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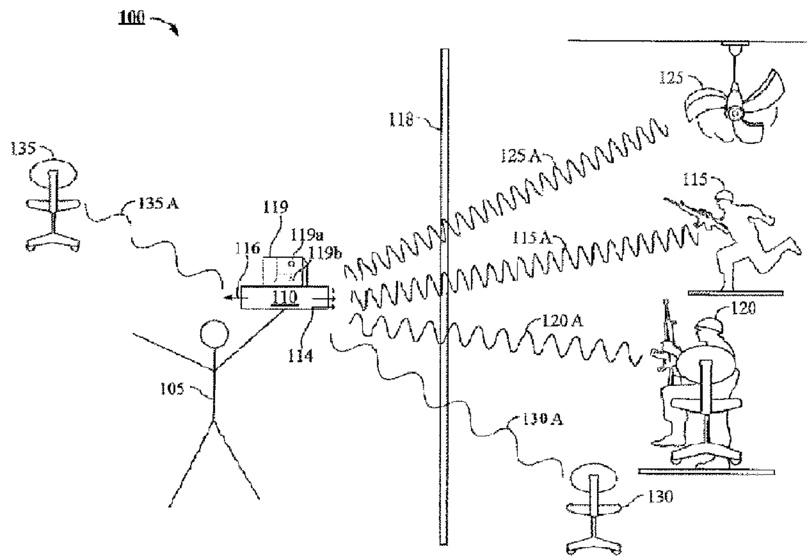

FIG. 1A

(57) **Abstract**: Provided herein are methods, devices and systems for the remote monitoring and/or surveillance of a patient's location, position, movement, vital signs, biopotentials, or a combination thereof using transmission of stepped-frequency radar signals, detecting reflections of the transmitted signals and processing the frequency and phase shifts.

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PATIENT MONITORING AND SURVEILLANCE TAG

CROSS REFERENCE

[0001] This application claims the benefit of priority to U.S. Application Serial No. 61/487,182, filed May 17, 2011, the contents of which are incorporated herein by reference in their entirety.

BACKGROUND OF THE INVENTION

[0002] Minimizing patient complications and decreasing length of hospital stay is of paramount importance to today's healthcare system where errors often cost lives and always cost money. Currently, standard non-critical patient monitoring protocols entail at best a nurse checking vital signs every 6 hours and more often only daily in sub-acute care facilities like rehabilitation wards and nursing homes. Generally, only the critically ill patients and those with active cardiac issues are able to be monitored continuously due to capital expenditure on equipment and staff limitations. As a result, urgent medical evaluation of non-critically ill patients only occurs after a patient has fallen or is critically ill for an indeterminate period of time.

[0003] There are currently a number of protocols and devices that attempt to prevent adverse patient events such as scheduled nursing evaluation intervals (*e.g.*, commonly, every 6 hours), bed alarms, as well as ‘patient sitters’, people hired by the hospital to stay in a room and watch a patient who is at high risk of complications but not critically ill.

SUMMARY OF THE INVENTION

[0004] Provided herein is a system for remote monitoring of a subject, said system comprising: a device comprising a transceiver adapted for transmission of a stepped-frequency radar signal and receipt of reflections of the transmitted signal; a signal processing unit configured to generate and analyze frequency and/or phase shifts between the transmitted signal and reflections of the transmitted signal data from the subject, wherein the device is adapted to trigger the tag to send identification information about the subject to the device, wherein the device is adapted to receive the identification from the tag, wherein the signal processing unit of the device comprises a digital signal processing- based computer that runs a target identification algorithm wherein the identification comprises a subject’s location, movement, position, vital signs, or a combination thereof.

[0005] In some embodiments, the transceiver is a homodyne microwave transceiver. In some embodiments, the device operates in an FCC-allocated radiolocation (radar) frequency band (3.1-3.4 GHz). In some embodiments, the transceiver generates its frequencies from a voltage controlled oscillator (VCO) that has a tuning range of 3.1-3.6 GHz. In some embodiments, the device operates in outside of an ISM band. In some embodiments, the device operates in within an ISM band.

[0006] In some embodiments, the transceiver samples each of two receive antennas at each of 120 frequency steps that are utilized at a rate of at most 7 kHz. In some embodiments, the transceiver has an overall sample rate of about 14 kHz.

[0007] In some embodiments, the transceiver samples each of two receive antennas at each of 50 frequency steps that are utilized at a rate of at most r 5 kHz. In some embodiments, the transceiver samples each of two receive antennas at each of 50 frequency steps that are utilized at a rate of at most 20 kHz In some embodiments, the transceiver samples each of two receive antennas at each of 200 frequency steps that are utilized at a rate of just at most 20 kHz. In some embodiments, the a receiver of the transceiver receives digital data at a rate of 500-9000, 6500-7500, 6000-8000, 6750 to 7250, 6900-7100 or 6950-7050 symbols per second. In some embodiments, the device receives data at a sample rate of less than 27 kilobits per second. In some embodiments, the device receives data at a sample rate of less than 128 kilobits per second. In some embodiments, the tag emits at a data rate of no more than 7 kilobits per second.

