(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 3 757 598 B1

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention of the grant of the patent:
21.08.2024 Bulletin 2024/34

(21) Application number: **20181924.0**

(22) Date of filing: **24.06.2020**

(51) International Patent Classification (IPC):
G01S 7/02 *(2006.01)* ***G01S 7/292*** *(2006.01)*
G01S 7/52 *(2006.01)* ***G01S 13/86*** *(2006.01)*

(52) Cooperative Patent Classification (CPC):
G01S 7/023; G01S 7/2928; G01S 13/86;
G01S 15/50

(54) **IN DEVICE INTERFERENCE MITIGATION USING SENSOR FUSION**

ABSCHWÄCHUNG VON INTERFERENZEN IN EINER VORRICHTUNG MITTELS SENSORFUSION

RÉDUCTION D'INTERFÉRENCE INTRA-DISPOSITIF AU MOYEN D'UNE FUSION DE CAPTEURS

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR

(30) Priority: **25.06.2019 US 201916452028**

(43) Date of publication of application:
30.12.2020 Bulletin 2020/53

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EP 3 757 598 B1

Description

TECHNICAL FIELD

[0001] The present disclosure relates generally to an electronic system and method, and, in particular embodiments, to an in device interference mitigation using sensor fusion.

BACKGROUND

[0002] Document WO 2018/129294 A1 proposes a radar presence detection system configured to detect oscillations within a building. The radar presence detection system includes an accelerometer, a radar, and a processing unit. The accelerometer is attached to the building and configured to detect structural vibration waves. The radar is configured to transmit a monitoring wave and receive a reflected wave. The processing unit includes a filter, an adaptive filter, and a detector. The filter is configured to receive a first signal indicative of the reflected wave and output a filtered reflected wave signal spanning a frequency range indicative of an oscillation within the building. The adaptive filter is configured to receive a second signal indicative of the structural vibration wave signal and output a focused vibration signal spanning a frequency range for the cancellation of vibration noise.

[0003] Applications in the millimeter-wave (mmWave) frequency regime have gained significant interest in the past few years due to the rapid advancement in low cost semiconductor technologies, such as silicon germanium (SiGe) and fine geometry complementary metal-oxide semiconductor (CMOS) processes. Availability of high-speed bipolar and metal-oxide semiconductor (MOS) transistors has led to a growing demand for integrated circuits for millimeter-wave applications at 24 GHz, 60 GHz, 77 GHz, and 80 GHz and also beyond 100 GHz. Such applications include, for example, automotive radar systems and multi-gigabit communication systems.

[0004] In some radar systems, the distance between the radar and a target is determined by transmitting a frequency modulated signal, receiving a reflection of the frequency modulated signal (also referred to as the echo), and determining a distance based on a time delay and/or frequency difference between the transmission and reception of the frequency modulated signal. Accordingly, some radar systems include a transmit antenna to transmit the radio-frequency (RF) signal, and a receive antenna to receive the reflected RF signal, as well as the associated RF circuitry used to generate the transmitted signal and to receive the RF signal. In some cases, multiple antennas may be used to implement directional beams using phased array techniques. A multiple-input and multiple-output (MIMO) configuration with multiple chipsets can be used to perform coherent and non-coherent signal processing as well.

SUMMARY

[0005] There may be a demand for providing an improved concept for a method of interference mitigation in a device and a corresponding device. Such a demand may be satisfied by the subject-matter of the independent claims. Further embodiments are given in the dependent claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] For a more complete understanding of the present invention, and the advantages thereof, reference is now made to the following descriptions taken in conjunction with the accompanying drawings, in which:

Figure 1 shows a radar system,
Figure 2 shows the millimeter-wave radar of Figure 1 inside an enclosure of an electronic device,
Figure 3 shows flow chart of a method for compensating radar measurements to mitigate interference,
Figure 4 shows the moving average filter of Figure 3 implemented as an ARMA filter,
Figure 5 shows an electronic device,
Figure 6 shows flow chart of a method for compensating radar measurements to mitigate interference,
Figure 7 shows an electronic device, according to the present invention;
Figure 8 shows flow chart of the method for compensating radar measurements to mitigate interference, according to the present invention;
Figure 9 shows the moving average filter of Figure 8 implemented as an ARMA filter, according to an embodiment of the present invention; and
Figure 10 shows a flow chart of an embodiment method for mitigating interference using a trained forecasting model, according to an embodiment of the present invention;

[0007] Corresponding numerals and symbols in different figures generally refer to corresponding parts unless otherwise indicated. The figures are drawn to clearly illustrate the relevant aspects of the preferred embodiments and are not necessarily drawn to scale.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

[0008] Embodiments of the present invention will be described in a specific context, a mobile device having millimeter-wave (mmWave) radar that mitigates interference caused by an actuator of the mobile device using one or more sensors. Embodiments of the present invention may be used in other types of devices, such as computers, sound systems, televisions, voice assistants, etc. The present invention is directed to a method of interference mitigation in a device comprising a millimeter-wave radar according to claim 1 and to a corresponding device according to claim 11.

[0009] In an embodiment of the present invention, a millimeter-wave radar mitigates interference caused by movement of an object (e.g., a speaker or an enclosure). The millimeter-wave radar transmits radar signals and receives reflected radar signals. A sensor is used to sense a signal indicative of the movement of the object. During the processing of the reflected radar signals, the sensed signal is transformed and subtracted from the reflected radar signals or the processed reflected radar signals to reduce or eliminate the interference. In some embodiments, the millimeter-wave radar generates a first spectrogram based on the reflected radar signals, where the first spectrogram includes an interference component caused by the moving object. The millimeter-wave radar also generates a second spectrogram based on the sensed signals, and then uses the first and second spectrograms (subtracts the second spectrogram from the first spectrogram) to obtain a compensated spectrogram, where the compensated spectrogram has reduced interference component compared to the first spectrogram. The compensated spectrogram is then used to perform further radar processing, thereby reducing or eliminating false positives.

[0010] In some embodiments, the object causing the interference is a non-target object (i.e., an object that the millimeter-wave radar should ignore) in the field-of-view (FoV) of the millimeter-wave radar.

[0011] Millimeter-wave radars may be used, for example, to detect moving or static objects in a field of view. For example, Figure 1 shows millimeter-wave radar system 100, according to an embodiment of the present invention. Millimeter wave radar system 100 includes millimeter-wave radar 102, and processor 104.

[0012] During normal operation, millimeter-wave radar 102 transmits radar signals 106, such as plurality of radiation pulses, such as chirps (e.g., linear chirps), towards scene 108. The transmitted radar signals 106 are reflected by objects in scene 108. The reflected radar signals 306 (not shown in Figure 1), which are also referred to as the echo signal, are detected by millimeter-wave radar 102 and processed by processor 104 to, for example, identify an object, detect an object's location, and/or Doppler velocity and/or trajectory, and other/or determine characteristics of objects in scene 108.

[0013] Objects in scene 108 may include static or moving objects. For the scene 108 may include one or more of a static person, a moving person, a face of a person, a finger or hand of a person (e.g., making a gesture), a fingerprint, a periodically moving object such as a fan, static objects such as furniture, etc. Other objects may also be included in scene 108.

[0014] Millimeter-wave radar 102 operates as a frequency-modulated continuous wave (FMCW) radar or pulsed Doppler radar that includes a millimeter-wave radar sensor circuit, a transmitting antenna(s), and a receiving antenna(s). Millimeter-wave radar 102 transmits and receives signals in the 20 GHz to 122 GHz range. Alternatively, frequencies outside of this range, such as frequencies between 1 GHz and 20 GHz, or frequencies between 122 GHz, and 300 GHz, may also be used.

[0015] In some embodiments, the echo signals received by the receiving antennas of millimeter-wave radar 102 are filtered and amplified using band-pass filter (BPFs), low-pass filter (LPFs), mixers, low-noise amplifier (LNAs), and intermediate frequency (IF) amplifiers in ways known in the art by, e.g., millimeter-wave radar 102. The echo signals are then digitized using one or more analog-to-digital converters (ADCs) for further processing, e.g., by processor 104. Other implementations are also possible.

[0016] Processor 104 may be implemented as a general purpose processor, controller or digital signal processor (DSP) that includes, for example, combinatorial circuits coupled to a memory. In some embodiments, the DSP may be implemented with an ARM architecture, for example. In some embodiments, processor 104 may be implemented as a custom application specific integrated circuit (ASIC). In some embodiments, processor 104 includes a plurality of processors, each having one or more processing cores. In other embodiments, processor 104 includes a single processor having one or more processing cores. Other implementations are also possible. For example, some embodiments may implement a decoder using software running in a general purpose micro-controller or processor having, for example, a CPU coupled to a memory and implemented with an ARM or x86 architecture. Some embodiments may be implemented as a combination of hardware accelerator and software running on a DSP or general purpose micro-controller.

[0017] In some embodiments, processor 104 is integrated inside millimeter-wave radar 102. In other embodiments, processor 104 is external to millimeter-wave radar 102.

[0018] In some embodiments, millimeter-wave radar 102 may be inside an enclosure, such as inside the enclosure of a smartphone. Figure 2 shows millimeter-wave radar 102 inside enclosure 208 of electronic device 200, according to an embodiment of the present invention. Electronic device 200 includes speaker 204 and microphone 206.

