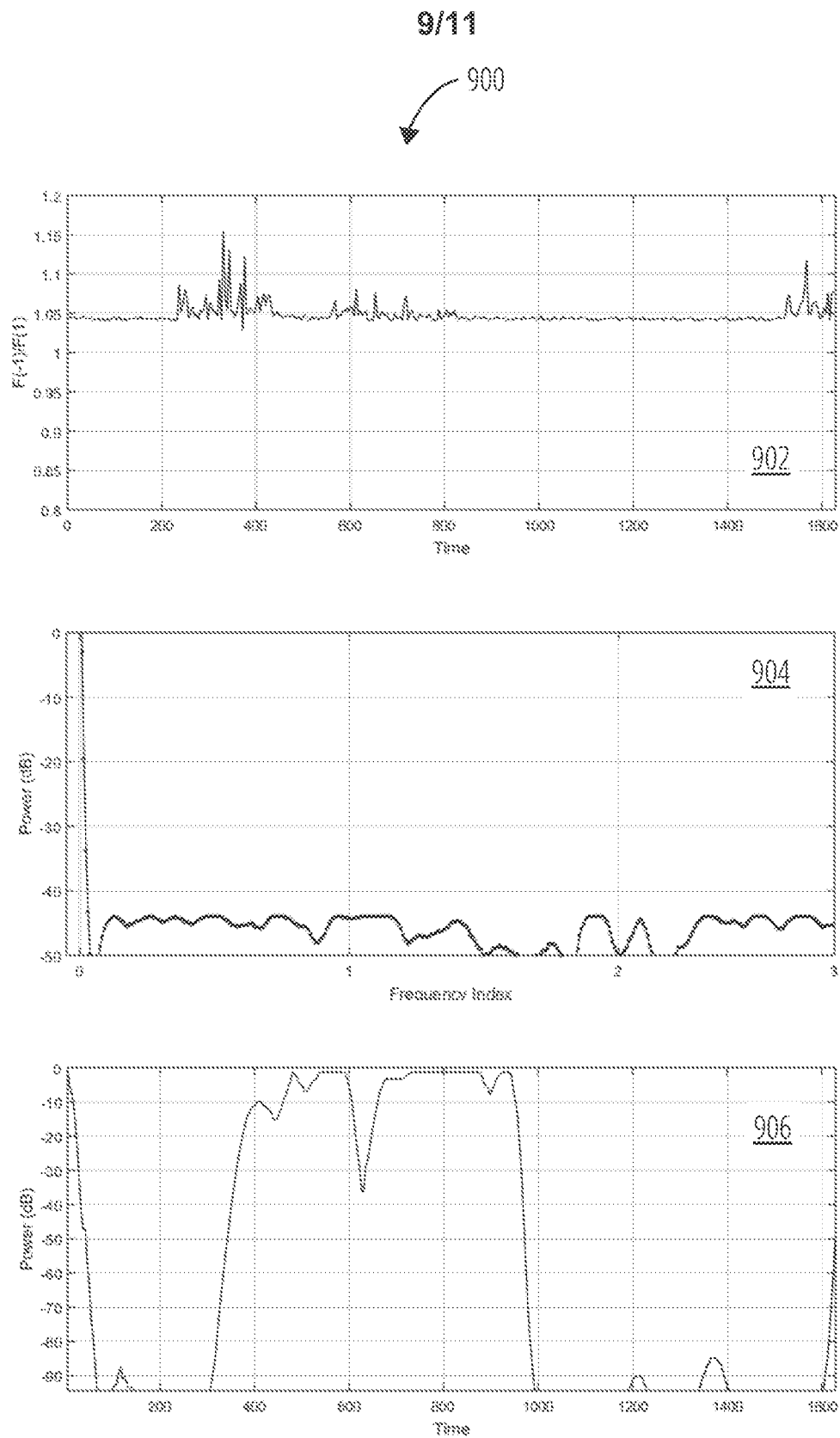


FIG. 9

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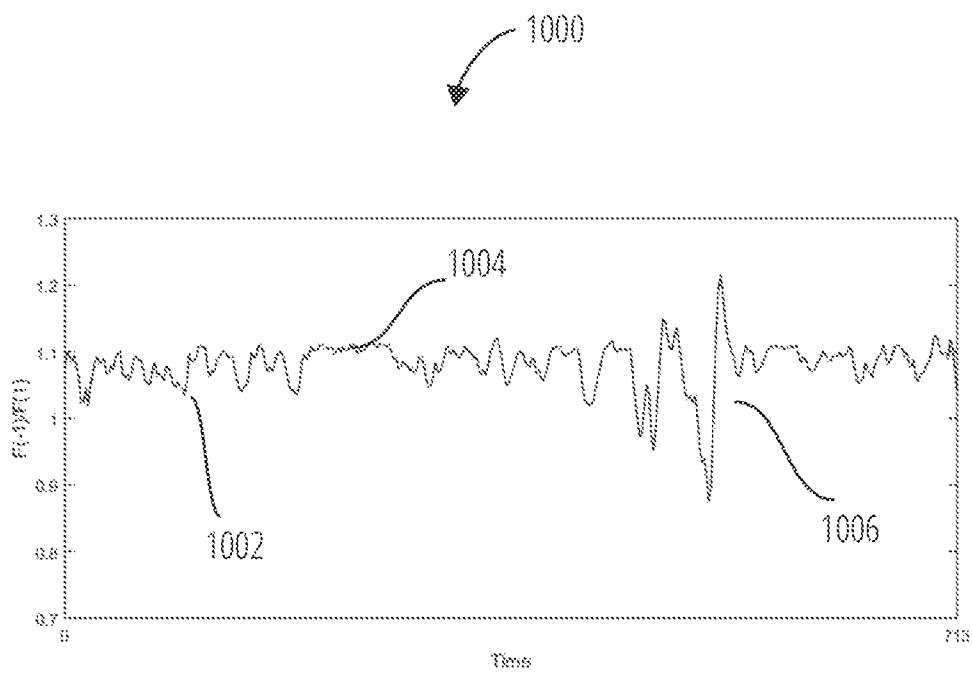