[0008] In some embodiments, the tag comprises a battery. In some embodiments, the tag is powered by the device.

[0009] In some embodiments, the tag uses a simple message system comprising on-off keying modulation. In some embodiments, the on-off keying modulation comprises ones and zeros encoded as either the absence or presence of a level shift halfway through a symbol period. In some embodiments, the tag can transmit the identification in a transmission period of six milliseconds. In some embodiments, the tag can transmit the identification in a transmission period of at most 6 milliseconds, about 6 milliseconds, 4-8 milliseconds, 10 milliseconds, at most 10 milliseconds, at most 25 milliseconds, at most 30 milliseconds, at most 50 milliseconds, at most 100 milliseconds, or about 10 milliseconds.

[0010] In some embodiments, the tag provides at most four meters of detection range. In some embodiments, the tag provides at least 1 meters of detection range, at least 2 meters of detection range, at least 3 meters of detection range, at least 4 meters of detection range, at least 5 meters of detection range, at least 6 meters of detection range, at least 7 meters of detection range, at least 8 meters of detection range, at least 9 meters of detection range, at least 10 meters of detection range, at least 12.5 meters of detection range, at least 15 meters of detection range, at least 17.5 meters of detection range, at least 20 meters of detection range, at least 25 meters of detection range, at least 30 meters of detection range, at least 40 meters of detection range, at least 50 meters of detection range, and/or at least 100 meters of detection range.

[0011] In some embodiments, the tag provides simple collision avoidance by waiting a random number of transmit periods before transmitting.

[0012] In some embodiments, the device comprises software that comprises a stepped-frequency continuous wave (SFCW) signal normally produced that is stopped and a single frequency tone is produced. In some embodiments, the device emits a single frequency tone. In some embodiments, on-off keying the single frequency tone triggers the tag if it is within range. In some embodiments, on-off keying the single frequency tone triggers any other tag within range. In some embodiments, the device waits for a preset period to receive all tag replies. In some embodiments, once the preset period to receive replies ends, a normal radar signal is restored and target detection resumes.

[0013] In some embodiments, the system comprises multiple tags to enhance detection of a patient's location, movement, position, vital signs, or a combination thereof.

[0014] In some embodiments, the system further comprises at least one small integrated circuit for measuring biopotentials. In some embodiments, the biopotentials are selected from the group consisting of ECG, EEG, EMG, oxygen saturation, temperature, blood pressure, glucose, action potentials and local field potentials.

[0015] Provided herein is a method for remotely monitoring a subject using a system comprising a device that is remote from the subject and a tag on the subject, said method comprising: the device determining by emission and receipt of a reflection of a stepped-frequency continuous wave (SFCW) signal if: a subject is within range of the device, or whether a subject has new information to be monitored, or a combination thereof; the device transmitting a single frequency tone; the device on-off keying the single frequency tone to trigger the tag on the subject; the tag emitting a reply, wherein the reply relates the subject's location, movement, position, vital signs, or a combination thereof; the device receiving the reply from the tag; the device analyzing reply to determine a subject's location, movement, position, vital signs, or a combination thereof; and the device emitting a stepped-frequency continuous wave signal once the reply is received from the tag.

[0016] In some embodiments, the device waits a preset period for the reply from the tag. In some embodiments, the vital signs comprise heart rate, heart rhythm, breathing rate, breathing rhythm or a combination thereof. In some embodiments, the position comprises standing upright, sitting down, lying flat, or a combination thereof. In some embodiments, the method further comprising measuring a patient's biopotentials.

[0017] Provided herein is a system for remote monitoring of a patient, the system comprising: a device adapted for transmission of a stepped-frequency radar signal and receipt of reflections of the transmitted signal; a signal processing unit configured to generate and analyze frequency and/or phase shifts between the transmitted signal and reflections of the transmitted signal data to determine a patient's location, movement, position, vital signs, or a combination thereof; and at least one tag allowing for identification, determination and/or transmission of a health parameter of the patient, tracking of a patient, or a combination thereof.

[0018] In some embodiments the system further comprises one portable monitoring units configured to display and relay information of a patient's location, movement, position, vital signs, or a combination thereof. In some instances signal processing unit is integrated into the portable monitoring unit. In certain instances, the portable monitoring unit is a wearable unit, hand-held display, table-top unit or wall-mounted unit. In other instances, the portable monitoring unit further comprises a visual and/or aural alarm that provides notification when at least one of a patient's location, position, movement or vital signs fall outside of a predetermined range. In some embodiments the system is real-time.