[0019] During normal operation, speaker 204 may reproduce audio, such as a song, a voice of a person talking, a ringtone, etc. To reproduce audio, speaker 204 receives electrical signals corresponding to the audio to be reproduced (not shown). When speaker 204 reproduces audio, a portion of speaker 204, such as the diaphragm, moves to push air, thereby converting the electrical signals received by speaker 204 into sound waves 210.

[0020] Speaker 204 may reproduce audio at the same time that millimeter-wave radar 102 is transmitting and receiving radar signals to perform, e.g., object detection, identification, and other radar processing. It is possible that the movement of the portion of speaker 204 (e.g., the movement of the diaphragm) when speaker 204 is reproducing audio is detected by millimeter-wave radar 102 as an object. For example, in some embodiments, speaker 204 is disposed inside the field-of-view of millimeter-wave radar 102. Millimeter-wave radar 102 transmits radar signals 106 that are reflected by the moving diaphragm of speaker 204 (which may be reflected multiple times between the diaphragm of speaker 204 and enclosure 208) and then reach millimeter-wave radar 102. Such received reflected radar signals 306 (not shown in Figure 2) may cause millimeter-wave radar 102 to detect an object, thereby resulting in an error such as a false positive error.

[0021] In an embodiment, microphone 206 is used to receive sound waves 212 (which correspond to sound waves 210) and convert them into received audio electrical signals. The received audio electrical signals may be used to determine the movement of the portion of speaker 204 (e.g., the diaphragm). The determined movement of the portion of speaker 204 may be used to compensate the measurements performed by millimeter-wave radar 102 to avoid false positive errors caused by the movement of the portion of speaker 204.

[0022] Electronic device 200 may be, for example, a smartphone or tablet. In some embodiments, electronic device 200 may be smartwatch, laptop, or other mobile device. In some embodiments, electronic device 200 may be a desktop computer, television, voice assistants, sound system, or any other device that includes a microphone, a speaker, and a millimeter-wave radar.

[0023] Speaker 204 may be, for example, a cone speaker (i.e., the diaphragm is coneshaped.). In some embodiments, speaker 204 may be a piezoelectric speaker. Other types of speakers may also be used. In some embodiments, speaker 204 is inside enclosure 208. In other embodiments, speaker 204 may be outside enclosure 208. For example, in some embodiments, enclosure 208 may be near (e.g., adjacent) to another device that includes speaker 204. For example, a smartphone that includes enclosure 208 is in a room, and an external device (e.g., another smartphone, a woofer, a loudspeaker, etc.) that includes speaker 204 is also in the room and is near (e.g., adjacent) to the smartphone that includes enclosure 208).

[0024] Microphone 206 may be, for example, a digital microphone. In some embodiments, an analog microphone is used.

[0025] Accroding to the present invention, a millimeter-wave radar mitigates interference caused by movement of an object (e.g., a speaker or an enclosure) by using a microphone to sense sound waves indicative of the movement of the object. A first spectrogram is generates based on the reflected signals received by the millimeter-wave radar. The audio signals generated by the microphone are used to generate the second spectrogram, which is then used in combination with the first spectrogram (subtracted from the first spectrogram) to generate the compensated spectrogram. The interference caused by the moving object are advantageously minimized or eliminated from the compensated spectrogram, thereby advantageously reducing false positives.

[0026] Figure 3 shows flow chart of method 300 for compensating radar measurements to mitigate interference. Method 300 may be performed, e.g., by millimeter-wave radar system 100, e.g., inside electronic device 200.

[0027] During step 302, millimeter-wave radar 102 transmits radar signals 106, which are reflected in objects in the field of millimeter-wave radar 102 to generate reflected radar signals 306. Objects in the field-of-view of millimeter-wave radar 102 may include enclosure 208, speaker 204, and objects outside enclosure 208, such as a hand, a finger, a face of a person, etc.

[0028] During step 308, millimeter-wave radar 102 receives reflected radar signals 306. Reflected radar signals 306 may include radar signals reflected from, e.g., the diaphragm of speaker 204.

[0029] During step 312, millimeter-wave radar 102 generates a first spectrogram (e.g., using processor 104) based on reflected radar signals 306 received during step 308. Millimeter-wave radar 102 may generate the first spectrogram by performing an FFT on the reflected radar signals 306 and then performing an absolute function. The first spectrogram may include data associated with the movement of the diaphragm of speaker 204.

[0030] During step 304, speaker 204 reproduces audio to produce sound waves 210. During step 310, microphone 206 receives sound waves 212, where the sound waves 212 correspond to sound waves 210. For example, in some embodiments, sound waves 210 are reflected in enclosure 208 to generate sound waves 212. In some embodiments, microphone 206 receives sound waves 212 directly from speaker 204 and without being reflected in enclosure 208.

[0031] During step 314, millimeter-wave radar 102 generates a second spectrogram (e.g., using processor 104) based on sound waves 212 received during step 310. Millimeter-wave radar 102 may generate the second spectrogram by performing an FFT on the sound waves 212 and then performing an absolute function.

[0032] During step 316, a moving average (MA) filter, such as an auto-regressive (AR) MA (ARMA) filter, is used to generate an error spectrogram based on the first and second spectrogram (an example implementation of step 316 is shown in Figure 4, according to an embodiment of the present invention). The error spectrogram is subtracted from the first spectrogram during step 318 to generate a compensated spectrogram. The compensated spectrogram minimizes or eliminates data associated with, e.g., the movement of the diaphragm of speaker 204, thereby mitigating any interference, e.g., caused by speaker 204 reproducing audio.

[0033] During step 320, millimeter-wave radar 102 performs further radar processing based on the compensated spectrogram. The further radar processing may include detecting a target, (e.g., by comparing peaks of the compensated spectrogram with a threshold), as well as determining a property of a target, such as the target's Doppler velocity, material, shape, etc.

[0034] Using an ARMA filter based on signals measured by a sensor, such as a microphone, to predict the interference caused by an actuator (such as a speaker as described above in an exemplary manner) or other object (such as an enclosure) advantageously allows the millimeter-wave radar to mitigate the interference despite any non-linearities of the electronic device, and despite any manufacturing variations that the electronic device may exhibit.

[0035] In some embodiments, such as when the electronic device is a smartphone or tablet, the electronic device may already include microphones for, e.g., noise cancellation. The same microphones may be used for radar interference mitigation, thereby allowing to achieve better radar performance without adding additional sensors.

[0036] Figure 4 shows moving average filter 316 implemented as an ARMA filter. Moving average filter 316 includes filters 402 and 404, and summation module 406. Moving average filter 316 aims to reduce the power of the error generated at the output of summation module 406 by adjusting the coefficients of filter 404.

[0037] As shown in Figure 4, the first spectrogram includes radar data A associated with the movement of speaker 204, and radar data R associated with other objects (e.g., different than speaker 204) that are in the field of view of millimeter-wave radar 102. The second spectrogram includes data *A*' (e.g., captured by microphone 206) associated with the movement of speaker 204. Data A'is similar but not necessary equal to data A. The differences between data A' and data A may be, for example, due to the linearity of the transfer function of microphone, the path that the sound waves 210 took to reach microphone 206, the path that the radiation signals 106 took to reach back millimeter-wave radar 102, etc.

[0038] During normal operation, filter 402 receives the first spectrogram and generates a filtered version of the first spectrogram. Filter 404 receives the second spectrogram and generates a filtered version of the second spectrogram. As shown in Figure 4, in order for the power of the error at the output of summation module 406 to be minimized, the coefficients of filter 404 are modified such that filter 404 generates from the second spectrogram a filtered version ($A'_{filtered}$) that is substantially similar to (and ideally equal to) the filtered radar data ($A_{filtered}$). The output of filter 404 is the error spectrogram used during step 318 to generate the compensated spectrogram.

[0039] In some embodiments, filter 316 uses algorithms such as steepest decent to minimize the power of the error at the output of summation module 406. Other algorithms may also be used.

[0040] Filters 402 and 404 may be implemented, for example, as finite impulse response (FIR) filters. Summation module 406 may be implemented as a digital block that performs the subtraction of the outputs of filter 404 from filter 402. Other implementations are also possible.

[0041] In the present claimed invention, sensors other than a microphone may be used to mitigate interference caused by one or more actuators of the mobile device. For example, Figure 5 shows electronic device 500. Electronic device 500 may operate in a similar manner as electronic device 200. Electronic device 500, however, includes haptic actuator 502 and accelerometer 506.

[0042] During normal operation, sound waves 210 may cause enclosure 508 to vibrate. For example, the low frequencies of sound waves 210 (e.g., from 100 Hz to 1 kHz) may cause enclosure 508 to vibrate. Similarly, haptic actuator 502, which may vibrate at frequencies from 80 Hz to 500 Hz, may cause enclosure 508 to vibrate.

[0043] Enclosure 508 may vibrate at the same time that millimeter-wave radar 102 is transmitting and receiving radar signals to perform, e.g., object detection, identification, and other radar processing. It is possible that the vibration of enclosure 508 is detected by millimeter-wave radar 102 as an object. For example, in some embodiments, millimeter-wave radar 102 transmits radar signals 106 that are reflected by enclosure 508 and then reach millimeter-wave radar 102. Such received reflected radar signals 306 (not shown in Figure 5) may cause millimeter-wave radar 102 to detect an object, thereby resulting in a false positive error.