FIG. 10

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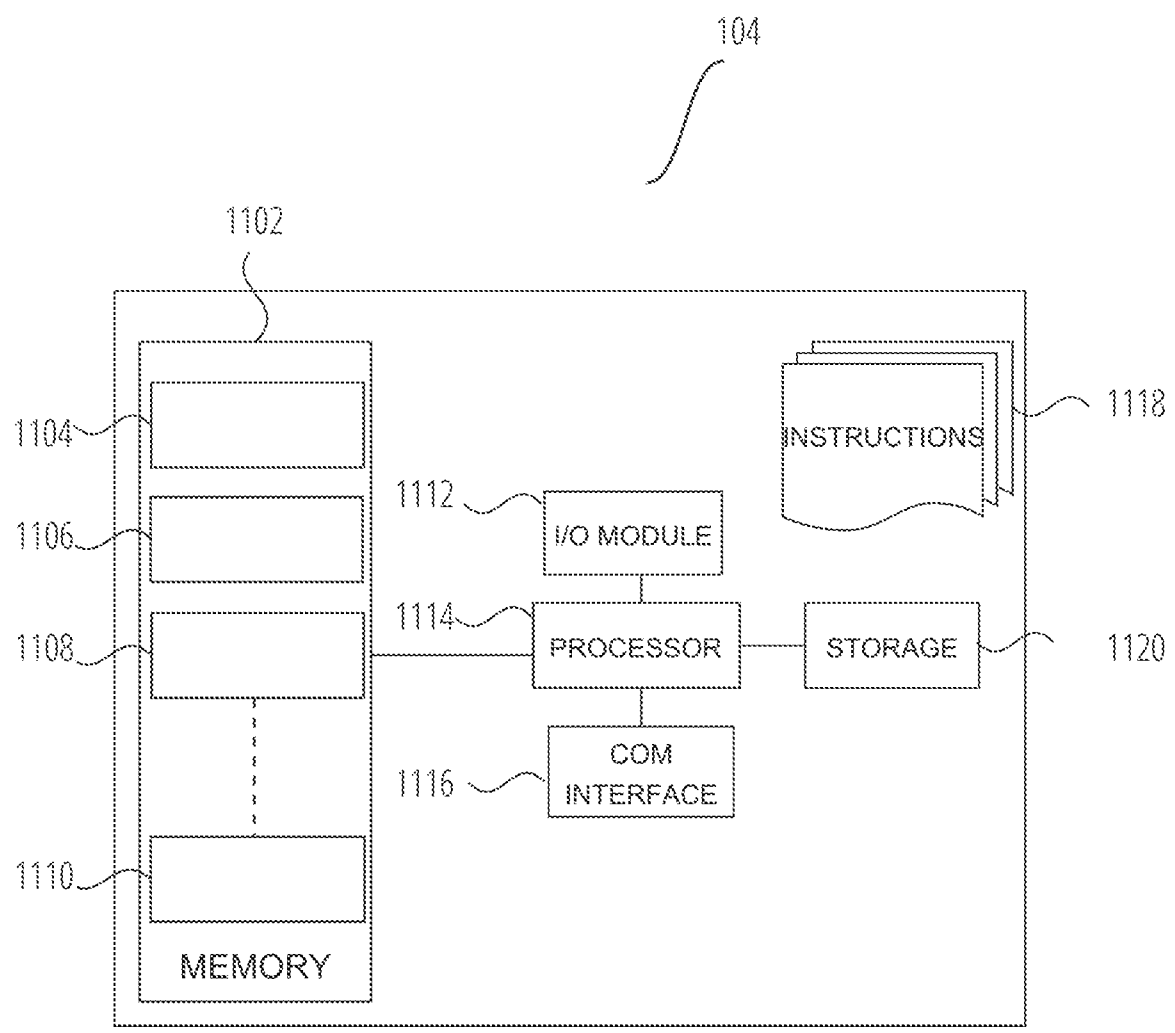


FIG. 11

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2018/025901**A. CLASSIFICATION OF SUBJECT MATTER****G01S 15/62(2006.01)i, G01S 7/534(2006.01)i**

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

B. FIELDS SEARCHEDMinimum documentation searched (classification system followed by classification symbols)
G01S 15/62; G01S 15/04; G06F 19/00; G01S 13/62; G06F 15/18; G06N 5/02; G01S 7/534Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility modelsElectronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & keywords: ultrasonic, side lobe, compare, threshold, presence**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2004-0125009 A1 (TADAO NISHIGUCHI et al.) 01 July 2004 See paragraphs [0042]-[0058], claims 1-3 and figures 1-3.	1-20
A	US 2009-0046538 A1 (DAVID S. BREED et al.) 19 February 2009 See paragraphs [0093]-[0099], [0157], claim 1 and figures 1-6.	1-20
A	US 2012-0143808 A1 (JAMES P. KARINS et al.) 07 June 2012 See claims 1, 9, 12 and figures 2-4.	1-20
A	US 2006-0235635 A1 (NATHAN INTRATOR et al.) 19 October 2006 See claims 1-10 and figures 1a-4.	1-20



Further documents are listed in the continuation of Box C.



See patent family annex.

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"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

24 July 2018 (24.07.2018)

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International Application Division

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