[0019] In some embodiments, the tag in the form of a card, fob, key, jewelry, clothing item, shoes or wearable patch to be in close proximity of the patient. In certain embodiments the tag is a wearable patch. In certain embodiments, the tag contains unique patient information. In other embodiments, the tag is associated with a patient's room and does not contain unique patient information. In yet other embodiments, the system comprises multiple tags to enhance detection of a patient's location, movement, position, vital signs, or a combination thereof.

[0020] In some embodiments, the system further comprises at least one small integrated circuit for measuring biopotentials. In certain instances, the biopotentials are selected from the group consisting of ECG, EEG, EMG, oxygen saturation, temperature, blood pressure, glucose, action potentials and local field potentials. In other embodiments, the small integrated circuit is configured into the patient identification tag.

[0021] Provided herein is a method for remotely monitoring a patient, the method comprising: transmitting a stepped-frequency radar signal; detecting reflections of the transmitted signal; generating data associated with frequency and phase shifts between the transmitted signal and the reflections of the transmitted signal; analyzing the generated data to determine a patient's location, movement, position, vital signs, or a combination thereof; and identifying a patient's identity.

[0022] In some embodiments, the method further comprises comparing said patient's location, movement, position, vital signs, or a combination thereof to a predetermined set of ranges for normal location, movement, position, vital signs, or a combination thereof and providing alarm notifications if said comparison falls outside of the predetermined ranges.

[0023] In some embodiments, the method is real-time. In some instances, the vital signs comprise heart rate, heart rhythm, breathing rate, breathing rhythm, or a combination thereof. In other instances, the position comprises standing upright, sitting down, lying flat, or a combination thereof.

[0024] In some embodiments, the method further comprises relaying and displaying the patient's location, movement, position and vital signs to portable monitoring units. In other embodiments, the method further comprises measuring a patient's biopotentials.

[0025] In certain embodiments, the method further comprises transmitting said patient's location, movement, position, vital signs, or a combination thereof to an offsite location. In certain embodiments, the method further comprises monitoring multiple patients simultaneously.

INCORPORATION BY REFERENCE

[0026] All publications, patents, and patent applications mentioned in this specification are herein incorporated by reference to the same extent as if each individual publication, patent, or patent application was specifically and individually indicated to be incorporated by reference.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027] The novel features of the invention are set forth with particularity in the appended claims. A better understanding of the features and advantages of the present invention will be obtained by reference to the following detailed description that sets forth illustrative embodiments, in which the principles of the invention are utilized, and the accompanying drawings of which:

[0028] FIG. 1A is a diagram illustrating use of a scanning device for detecting moving entities.

[0029] FIG. 1B is a block diagram of a stepped-frequency scanning device configured to detect moving entities.

[0030] FIGS. 2A and 2B are perspective views of an antenna design for the device of FIG. 1B.

[0031] FIG. 3 is a diagram of an example conversion circuit in a scanning device.

[0032] FIG. 4A depicts a configuration of a signal processing unit with a transmitter device and a receiver.

[0033] FIG. 4B depicts a diagram of two patient rooms with adjoining bathrooms with a center transmitter device.

[0034] FIG. 5 is a diagram illustrating use of interferometric measurement with a scanning device.

[0035] FIG. 6 is a diagram illustrating use of multi-static motion detection with a scanning device.

[0036] FIG. 7 is a diagram illustrating use of transceivers to conduct interferometric measurement and multi-static motion detection with a scanning device.

[0037] FIG. 8 is a diagram illustrating use of synthetic aperture radar imaging with a scanning device.

[0038] FIG. 9 is a flow chart of an example of a process to analyze data associated with frequency and phase shifts generated by a scanning device.

[0039] FIG. 10 depicts a display representation of two portable monitoring devices.

[0040] FIG. 11 depicts a display representation of a portable monitoring device.

DETAILED DESCRIPTION OF THE INVENTION

[0041] Disclosed herein are methods, systems and devices for remote patient monitoring and surveillance of a patient's vital signs, position, location, movement or a combination thereof via transmission of stepped-up frequency radar signals and detections of signal reflections. As used herein, the term "vital sign" may be used to mean any of the traditional vital signs, including but not limited to, temperature, heart rate or pulse, respiratory rate, and blood pressure, and/or it may mean any health parameter of interest to a monitoring caregiver, such as, for non-limiting example: ECG, EEG, EMG, oxygen saturation, blood glucose level, action potentials and local field potentials, and body mass index. A vital sign may be termed a health parameter or health sign herein, or refer to other biopotential signals, and thus refer to any aspect of the patient's health of interest to a caregiver. The biopotential signals can be recorded and transmitted in real-time thereby offering real-time telemetry readings of, for instance, cardiac electrical activity.