[0044] In an embodiment, accelerometer 506 is used to measure vibrations of enclosure 508. The measured vibrations may be used to determine the movement of enclosure 508. The determined movement of enclosure 508 may be used to compensate the measurements performed by millimeter-wave radar 102 to avoid false positive errors caused by the movement of enclosure 508.

[0045] Haptic actuator 502 may be implemented in any way known in the art. For example, in some embodiments, the haptic actuator is of the eccentric rotating mass (ERM) type. In other embodiments, haptic actuator 502 is of the linear resonant actuator (LRA) type. Other haptic actuator implementations, such as haptic actuators of the piezoelectric type, and of the brushless DC motor (BLDC) type are also possible.

[0046] Accelerometer 506 may be implemented in any way known in the art. For example, in some embodiments, accelerometer may be attached to enclosure 508. In other embodiments, accelerometer 506 may be attached onto a surface that is mechanically coupled to enclosure 508 and vibrates along enclosure 508. Other implementations are also possible.

[0047] In some embodiments, accelerometer 506 measures vibrations in the y-axis only and passes the measurements onto processor 104 for further processing. In other embodiments, vibrations in other directions, such as along the x axis and/or the z axis are also passed along onto processor 104 for further processing.

[0048] Figure 6 shows flow chart of embodiment method 600 for compensating radar measurements to mitigate interference, according to an embodiment of the present invention. Method 600 may be performed, e.g., by millimeter-wave radar system 100, e.g., inside electronic device 500. Steps 302, 304, 316, 318, and 320 are described above with respect to Figure 3.

[0049] During step 608, millimeter-wave radar 102 receives reflected radar signals 306. Reflected radar signals 306 may include radar signals reflected from, e.g., enclosure 508.

[0050] During step 612, millimeter-wave radar 102 generates a first spectrogram (e.g., using processor 104) based on reflected radar signals 306 received during step 608. Millimeter-wave radar 102 may generate the first spectrogram by performing an FFT on the reflected radar signals 306 and then performing an absolute function. The first spectrogram may include data associated with the movement of enclosure 508.

[0051] During step 304, speaker 204 may reproduce audio to produce sound waves 210, which may produce vibrations of enclosure 508. During step 602, haptic actuator 502 may reproduce haptic effects 606, which produce vibration of enclosure 508.

[0052] During step 610, accelerometer 506 measures vibration of enclosure 508. Such vibration measurements are used by millimeter-wave radar 102 during step 614 to generate a second spectrogram (e.g., using processor 104). Millimeter-wave radar 102 may generate the second spectrogram by performing an FFT on the measured vibrations and then performing an absolute function.

[0053] Step 316, 318 and 320 are performed, e.g., as described with respect to Figure 3 to generate a compensated spectrogram and perform further radar processing.

[0054] According to the invention, interference from more than one source may be mitigated. For example, Figure 7 shows electronic device 700, according to the present invention. Electronic device 700 includes speaker 204, microphone 206, haptic actuator 502 and accelerometer 506.

[0055] Figure 8 shows flow chart of method 800 for compensating radar measurements to mitigate interference, according to the present invention. Method 800 may be performed, e.g., by millimeter-wave radar system 100, e.g., inside electronic device 700. Steps 302, 304, 310,320, 602, and 614 are described above with respect to Figures 3 and 6.

[0056] During step 808, millimeter-wave radar 102 receives reflected radar signals 306. Reflected radar signals 306 may include radar signals reflected from, e.g., enclosure 508 and/or from the diaphragm of speaker 204.

[0057] During step 812, millimeter-wave radar 102 generates a first spectrogram (e.g., using processor 104) based on reflected radar signals 306 received during step 808. Millimeter-wave radar 102 may generate the first spectrogram by performing an FFT on the reflected radar signals 306 and then performing an absolute function. The first spectrogram may include data associated with the movement of enclosure 508 and/or the diaphragm of speaker 204.

[0058] During step 304, speaker 204 may reproduce audio to produce sound waves 210, which may produce vibrations of enclosure 508. During step 602, haptic actuator 502 may reproduce haptic effects 606, which produce vibration of enclosure 508.

[0059] During step 810, accelerometer 506 and/or microphone 206 measures vibration of enclosure 508 (microphone 206 may capture vibrations in some embodiments because such vibrations may produce sound in the audible range). Such sound waves and vibration measurements are used by millimeter-wave radar 102 during steps 314 and 814 to generate second and third spectrograms, respectively (e.g., using processor 104).

[0060] During step 816, an MA filter, such as an ARMA filter, is used to generate an error spectrogram based on the second and third spectrograms. The error spectrogram is subtracted from the first spectrogram during step 818 to generate a compensated spectrogram. The compensated spectrogram minimizes or eliminates data associated with the movement of the diaphragm of speaker 204 and/or with the movement of enclosure 508, thereby mitigating any interference caused by speaker 204 reproducing audio and/or by vibrations of enclosure 508.

[0061] Step 320 is performed, e.g., as described with respect to Figure 3 to perform further radar processing.

[0062] In some embodiments, such as when the electronic device is a smartphone or tablet, the electronic device may already include microphones for, e.g., noise cancellation and an accelerometer. The same microphones and accelerometer may be used for radar interference mitigation, thereby allowing achieving better radar performance without adding additional sensors.

[0063] Figure 9 shows moving average filter 816 implemented as an ARMA filter, according to an embodiment of the present invention. Moving average filter 816 includes filters 402, 404, and 902, and summation modules 406 and 904. Moving average filter 816 aims to reduce the power of the error generates at the output of summation module 906 by adjusting the coefficients of filters 404 and 902.

[0064] As shown in Figure 9, the first spectrogram includes radar data A associated with the movement of speaker 204, radar data V associated with the movement of enclosure 508, and radar data R associated with other objects (e.g., different than speaker 204 and enclosure 508) that are in the field of view of millimeter-wave radar 102. The second spectrogram includes data *A'* (e.g., captured by microphone 206) associated with the movement of speaker 204. Data A'is similar but not necessary equal to data A. In some embodiments, the second spectrogram may also include data V associated with the movement of enclosure 508 (since some vibrations may occur in the audible range). The differences between data A' and data A and between data V' and V, may be, for example, due to the linearity of the transfer function of microphone, the path that the sound waves 210 took to reach microphone 206, the path that the radiation signals 106 took to reach back millimeter-wave radar 102, etc.

[0065] The third spectrogram includes data *V'* (e.g., captured by accelerometer 506) associated with the movement of enclosure 508. Data *V'* is similar but not necessary equal to data V. The differences between data *V"* and data *V* may be, for example, due to the linearity of the transfer function of the accelerometer, the path that the radiation signals 106 took to reach back millimeter-wave radar 102, etc.

[0066] During normal operation, filters 402, 404, and 902 receive the first, second, and third spectrograms, respectively, and respectively generate a filtered version of the first, second, and third spectrograms. As shown in Figure 4, in order for the power of the error at the output of summation module 406 to be minimized, the coefficients of filters 404 and 902 are modified such that $R_{\text{filtered}} + A_{\text{filtered}} + V_{\text{filtered}} - A'_{\text{filtered}} - V'_{\text{filtered}} - V''_{\text{filtered}}$ is equal to R_{filtered}. Summation module 904 adds the outputs of filters 404 and 902 to generate the error spectrogram used during step 818 to generate the compensated spectrogram.

[0067] In some embodiments, filter 816 uses algorithms such as steepest decent to minimize the power of the error at the output of summation module 906. Other algorithms may also be used.

[0068] Filters 402, 404, and 902 may be implemented, for example, as FIR filters. Summation module 904 and 906 may be implemented as a digital block that performs the addition and/or subtractions. Other implementations are also possible.

[0069] In some embodiment, the estimate of the interference may be performed by using a predetermined model, such as a pre-trained model. For example, Figure 10 shows a flow chart of embodiment method 1000 for mitigating interference using trained forecasting model 1002, according to an embodiment of the present invention. Method 1000 may be performed, e.g., by millimeter-wave radar system 100, e.g., inside electronic device 200, 700 or 900.

[0070] As shown in Figure 10, inputs X_{t-N} to X_t are fed to trained forecasting model 1002, where inputs X_{t-N} to X_t include information corresponding to the movement of a non-target object, such as a speaker or enclosure. Forecasting model 1002 then produces a predicted output based on the inputs X_{t-N} to X_t. Summation module 1010 subtracts the predicted output X_t from the input X_t to generate a compensated output X_t, where the compensated output X_t does not include information corresponding to the movements of the non-target object (or includes a small amount of such information when compared with input X_t). The compensated output X_t is then used for further radar processing during step 1012.

[0071] In some embodiments, inputs X_{t-N} to X_t are Mel Frequencies Cepstrum Coefficients (MFCC). In such embodiments, output X_t is the time series prediction of the MFCC (at time t). In other embodiments, inputs X_{t-N} to X_t are raw time domain data from millimeter-wave radar 102. In such embodiments, output X_t is the time domain prediction of the next time domain raw data (the predicted value of the raw time domain data at time t). In yet other embodiments, inputs X_{t-N} to X_t are features extracted from a preceding time-distributed convolutional neural network (CNN). In such embodiments, output X_t is the CNN-extracted feature at time t. In yet other embodiments, inputs X_{t-N} to X_t are vectors of a first spectrogram (e.g., where inputs X_{t-N} to X_t together form the first spectrogram), such as the first spectrogram generated in steps 312, 612, or 812, for example. In such embodiments, output X_t is a predicted spectrogram indicative of the movement of a non-target object, such as enclosures 208 (or 508) and/or speaker 204, where speaker 204 may be inside enclosures 208 (or 508), or outside enclosures 208 (or 508).