[0042] In one aspect, in order to detect patients remotely when visual detection is blocked (*e.g.*, by a wall), a system includes at least one stepped-frequency radar transmitter and receiver device. A transmitter emits a radar based signal that includes different frequencies omni-directionally. The emitted signal strikes objects and is at least partially reflected. The reflected signal may be affected an object's locational and positional characteristics, *e.g.*, movement of an object or distance to an object. For example, if an object such as a patient is moving toward or away a device, signals reflected from the object will exhibit frequency shifts (*i.e.*, Doppler shifts) that may be observed and processed by the device. Also, the distance a signal travels before or after being partially reflected affects the phase of the reflected signal at the receiver. In various configurations, a receiver may be a part of the transmitter device or as a separate entity. In some embodiments, the device is configured with one or more antennas to aid in the transmission and receipt of a signal. In other embodiments, the device is placed in one or more specific locations such as for example, a patient's room, common areas, hallways, and/or other sites in a hospital or ward that will offer omni-directional coverage that enables detection of patient monitoring and regardless of orientation. In yet other embodiments, the device may be placed on a moveable location, such as a cart.

[0043] In certain aspects, processing of the reflected signals includes one or more signal processing units that communicates with the transmitter and receiver. Communication between a transmitter and receiver and a signal processing unit can occur by any known communication protocol or method. In a signal processing unit, various processing methodologies and hardware configurations can be used to analyze characteristics of a reflected signal for useful information. A signal processing unit can be configured to generate and analyze frequency and/or phase shifts between the transmitted signal and reflections of the transmitted signal data. For example, processing information received from multiple receivers can be used to determine a location in 2 or 3 spatial dimensions of an object and any detected movement. Also detecting differing rates of movement and vital signs may require separate processing algorithms and/or separate characteristics of the transmitted signal and may be used in embodiments of the invention. For example, in one non-limiting implementation, a longer signal transmission may be employed to detect fine-grain movements of about 50 microns or less.

[0044] Signal processing units can be mobile or immobilized as a central station. The units may be, in certain configurations, integrated to the transmitter and receiver devices together in one form or in some other configurations, separately and remotely connected in wired or wireless configurations. Signal processing units and transmitter and receiver devices are not limited by distance. For example, a signal processing unit may be in the same general location as a transmitter and receiver device (*e.g.*, in the same patient ward) or a signal processing unit may be in a different location (*e.g.*, in a different hospital building or offsite in a different city for home based patient monitoring systems).

[0045] Exemplary configurations of transmitter/receiver devices, signal processing units and processing methodologies are described in U.S. Application Ser. No. 12/391,940; published as US 2009/0262006, all of which is hereby incorporated by reference.

[0046] In order to detect the presence of entities through movement when visual detection is blocked (e.g., by a wall) or inconvenient, a device, such as a handheld scanner, includes a stepped-frequency radar transmitter. The transmitter emits a radar based signal that includes different frequencies. The emitted signal strikes objects and is partially reflected. The reflected signal may be affected by environmental characteristics (e.g., movement of an object or entity or distance to the object or entity). For example, if an object (e.g. a patient) is moving closer to the device, signals reflected from the object will exhibit a frequency shift (i.e., a Doppler shift) that may be observed and processed by the device. Also, the distance a signal travels before or after being partially reflected affects the phase of the reflected signal at the receiver.

[0047] Various processing methodologies and hardware configurations can be used by the device to analyze characteristics of reflected signal for useful information. For example, processing information received from multiple receivers can be used to determine a location in 2 or 3 spatial dimensions of detected movement. Also, detecting differing rates of movement may require separate processing algorithms and/or separate characteristics of the transmitted signal. For example, in one implementation, a shorter duration (e.g., a few seconds) of signal transmission at a set of frequencies may be transmitted to detect fast moving objects, such as an individual running while a longer duration (e.g., less than 10 seconds) signal transmission may be employed to detect slower moving objects, such as the chest cavity of a patient breathing and/or to determine a breathing rate or pulse.

[0048] The device may be used in various scenarios, such as to aid in search and rescue missions or to aid in hospital remote monitoring. For example, firefighters who must enter a dangerous building may be tracked and monitored by other personnel outside the building. Hospital caregivers may use the device to remotely monitor a particular patients' vital signs, location, and position in a room or in the ward. The device may be used through walls, if necessary, but it is not a requirement for use, as the device may work whether through a wall or not. The signal from the device may penetrate walls and doors, and partially reflect when striking an individual (e.g., patient). The reflected portion of the signal may exhibit a frequency shift detectable by the device at multiple receivers. The device receives and processes the reflected signal from the receivers, and may determine a presence in three spatial dimensions of one or more entities (the patient, the hospital bed, a nurse in the room). The device may not only be used to detect the presence of an individual remotely based on subtle movement, such as breathing, but it may also be used to monitor that breathing or other vital signs, e.g. by determining the breathing rate (respiratory rate) from that subtle movement. Moreover, if the individual is wearing a tag (as described herein), the individual may be identified and further health parameters may be determined from the tag, depending on the embodiment.

[0049] FIG. 1A shows a diagram 100 illustrating use of a scanning device for detecting moving entities. In the diagram 100, a user 105 holds an activated handheld stepped-frequency sensor device 110, which transmits stepped-frequency radar signals.

[0050] As used herein, the terms "entity," "object", "patient", "individual", "subject", or plural forms thereof may all be used interchangeably as an element detectable by a device described herein. Depending on the embodiment, one might detect several elements using the systems, devices, and/or methods described herein--one of which elements might be a patient, another might be a bed. Description of detection or movement of an entity may be also and/or alternatively be described in relation to movement of a patient, depending on the embodiment. The movement of such entity detected need not be large movements, such as running or walking, but instead may be as subtle as the movement of an individual's blood through a vessel or heart, or his respiratory movement, or other movements that with the addition of a tag would allow for identification and monitoring of the individual's health (e.g. vital signs or other health signs of interest depending on the circumstances). The device, therefore, in some embodiments, not only detects moving entities, but determines characteristics from the detected signals such as, for non-limiting example: identity, location, position, vital signs, other health signs in order to remotely monitor the individual. A tag on the individual may be used in certain embodiments to assist in this remote monitoring and identification of the individual.

[0051] As shown, the device 110 includes several forward looking antennas 114 and a backward looking antenna 116 (shown as arrows). This configuration is one example, various implementations of the device 110 and its arrangement of antennas are discussed in FIGS. 5-7. Also, a single transmitted signal from the device 110 is described for simplicity, although multiple signals can be transmitted as discussed in FIGS. 6-7. The device 110 may differentiate between signals received from the forward looking antennas 114 and those received from the backward looking antenna 116 to determine information associated with the location of detected movement (e.g., whether the movement occurs in front of or behind the device).

[0052] In the diagram 100, the device 110 has been operated to transmit a signal either with one of more of the antennas as transceivers or with a separate transmitter. The signal (not shown) propagates outwards, strikes objects, and is reflected 115A, 120A, 125A, 130A, and 135A. As received by the device 110, the reflected signal exhibits a frequency shift proportional to the magnitude of the object's movement towards or away from the device.

[0053] In particular, the signal may penetrate a wall 118 and be partially reflected by a running individual 115, a sitting individual 120, a spinning ceiling fan 125, and a stationary chair 130 on the opposite side of the wall. The signal also is partially reflected by a nearby stationary chair 135 that is on the same side of the wall 118 as the user 105. The signal 120A reflected by the sitting individual 120 exhibits a small frequency shift due to the breathing movement of the individual's chest cavity. The signal 115A reflected by the running individual 115 exhibits a larger frequency shift than the partially reflected signal 120A from the sitting individual 120, with this frequency shift being due to the more pronounced movement of the body of the running individual 115. The signal 125A reflected by the spinning ceiling fan 125 exhibits a frequency shift that is characteristic of a repeated mechanical movement. The signals 130A and 135A that are reflected by the stationary chair 130 and the nearby stationary chair 135 exhibit no frequency shift.

[0054] The device 110 receives and processes the frequency and phase information from the partially-reflected signals 115A, 120A, 125A, 130A, and 135A. The signals may be received using a single antenna or using forward and backward looking antennas. In an initial scan function, the device 110 may calibrate against data associated with partially-reflected signals that exhibit no frequency shift 130A and 135A or that exhibit only a frequency shift due to mechanically repeated movement 125. The processed data indicates movement reflective of both breathing and running. In some implementations, the device 110 provides indications of detected moving objects by lighting separate lights or providing other types of visual indicators. In other implementations, the device 110 can provide the results of the scan on a display screen 119 along with various information determined by processing.

[0055] In this example, the device uses three forward looking antennas to determine the location of objects in three spatial dimensions (as discussed with respect to FIG. 5) and provides a visual display of the relative location of two detected moving objects. Although reflected signal from the running individual 115, the sitting individual 120, the spinning ceiling fan 125, and the stationary chairs 130 and 135 have all indicated the existence of objects, only two are shown on the display screen 119. Using processing techniques discussed below, the device 110 has removed the fully stationary objects (e.g., the chairs 130 and 135) and the objects exhibiting characteristics of repetitious mechanical movement (e.g., spinning ceiling fan 125) from consideration. Also, processing techniques of the device 110 have determined the sitting individual 120 to be exhibiting movement indicative of a stationary person (e.g., only subtle breathing movement) and the running individual 115 to be exhibiting movement indicative of an active person. Therefore, of the detected objects, only the two individuals are represented on the display screen 119. The particular movements of the individuals (respiratory or heart rate for non-limiting example), may further be calculated and displayed and even compared to expected or target movements (e.g. normal heart rates, breathing rates) to determine whether an alarm status should be associated with the individual and/or with his health. Thus, the individuals (or a particular individual) may be monitored remotely. Moreover, if the individuals are wearing tags, the device may determine the identity or other health parameters of the individuals such as temperature for non-limiting example.