[0072] In some embodiments, trained forecasting model 1002 comprises a long-short term memory network (LSTM) autoencoder that includes encoder LSTM model 1004, decoder LSTM model 1006, and dense and sigmoid activation module 1008. An LSTM autoencoder may be understood as a neural network model that aims to learn a compressed representation of an input in order to recreate the input.

[0073] During normal operation, encoder LSTM model 1004 reads inputs X_{t-N} to X_t step by step. After reading the entire sequence of inputs X_{t-N} to X_t, encoder LSTM model 1004 produces a fixed-length vector. Decoder LSTM model 1006 receives the fixed-length vector and generates a predicted sequence. Dense and sigmoid activation module 1008 may be used to receive the predicted sequence and recreates the input by applying weights to the predicted sequence. Other LSTM autoencoder implementations known in the art may also be used.

[0074] In some embodiments, trained forecasting model 1002 may be trained after a device is assembled. For example, once electronic device 200 is assembled and speaker 204, millimeter-wave radar 102, and microphone 206 are inside enclosure 208, the forecasting model 1002 is trained, e.g., based on known audio received by microphone 206. The known audio may be, e.g., reproduced by speaker 204, where speaker 204 may be inside or outside an enclosure (e.g., 208 or 508) of the device.

[0075] In some embodiments, each electronic device (e.g., 200 or 700) that is manufactured undergoes the training of forecasting model 1002. Therefore, each manufactured electronic device may have a different trained forecasting model 1002 since the trained forecasting model 1002 is based on the particular characteristics of, e.g., microphone 206, speaker 204 and enclosure 208, which may vary from electronic device to electronic device. Using a trained forecasting model 1002 advantageously allows for better convergence and accuracy than implementations using, e.g., an ARMA filter.

Claims

1. A method (300, 600, 800) of interference mitigation in a device (200,500,700) comprising a millimeter-

wave radar, the method comprising:

transmitting (302) radar signals with the millimeter-wave radar;
receiving (306, 608) reflected radar signals with the millimeter-wave radar, the reflected radar signals corresponding to the transmitted radar signals;
generating (312, 612, 812) a first spectrogram based on the reflected radar signals;
generating (314, 614, 814) a second spectrogram indicative of movement of a non-target object;
wherein the non-target object comprises an actuator (502), wherein the actuator (502) comprises a speaker, wherein an output of the actuator (502) comprises sound waves (210),
wherein the non-target object comprises an enclosure of the device (200, 500, 700), and
wherein the method (300, 600, 800) further comprises:

measuring the output of the actuator (502) with a microphone (206) to generate a measured output, wherein the second spectrogram is based on the measured output;
measuring vibrations of the enclosure of the device (200, 500, 700) with an accelerometer (506); and
generating (314, 814) a third spectrogram based on an output of the accelerometer (506),
generating (318, 818) a compensated radar spectrogram based on the first, second and third spectrograms to compensate for an influence of the movement of the non-target object and of the actuator in the first spectrogram, wherein generating the compensated radar spectrogram comprises subtracting the second and third spectrograms from the first spectrogram; and detecting (320) a target or a property of the target based on the compensated radar spectrogram.

2. The method (300, 600, 800) of claim 1, further comprising activating the actuator (502), wherein the device (200, 500, 700) comprises the actuator (502).

3. The method (300, 600, 800) of claim 1, wherein the actuator (502) is external to the device (200, 500, 700).

4. The method (300, 600, 800) of claim 2 or claim 3, wherein the actuator (502) comprises a haptic actuator.

5. The method (300, 600, 800) of any of the preceding claims, wherein generating (314, 614,814) the second spectrogram comprises using a moving average filter.

6. The method (300, 600, 800) of claim 5, wherein generating the moving average filter is an autoregressive-moving average, ARMA, filter.

7. The method (300, 600, 800) of any of the preceding claims, wherein generating the second spectrogram comprises predicting (1002) the second spectrogram based on a model that receives as input data based on the reflected radar signals.

8. The method (300, 600, 800) of claim 7, wherein the model is based on neural networks.

9. The method (300, 600, 800) of claim 7 or claim 8, wherein the model is based on a recurrent neural network.

10. The method (300, 600, 800) of any of claims 7 to 9, wherein the model is a long-short term memory, LSTM, recurrent neural network.

11. A device (200, 500, 700) comprising:

a millimeter-wave radar (102) configured to transmit radar signals (106) and receive reflected radar signals, wherein the reflected radar signals correspond to the transmitted radar signals (106); and
a controller (104) configured to:

generate a first spectrogram based on the reflected radar signals;
generate a second spectrogram indicative of movement of a non-target object;

wherein the non-target object comprises an actuator (502), wherein the actuator (502) comprises a speaker, wherein an output of the actuator (502) comprises sound waves, wherein the non-target object comprises an enclosure of the device (200, 500, 700), wherein the device (200, 500, 700) further comprises:

a microphone (206) configured to measure the output of the actuator (502) to generate a measured output, wherein the second spectrogram is based on the measured output; and
an accelerometer (506) configured to measure vibrations of the enclosure of the device (200,500,700),
wherein the controller (104) is further configured to generate a third spectrogram based on an output of the accelerometer

(506), and

generate a compensated radar spectrogram based on the first, second and third spectrograms to compensate for an influence of the movement of the non-target object and of the actuator in the first spectrogram, wherein, for generating the compensated radar spectrogram, the controller (104) is configured to subtract the second and third spectrograms from the first spectrogram; and detect a target or a property of the target based on the compensated radar spectrogram.

12. The device (200, 500, 700) of claim 11, wherein, for generating the second spectrogram, the controller (104) is configured to predict the second spectrogram based on a model that receives as input data based on the reflected radar signals.

13. The device (200, 500, 700) of claim 12, wherein the model is based on neural networks.

14. The device (200, 500, 700) of claim 12 or claim 13, wherein the model is based on a recurrent neural network.

15. The device (200, 500, 700) of any of claims 12 to 14, wherein the model is a long-short term memory, LSTM, recurrent neural network.

Patentansprüche

1. Ein Verfahren (300, 600, 800) zur Interferenzminderung in einer Vorrichtung (200, 500, 700), umfassend ein Millimeterwellenradar, das Verfahren umfassend:

Senden (302) von Radarsignalen mit dem Millimeterwellenradar;

Empfangen (306, 608) von reflektierten Radarsignalen mit dem Millimeterwellenradar, wobei die reflektierten Radarsignale den gesendeten Radarsignalen entsprechen;

Erzeugen (312, 612, 812) eines ersten Spektrogramms basierend auf den reflektierten Radarsignalen;

Erzeugen (314, 614, 814) eines zweiten Spektrogramms, das eine Bewegung eines Nicht-Zielobjekts anzeigt;

wobei das Nicht-Zielobjekt einen Aktuator (502) umfasst, wobei der Aktuator (502) einen Lautsprecher umfasst, wobei ein Ausgang des Aktuators (502) Schallwellen (210) umfasst, wobei das Nicht-Zielobjekt eine Umhüllung der Vorrichtung (200, 500, 700) umfasst, und das Verfahren (300, 600, 800) ferner umfassend:

Messen des Ausgangs des Aktuators (502) mit einem Mikrofon (206), um einen gemessenen Ausgang zu erzeugen, wobei das zweite Spektrogramm auf dem gemessenen Ausgang basiert;

Messen von Vibrationen der Umhüllung der Vorrichtung (200, 500, 700) mit einem Beschleunigungssensor (506); und

Erzeugen (314, 814) eines dritten Spektrogramms basierend auf einem Ausgang des Beschleunigungssensors (506),

Erzeugen (318, 818) eines kompensierten Radarspektrogramms basierend auf dem ersten, zweiten und dritten Spektrogramm, um einen Einfluss der Bewegung des Nicht-Zielobjekts und des Aktuators in dem ersten Spektrogramm zu kompensieren, wobei das Erzeugen des kompensierten Radarspektrogramms ein Subtrahieren des zweiten und dritten Spektrogramms von dem ersten Spektrogramm umfasst; und Detektieren (320) eines Ziels oder einer Eigenschaft des Ziels basierend auf dem kompensierten Radarspektrogramm.

2. Das Verfahren (300, 600, 800) gemäß Anspruch 1, ferner umfassend ein Aktivieren des Aktuators (502), wobei die Vorrichtung (200, 500, 700) den Aktuator (502) umfasst.

3. Das Verfahren (300, 600, 800) gemäß Anspruch 1, wobei der Aktuator (502) extern zu der Vorrichtung (200, 500, 700) ist.

4. Das Verfahren (300, 600, 800) gemäß Anspruch 2 oder Anspruch 3, wobei der Aktuator (502) einen haptischen Aktuator umfasst.

5. Das Verfahren (300, 600, 800) gemäß einem der vorangehenden Ansprüche, wobei das Erzeugen (314, 614, 814) des zweiten Spektrogramms ein Verwenden eines Gleitender-Mittelwert-Filters umfasst.