[0056] The significance of the movement and its location in space relative to the device are shown. Specifically, the running individual 115 is represented on the display screen with a larger, more pronounced indication 119a to signify the significant level of movement whereas the sitting individual 120 is represented on the display screen with a smaller, less pronounced indication 119b to signify the less significant movement. Other implementations may show (or include options to show) all detected objects or a subset thereof (e.g., show objects with repeated mechanical movement, show stationary objects, show any object detected that is between a detected moving object and the device 110). Other examples of displays are provided in FIGs. 10-11 and in Example 5.

[0057] FIG. 1B is a block diagram of a stepped-frequency scanning device 150 configured to detect moving entities. Although discussed in terms of a device, the elements can be used as a system or apparatus of commonly located or separated elements. The device 150 includes antennas 155 and 160 for transmitting and receiving a stepped-frequency radio frequency signal (an "RF signal") to detect moving entities. The device 150 is shown as a bistatic radar, in that there are separate antennas for transmitting and receiving the RF signal. In particular, a transmit antenna 155 is connected to a radar transmitter and transmits an RF signal toward a target, and a receive antenna 160 is connected to a radar receiver and receives a portion of the RF signal that is reflected by the target. In other implementations, the device 150 may be a monostatic radar that uses a single antenna as a transceiver to both transmit and receive the RF signal. Also, various implementations may use multiple transmit antennas 155 and/or multiple receiving antennas 160.

[0058] The transmit antenna 155 is connected to a radar transmitter 165 that transmits an RF signal toward a target. Implementations using more than one concurrent transmission (discussed below) may use one or more transmit antennas 155 which can be coupled to either a single shared/multiplexed radar transmitter 165 or multiple dedicated radar transmitters 165. The transmitted RF signal can include frequencies that cover a bandwidth in increments of frequency steps. For example, the signal may include a nominal frequency operating with a center frequency in the UHF band (e.g. 300 MHz to 3 GHz), L band (e.g. 1 GHz to 2 GHz), S band (e.g. 2 GHz to 4 GHz), and/or X band (e.g. 7.9 GHz to 8.4 GHz). The receive antenna 160 is connected to a radar receiver 170 and receives the reflected RF signal from the target. For simplicity, the receive antenna 160 is discussed in terms of the implementation including a single antenna. Nevertheless, the receive antenna 160 may represent two or more antennas as shown by the forward looking antennas 114 of FIG. 1A. Implementations employing multiple antennas may each have a dedicated receiver which is shared or otherwise multiplexed, or may include multiple dedicated receivers.

[0059] The receiver 170 is coupled to a signal processor 175 that processes received RF signals from the receiving antenna 160. The signal processor 175 is coupled to a display 180 and a timing and control module 185. The display 180 provides audible and/or visual information or alerts of objects detected by the device, such as those described with the display screen 119 of FIG. 1A. The timing and control module 185 may be connected to the transmitter 165, the receiver 170, the signal processor 175, and the display 180. The timing and control module provides signals, such as a clock signal and control signals, to the other components of the device 150. Implementations may employ detection processes for slow or fast movement that run in real-time on an embedded processor. Implementations also may employ interference detection processes.

[0060] The signal processor 175 can include an interferometer/interferometer processing. The interferometer can process received signal to enable location of entities or targets within a given environment. The interferometer also can provide simultaneous stationary object mapping capability. In particular, the interferometer may receive channel signals, use a low-pass filtered to provide stationary object mapping, and use a high-pass filter for moving target angle estimation.

[0061] The device 150 also includes a motion sensor 190 which may include an internal inertial sensor and/or global positioning system (GPS) sensor or other location sensors. Detection of moving and/or breathing individuals during handheld and/or on-the-move operation of the device 150 is supported through use of the motion sensor's measurement and resulting compensation during processing. This may be necessary, for example, when a caregiver carries the device with him while he conducts examinations of other patient but wishes to simultaneously and continuously wishes to monitor a patient in another location. In various implementations, an inertial measurement sensor, with or without the use of a global positioning sensor, can be incorporated with the motion sensor 190 to provide sensor motion measurement, thereby supporting motion compensation processing to factor out device 150 motion (as discussed below). Alternatively, or in conjunction, adaptive processing of the radar return can be used by the motion sensor 190 and/or the signal processor 175 to estimate the sensor motion independent of measurements by the motions sensor 190. Such adaptive processing can be employed by using the phase change of stationary scattering present in the scene to estimate the sensor motion.

[0062] FIG. 2A illustrates an antenna design 200 employed in one implementation of the device of FIG. 1B. The design 200 employs separate transmit and receive antennas 205 and 210 to simplify the electronics, provide spatial separation and reduce very shallow reflections. The antennas 205 and 210, which may serve as particular implementations of the antennas 114 and 116 of FIG. 1B, may be placed in a housing 215, and a cover 220 may be placed over the antennas. The cover 220 may be made of a suitable radome material.

[0063] FIG. 2B further illustrates aspects of the design 200 discussed above with respect to FIG. 2A. Although the following discussion refers to the receive antenna 210, it is equally applicable to transmit antenna 205 or other antennas. As shown, the design 200 employs a spiral antenna as the receive antenna 210 to permit significant size reduction. For an antenna to be an efficient radiator, it must normally have a dimension of at least one-half wavelength. The spiral radiates efficiently when it has an outer circumference of at least one wavelength. This means that the antenna needs a maximum diameter of about one-third wavelength. The upper frequency limit for efficient spiral radiation is set by the size of the feed point attachments, and the lower frequency limit is set by the outer diameter of the spiral structure. Within these limits, the spiral radiates efficiently in a frequency-independent manner. The input impedance and the radiation patterns may vary little over this frequency range.

[0064] The receive antenna 210 may be constructed by etching a spiral pattern on a printed circuit board. A planar, printed circuit, spiral antenna radiates perpendicularly to the plane of the spiral. The spiral 225 itself is located at the end of a cylindrical metal cavity 230 (the cavity back) to provide isolation from neighboring elements and electronics. Typically, an absorber 235 is used on the back side of the spiral inside the cavity 230 to make sure the element responds only forward.

[0065] The previous description provides an example implementation of an antenna design. Other implementations may include different antennas, such as an endfire waveguide antenna. Such a configuration may be slightly larger than the spiral configuration. The endfire waveguide antenna reduces the measurement spot size, thus making a more precise position of a concealed object easier to locate. Other suitable types of wideband antennas may also be used.

[0066] FIG. 3 is a diagram of an example conversion circuit 300 in a scanning device. The circuit 300 can be used as portions of the transmitter 165 and receiver 170 of FIG. 1B. Also, the circuit 300 includes a signal generator 310, a signal control 320, a transmission multiplexer 330, a receive multiplexer 340, and a mixer 350, which may be in the form of a quadrature demodulator. In the circuit 300, one or more transmission signals are generated and transmitted through one or more transmit antennas. Reflected portions of the transmitted signal are received through one or more receive antennas, which may optionally be the same antennas as the one or more transmit antennas. The received signal and the signal generated by the signal generator 310 are input to the mixer 350, which outputs an in-phase signal and an out-of-phase (quadrature) signal.

[0067] Specifically, the signal generator 310 generates a signal to be transmitted by the one or more transmit antennas. The signal generator 310 may include a phase lock loop synchronized by an oscillator. In one implementation, a temperature controlled crystal oscillator is used to synchronize a voltage controlled oscillator. The signal generated by the signal generator 310 may be input to a mixer 350 and to a signal control 320. The signal control 320 may amplify or otherwise condition the signal to enable transmission by the one or more transmit antennas. The signal control 320 inputs the signal to the one or more transmit antennas and to a transmission multiplexer 330. The signal control 320 includes one or more signal outputs, each dedicated to one of the one or more transmit antennas and coupled to the transmission multiplexer 330. The transmission multiplexer 330 enables sequential sampling of the one or more signal outputs of the signal control 320 to provide feedback of the transmission signal to the mixer 350. The transmission multiplexer 330 may function as a single pole double throw (SPDT) switch for each of the signal outputs of the signal control 320.

[0068] The one or more transmit antennas emit the transmission signal, which encounters objects in the environment. Portions of the transmission signal may be reflected. The reflected portions, which may exhibit a frequency and phase shift, are received by the one or more receive antennas. Each receive antenna inputs received signal to a receive multiplexer 340. The receive multiplexer 340 enables sequential sampling, by the mixer 350, of the signal received by each of the one or more receive antennas. The receive multiplexer 340 may function as a SPDT switch for each of the signals received by the one or more receive antennas. Some implementations may use other mechanisms, such as a control system, in place of the transmission multiplexer 330 and the receive multiplexer 340. In one implementation, the one or more receive antennas are input directly to a mixer without a multiplexer. The mixer 350 receives the signal from the signal generator 310 at a first input. Based on the transmission multiplexer 330 and the receive multiplexer 340, either the transmission signal or the received signal is provided to the mixer 350 at a second input. The mixer 350 converts input signals to a form that is more easily processed, such as, for example, an in-phase and an out of phase component at a baseband frequency. As shown, the mixer 350 is a quadrature demodulator, though other signal conversion systems may be used. The quadrature demodulator outputs "I" and "Q" data (referred to as IQ data) which can be sent to an analog-to-digital (A/D) converter. In some implementations, separate IQ data may be generated for each transmitted frequency.