6. Das Verfahren (300, 600, 800) gemäß Anspruch 5, wobei das Erzeugen des Gleitender-Mittelwert-Filters ein Autoregressiver-Gleitender-Mittelwert-, ARMA, Filter ist.

7. Das Verfahren (300, 600, 800) gemäß einem der vorangehenden Ansprüche, wobei das Erzeugen des zweiten Spektrogramms ein Vorhersagen (1002) des zweiten Spektrogramms basierend auf einem Modell umfasst, das als Eingang Daten basierend auf den reflektierten Radarsignalen empfängt.

8. Das Verfahren (300, 600, 800) gemäß Anspruch 7, wobei das Modell auf neuronalen Netzen basiert.

9. Das Verfahren (300, 600, 800) gemäß Anspruch 7 oder Anspruch 8, wobei das Modell auf einem rekurrenten neuronalen Netz basiert.

10. Das Verfahren (300, 600, 800) gemäß einem der Ansprüche 7 bis 9, wobei das Modell ein Long-Short-Term-Memory-, LSTM, Rekurrentes-Neuronales-Netz ist.

11. Eine Vorrichtung (200, 500, 700), umfassend:

ein Millimeterwellenradar (102), das ausgebildet ist, um Radarsignale (106) zu senden und reflektierte Radarsignale zu empfangen, wobei die reflektierten Radarsignale den gesendeten Radarsignalen (106) entsprechen; und
eine Steuerung (104), die ausgebildet ist zum:

Erzeugen eines ersten Spektrogramms basierend auf den reflektierten Radarsignalen;
Erzeugen eines zweiten Spektrogramms, das eine Bewegung eines Nicht-Zielobjekts anzeigt;

wobei das Nicht-Zielobjekt einen Aktuator (502) umfasst, wobei der Aktuator (502) einen Lautsprecher umfasst, wobei ein Ausgang des Aktuators (502) Schallwellen umfasst, wobei das Nicht-Zielobjekt eine Umhüllung der Vorrichtung (200, 500, 700) umfasst, die Vorrichtung (200, 500, 700) ferner umfassend:

ein Mikrofon (206), das ausgebildet ist, um den Ausgang des Aktuators (502) zu messen, um einen gemessenen Ausgang zu erzeugen, wobei das zweite Spektrogramm auf dem gemessenen Ausgang basiert; und
einen Beschleunigungssensor (506), der ausgebildet ist, um Vibrationen der Umhüllung der Vorrichtung (200, 500, 700) zu messen,
wobei die Steuerung (104) ferner ausgebildet ist, um ein drittes Spektrogramm basierend auf einem Ausgang des Beschleunigungssensors (506) zu erzeugen, und
Erzeugen eines kompensierten Radarspektrogramms basierend auf dem ersten, zweiten und dritten Spektrogramm, um einen Einfluss der Bewegung des Nicht-Zielobjekts und des Aktuators in dem ersten Spektrogramm zu kompensieren, wobei zum Erzeugen des kompensierten Radarspektrogramms die Steuerung (104) ausgebildet ist, um das zweite und dritte Spektrogramm von dem ersten Spektrogramm zu subtrahieren; und Detektieren eines Ziels oder einer Eigenschaft des Ziels basierend auf dem kompensierten Radarspektrogramm.

12. Die Vorrichtung (200, 500, 700) gemäß Anspruch 11, wobei zum Erzeugen des zweiten Spektrogramms die Steuerung (104) ausgebildet ist zum Vorhersagen des zweiten Spektrogramms basierend auf einem Modell, das als Eingang Daten basierend auf den reflektierten Radarsignalen empfängt.

13. Die Vorrichtung (200, 500, 700) gemäß Anspruch 12, wobei das Modell auf neuronalen Netzen basiert.

14. Die Vorrichtung (200, 500, 700) gemäß Anspruch 12 oder Anspruch 13, wobei das Modell auf einem rekurrenten neuronalen Netz basiert.

15. Die Vorrichtung (200, 500, 700) gemäß einem der Ansprüche 12 bis 14, wobei das Modell ein Long-Short-Term-Memory-, LSTM, Rekurrentes-Neuronales-Netz ist.

Revendications

1. Procédé (300, 600, 800) d'atténuation d'interférences dans un dispositif (200, 500, 700) comprenant un radar à ondes millimétriques, le procédé comprenant le fait de :

transmettre (302) des signaux radar avec le radar à ondes millimétriques ;
recevoir (306, 608) des signaux radar réfléchis avec le radar à ondes millimétriques, les signaux radar réfléchis correspondant aux signaux radar transmis ;
générer (312, 612, 812) un premier spectrogramme sur la base des signaux radar réfléchis ;
générer (314, 614, 814) un deuxième spectrogramme indicatif d'un mouvement d'un objet non cible ;
dans lequel l'objet non cible comprend un actionneur (502), dans lequel l'actionneur (502) comprend un haut-parleur, dans lequel une sortie de l'actionneur (502) comprend des ondes sonores (210), dans lequel l'objet non cible comprend une enceinte du dispositif (200, 500, 700), et dans lequel le procédé (300, 600, 800) comprend en outre le fait de :

mesurer la sortie de l'actionneur (502) avec un microphone (206) pour générer une sortie mesurée, le deuxième spectrogramme étant basé sur la sortie mesurée ;
mesurer des vibrations de l'enceinte du dispositif (200, 500, 700) avec un accéléromètre (506) ; et

générer (314, 814) un troisième spectrogramme sur la base d'une sortie de l'accéléromètre (506),
générer (318, 818) un spectrogramme radar compensé sur la base des premier, deuxième et troisième spectrogrammes afin de compenser une influence du mouvement de l'objet non cible et de l'actionneur dans le premier spectrogramme, la génération du spectrogramme radar compensé comprenant le fait de soustraire les deuxième et troisième spectrogrammes du premier spectrogramme ; et détecter (320) une cible ou une propriété de la cible sur la base du spectrogramme radar compensé.

2. Procédé (300, 600, 800) selon la revendication 1, comprenant en outre le fait d'activer l'actionneur (502), dans lequel le dispositif (200, 500, 700) comprend l'actionneur (502).

3. Procédé (300, 600, 800) selon la revendication 1, dans lequel l'actionneur (502) est externe au dispositif (200, 500, 700).

4. Procédé (300, 600, 800) selon la revendication 2 ou la revendication 3, dans lequel l'actionneur (502) comprend un actionneur haptique.

5. Procédé (300, 600, 800) selon l'une des revendications précédentes, dans lequel la génération (314, 614, 814) du deuxième spectrogramme comprend le fait d'utiliser un filtre à moyenne mobile.

6. Procédé (300, 600, 800) selon la revendication 5, dans lequel la génération du filtre à moyenne mobile est un filtre à moyenne mobile autorégressive, ARMA.

7. Procédé (300, 600, 800) selon l'une des revendications précédentes, dans lequel la génération du deuxième spectrogramme comprend le fait de prédire (1002) le deuxième spectrogramme sur la base d'un modèle qui reçoit comme entrée des données basées sur les signaux radar réfléchis.

8. Procédé (300, 600, 800) selon la revendication 7, dans lequel le modèle est basé sur des réseaux neuronaux.

9. Procédé (300, 600, 800) selon la revendication 7 ou la revendication 8, dans lequel le modèle est basé sur un réseau de neurones récurrents.

10. Procédé (300, 600, 800) selon l'une des revendications 7 à 9, dans lequel le modèle est un réseau de neurones récurrents à mémoire court et long terme, LSTM.

11. Dispositif (200,500,700) comprenant :

un radar à ondes millimétriques (102) configuré pour transmettre des signaux radar (106) et recevoir des signaux radar réfléchis, les signaux radar réfléchis correspondant aux signaux radar (106) transmis ; et
un contrôleur (104) configuré pour :

générer un premier spectrogramme sur la base des signaux radar réfléchis ;
générer un deuxième spectrogramme indicatif d'un mouvement d'un objet non cible ;

dans lequel l'objet non cible comprend un actionneur (502), dans lequel l'actionneur (502) comprend un haut-parleur, dans lequel une sortie de l'actionneur (502) comprend des ondes sonores, dans lequel l'objet non cible comprend une enceinte du dispositif (200, 500, 700), dans lequel le dispositif (200, 500, 700) comprend en outre :

un microphone (206) configuré pour mesurer la sortie de l'actionneur (502) afin de générer une sortie mesurée, le deuxième spectrogramme étant basé sur la sortie mesurée ; et
un accéléromètre (506) configuré pour mesurer des vibrations de l'enceinte du dispositif (200,500,700),
le contrôleur (104) étant en outre configuré pour générer un troisième spectrogramme sur la base d'une sortie de l'accéléromètre (506), et
générer un spectrogramme radar compensé sur la base des premier, deuxième et troisième spectrogrammes afin de compenser une influence du mouvement de l'objet non cible et de l'actionneur dans le premier spectrogramme, dans lequel, pour générer le spectrogramme radar compensé, le contrôleur (104) est configuré pour soustraire les deuxième et troisième spectrogrammes du premier spectrogramme ; et détecter une cible ou une propriété de la cible sur la base du spectrogramme radar compensé.

12. Dispositif (200, 500, 700) selon la revendication 11, dans lequel, pour générer le deuxième spectrogramme, le contrôleur (104) est configuré pour prédire le deuxième spectrogramme sur la base d'un modèle qui reçoit comme entrée des données basées sur les signaux radar réfléchis.

13. Dispositif (200, 500, 700) selon la revendication 12, dans lequel le modèle est basé sur des réseaux neuronaux.

14. Dispositif (200, 500, 700) selon la revendication 12 ou la revendication 13, dans lequel le modèle est basé sur un réseau de neurones récurrents.

15. Dispositif (200, 500, 700) selon l'une des revendications 12 à 14, dans lequel le modèle est un réseau de neurones récurrents à mémoire court et long terme, LSTM.

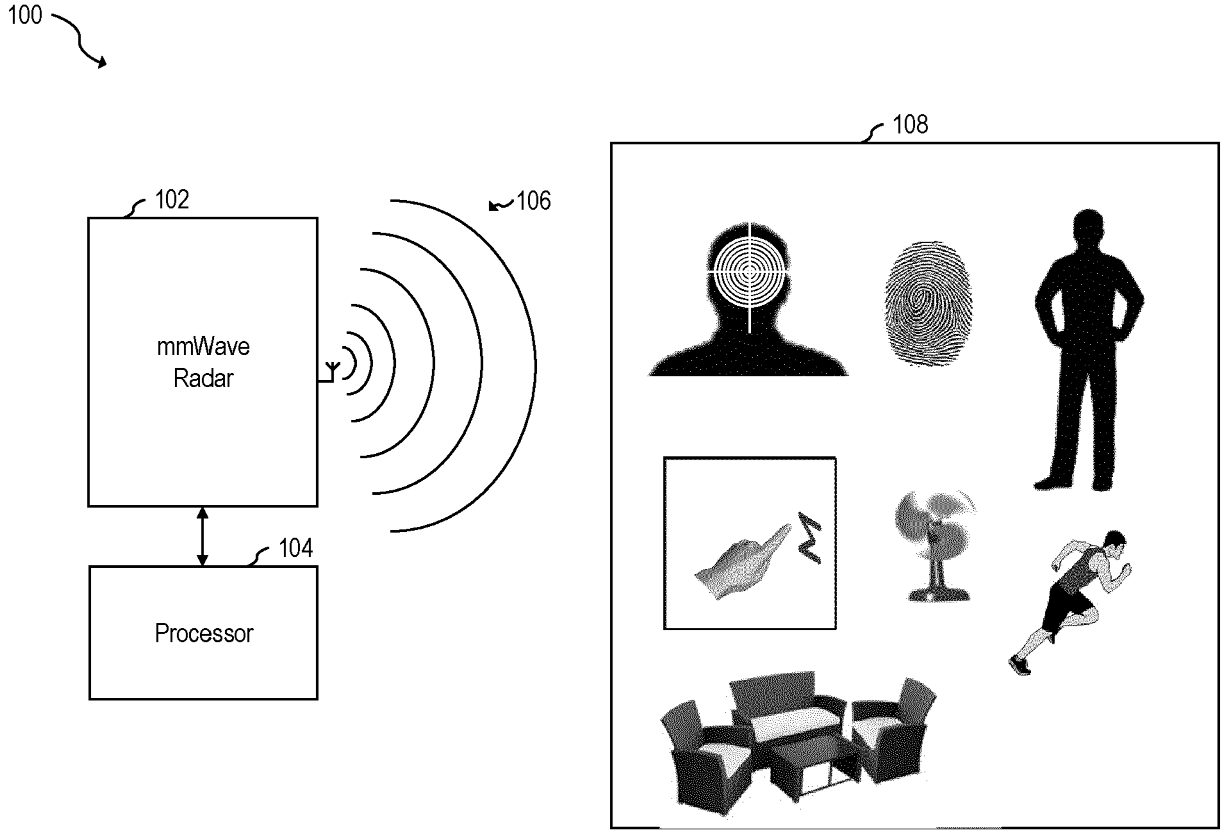
100
102
mmWave
Radar
106
108
104
Processor

FIG. 1

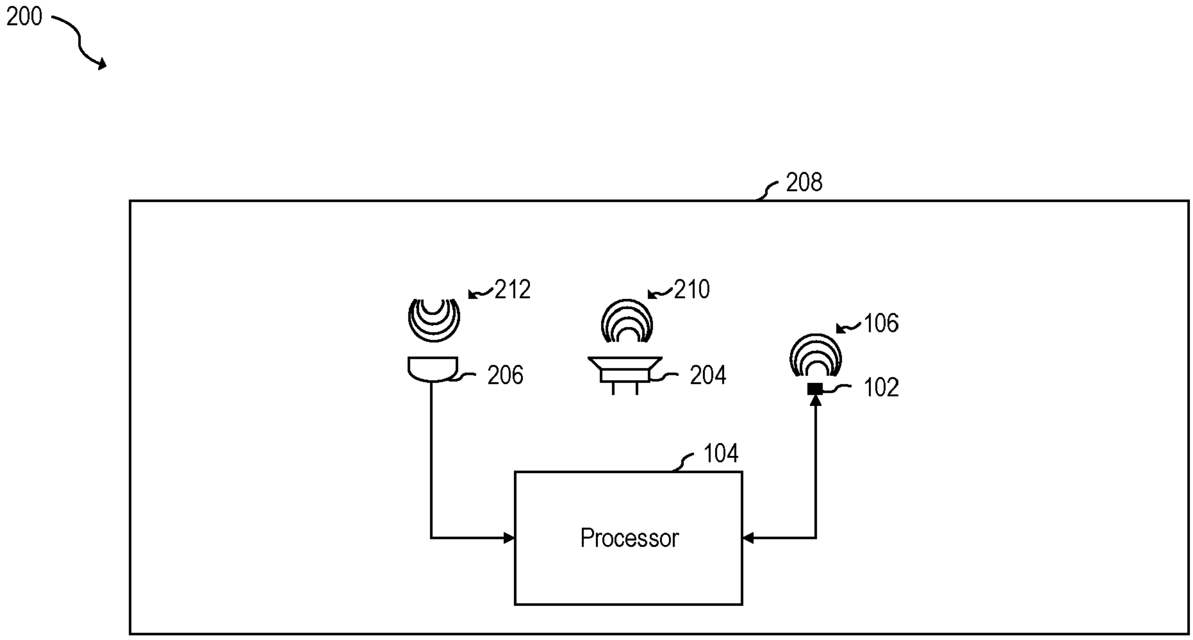
200
208
212
210
106
206
204
102
104
Processor

FIG. 2

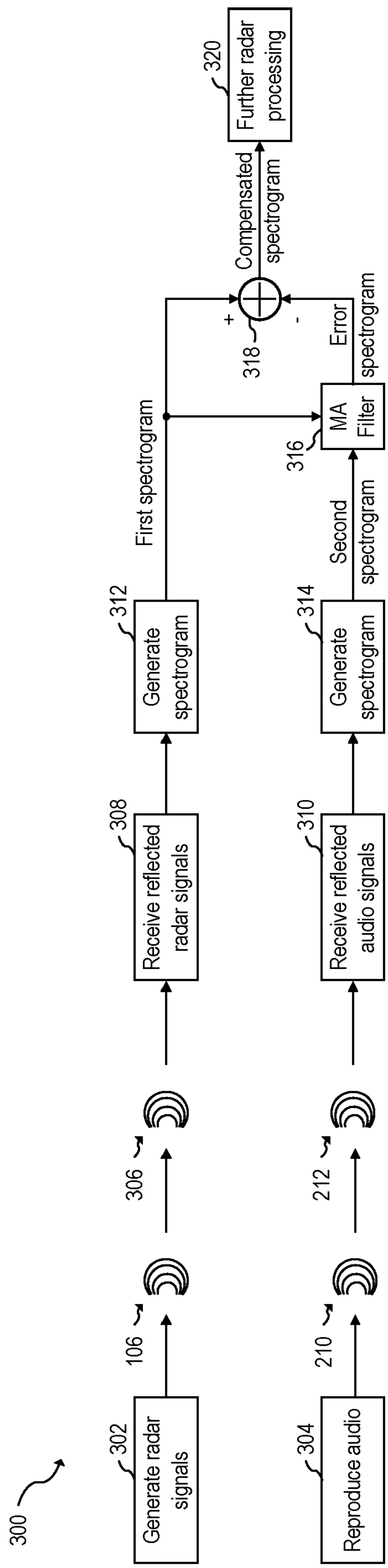
300
Generate radar signals
302
106
306
Receive reflected radar signals
308
Generate spectrogram
312
First spectrogram
318
+
-
Compensated spectrogram
Further radar processing
320
Reproduce audio
304
210
212
Receive reflected audio signals
310
Generate spectrogram
314
Second spectrogram
MA Filter
316
Error spectrogram

FIG. 3

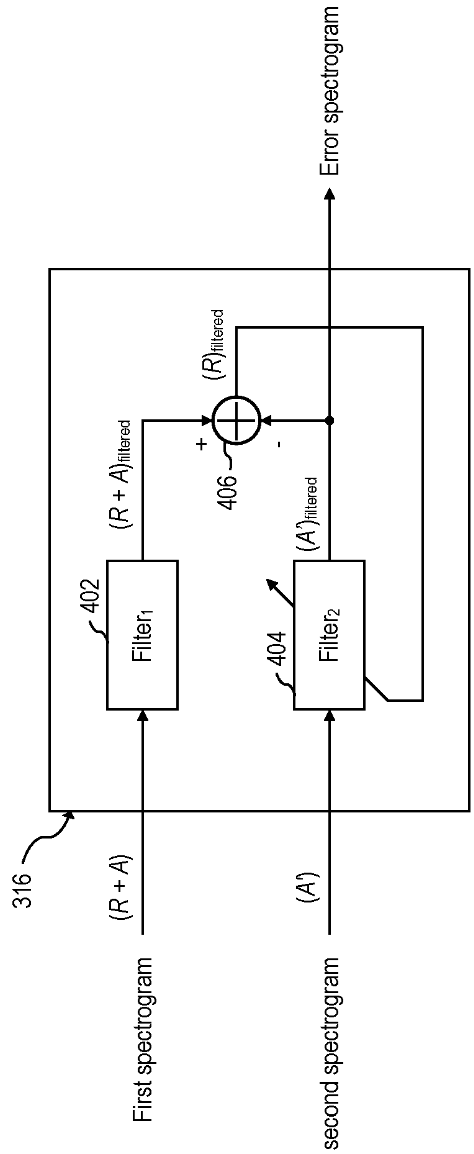
316
First spectrogram
(R + A)
Filter1
402
(R + A)filtered
+
406
-
(R)filtered
second spectrogram
(A')
Filter2
404
(A')filtered
Error spectrogram

FIG. 4

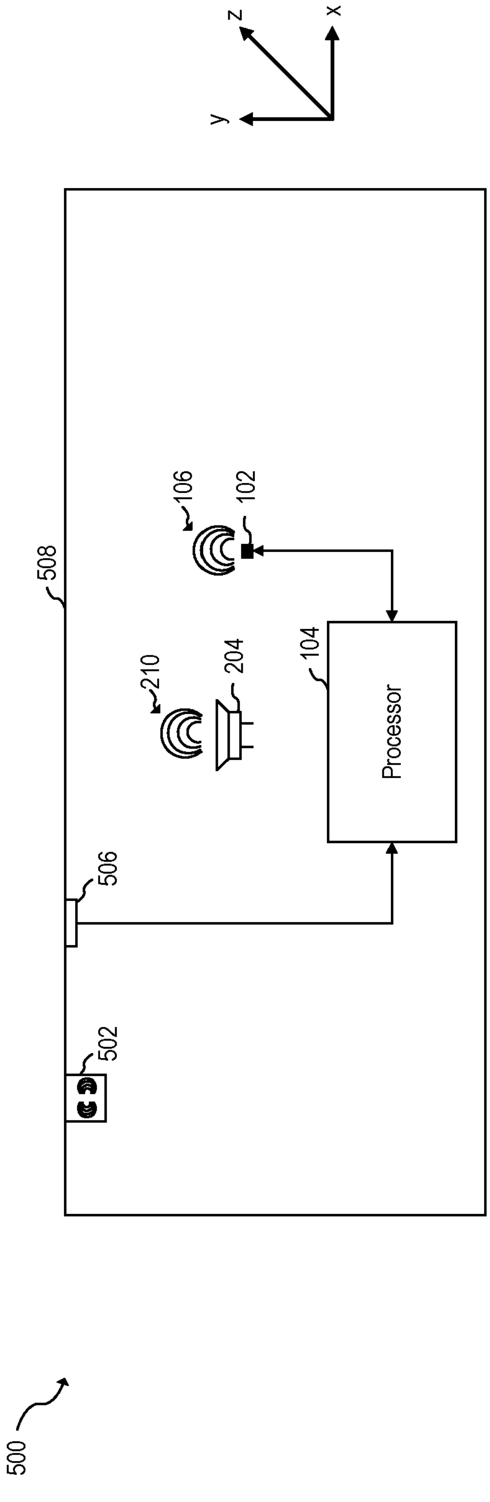
500
508
502
506
Processor
104
210
204
106
102
x
y
z

FIG. 5

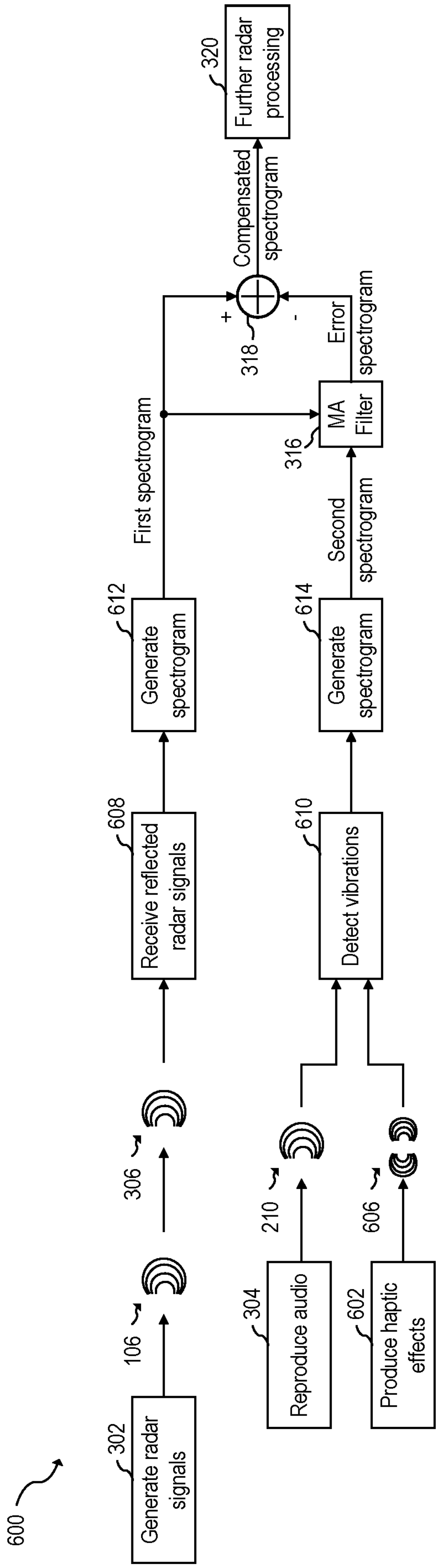
600
Generate radar signals
302
106
306
Receive reflected radar signals
608
Generate spectrogram
612
First spectrogram
Reproduce audio
304
210
Produce haptic effects
602
606
Detect vibrations
610
Generate spectrogram
614
Second spectrogram
MA Filter
316
Error spectrogram
318
+
-
Compensated spectrogram
Further radar processing
320

FIG. 6

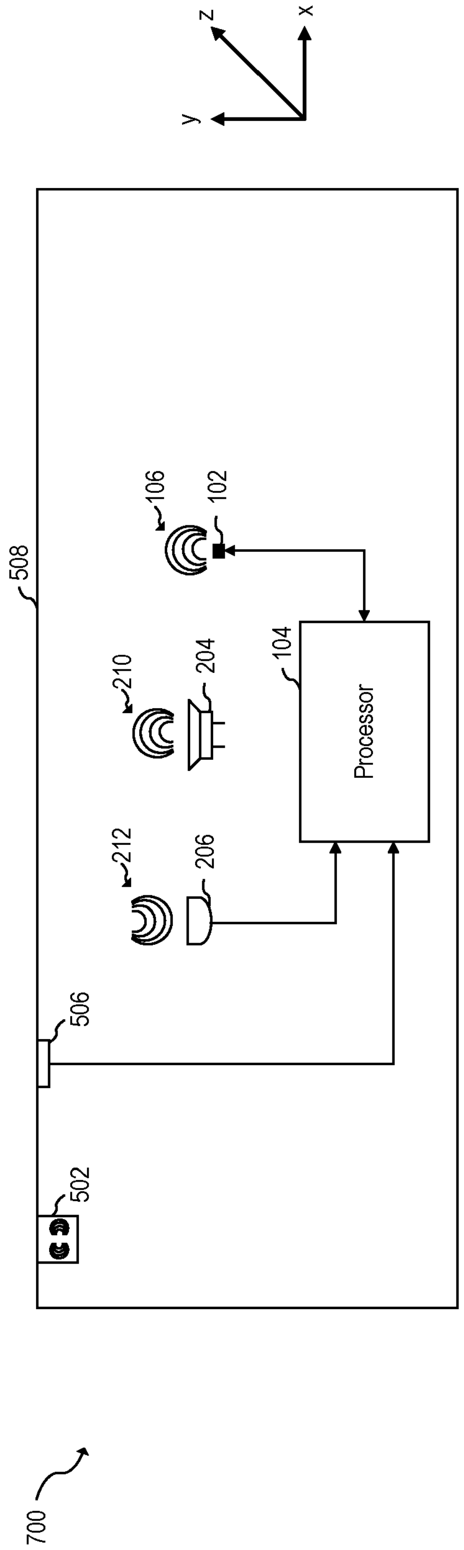
700
502
506
508
212
206
210
204
104
Processor
106
102
y
z
x

FIG. 7

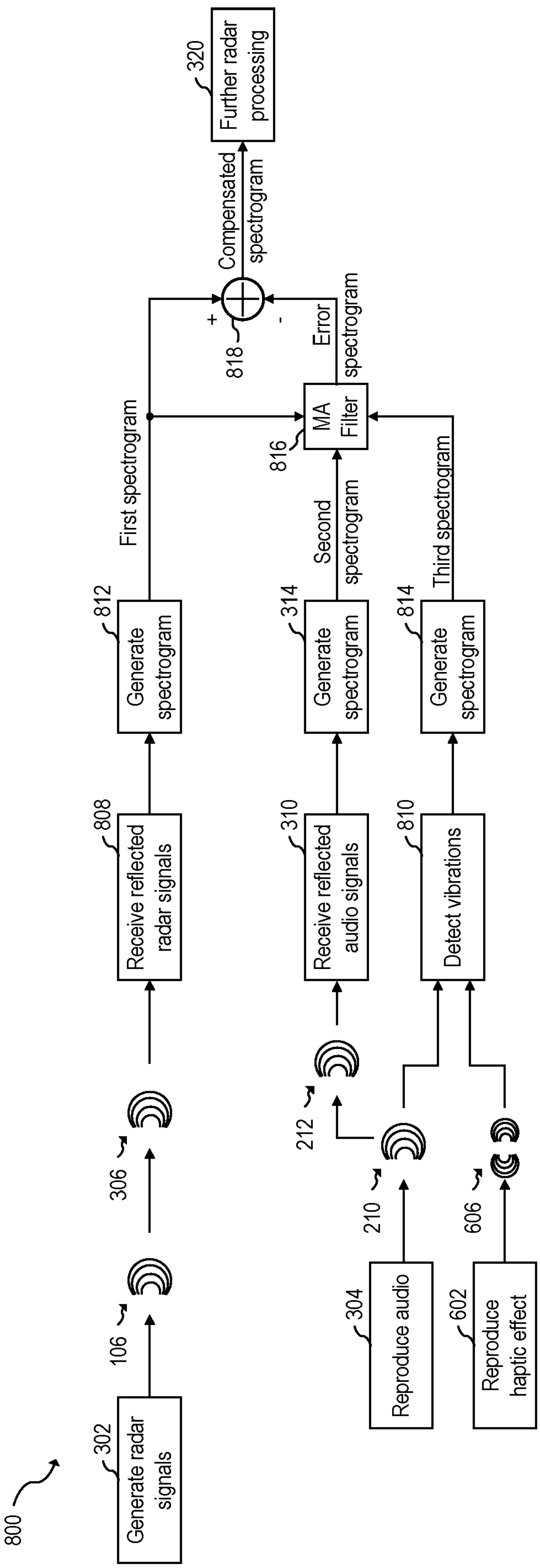
800
302
Generate radar signals
106
306
808
Receive reflected radar signals
812
Generate spectrogram
First spectrogram
816
MA Filter
818
+
-
Error spectrogram
Compensated spectrogram
320
Further radar processing
212
310
Receive reflected audio signals
314
Generate spectrogram
Second spectrogram
210
304
Reproduce audio
810
Detect vibrations
814
Generate spectrogram
Third spectrogram
606
602
Reproduce haptic effect

FIG. 8

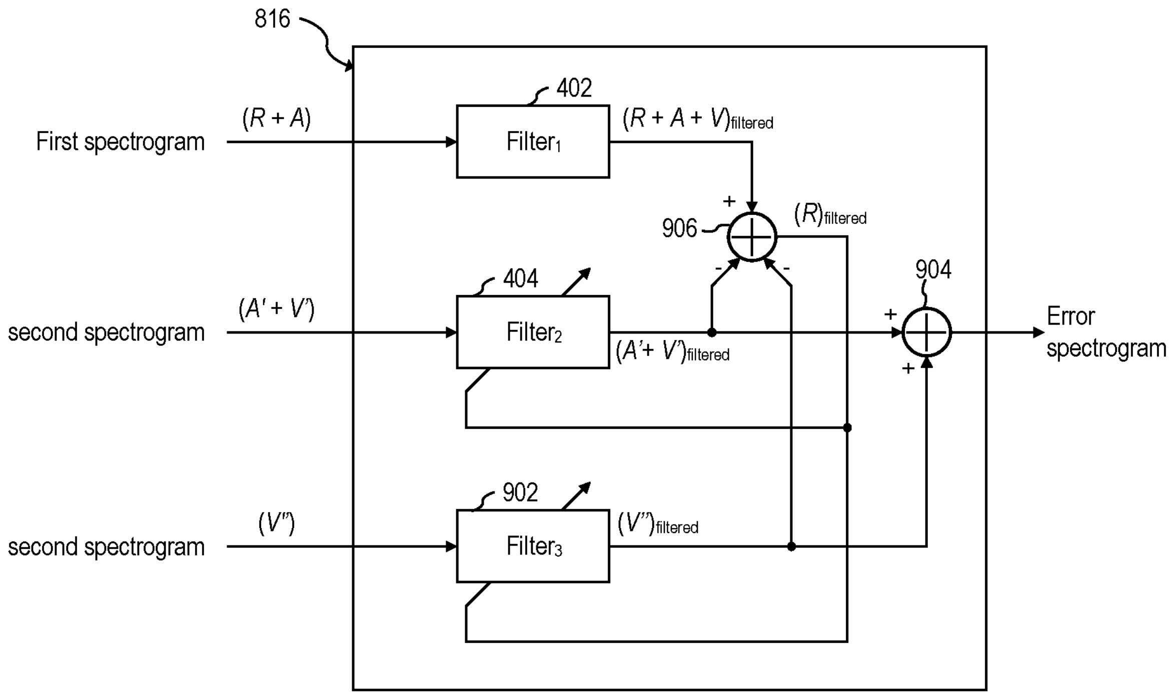
816
402
First spectrogram
(R + A)
Filter1
(R + A + V)filtered
+
906
(R)filtered
-
-
404
904
second spectrogram
(A' + V')
Filter2
(A'+ V')filtered
+
+
Error spectrogram
902
second spectrogram
(V'')
Filter3
(V'')filtered

FIG. 9

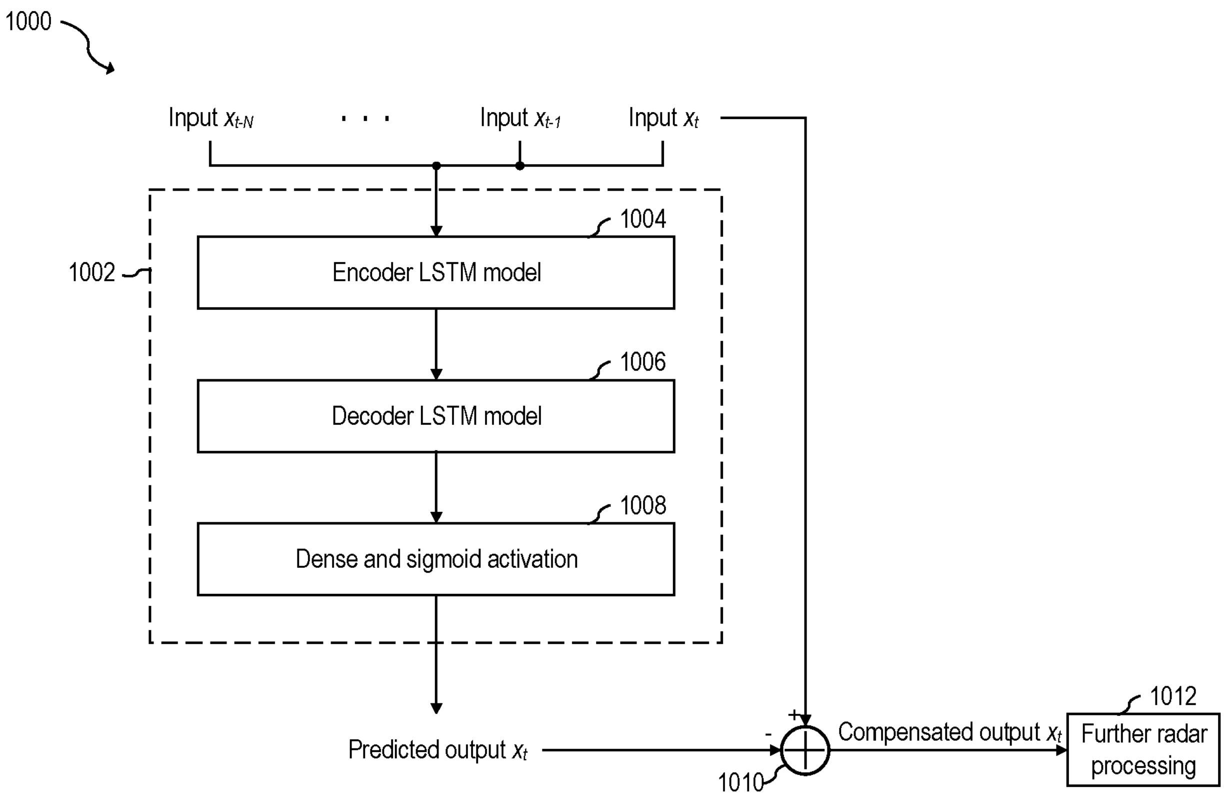
1000
Input xt-N
. . .
Input xt-1
Input xt
1004
1002
Encoder LSTM model
1006
Decoder LSTM model
1008
Dense and sigmoid activation
1012
+
-
Predicted output xt
Compensated output xt
Further radar processing
1010

FIG. 10

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- WO 2018129294 A1 **[0002]**