[0069] The previous description is an example implementation of the transmit and receive circuit. Other implementations may include different components. For example, in various implementations, a single transmit antenna and a single receive antenna are each coupled to a switch rather than the transmission multiplexer 330 and the receive multiplexer 340. An example of a process to detect moving entities using a transmitted stepped-frequency signal with a scanning device comprises at least one of the steps: 4a) transmit a stepped-frequency signal; 4b) detect reflected portions of the signal; 4c) process the reflected portions to generate data associated with frequency and phase shifts; 4d) analyze the processed data and/or determine if the reflected portions of the signal are associated with moving objects or entities; 4e) display results of the analyzed data. The process may be implemented with the device 150 of FIG. 1B or with other devices. Also, the process may be implemented in conjunction with other processes described herein.

[0070] The process begins when a stepped-frequency signal is transmitted by a device (step 4a). The stepped-frequency signal may be an RF radar signal including multiple frequencies and phases that are transmitted concurrently or consecutively. In one implementation, each transmission includes cycling through a frequency band such that multiple frequencies are transmitted. Specifically, while cycling through the band, each frequency is transmitted for a period of time, followed by the next frequency, until the bandwidth has been crossed. Although multiple frequencies may be sent, one after another, the transmitted and received signals are discussed here and elsewhere as a single signal to simplify discussion. After transmission, the signal strikes an object (an individual, a bed, a light, etc.) and is partially reflected.

[0071] Some implementations use multiple concurrent transmission for multi-static motion detection. Specifically, the multiple transmissions of the stepped frequency signal (step 4a) may include use of multiple transmit antennas simultaneously to form a multi-static radar. The transmit antennas may be located on a single device or across multiple devices. The combined measurements of signals can be received from the multiple transmissions by one or more receivers and can be used in processing to reduce interference and enhance detection of movement or location thereof. In some implementations, the transmit frequencies of the antennas are made different to avoid mutual transmission-interference. Also, the antennas can be networked (on a single device or between multiple devices) such that their transmit times are coordinated and the subsequent pre-processed data from each antenna can be processed in a central location. For implementations using multiple devices, the distances between antennas can be determined through static location survey or by using position measurement sensors.

[0072] Also, randomized frequency ordering and wide bandwidth of the transmissions may be utilized to disguise the coherent nature or minimize the effects of intentional or incidental jamming. For example, various implementations utilize a stepped-frequency pulse in which certain pulse frequencies are omitted in processing to screen out radio frequency interference from surrounding incidental or intentional sources. Also, a non-uniformly spaced, monotonically ordered, stepped-frequency waveform may be used. Further, a non-monotonically ordered stepped-frequency waveform or a frequency-hopped tonal waveform also may be used. The transmitted waveform frequency steps can be transmitted in an order dictated by a quadratic congruential sequence. Two or more antennas can be operated simultaneously using mutually orthogonal stepped-frequency transmit sequences, such as, for example Bellegardia Sequences or Quadratic Congruences.

[0073] In addition, some implementations enhance the effective aperture of the radar by moving the transmitting antenna along a pre-determined or motion-sensed line segment using a synthetic aperture radar (SAR) imaging operation mode. In particular, the stepped-frequency signal is transmitted by the device (step 4a) while the device is linearly moved. The known movement is combined with the received reflections and taken into account during processing to form a SAR image. During such operation, information provided by a device's inertial measurement and/or location sensors can be used to assist the user in providing a proper motion or by the processor in correcting for imperfections in the motion.

[0074] The device detects the reflected portion of the signal (step 4b). This detection can be accomplished using a transceiver, a separate antenna, or multiple separate antennas (e.g., a forward looking and backward looking antennas or multiple forward looking antennas). In one implementation, a single transceiver transmits the stepped-frequency signal and receives reflected portions therefrom. The detected signal includes a frequency that may have been altered by movement of the struck object and a phase that may be affected by the distance to the object.

[0075] Other implementation use multiple antennas for detection to enable more specific determination as to the location of an object (entity, individual, patient, etc.). Using multiple antennas spaced at known distances and positioned to receive signals in a similar direction can enable a more accurate two or three dimensional identification of an entity. In particular, processing the measurements from two or more antennas, separated in a horizontal direction may be conducted to provide an estimate of azimuth angle-of-arrival. Moreover, elevation angle-of-arrival estimation may be provided by processing measurements from two or more antennas that are separated in a vertical direction. Simultaneous azimuth and elevation interferometry can enable estimation of each target's location in three spatial dimensions. The device's existing receiver can be multiplexed between multiple receiving antennas and/or additional receivers can be added to the device to receive the signals from multiple antennas simultaneously.

[0076] The device processes the reflected portions of the signal to generate data associated with frequency and phase shifts (step 4c). The processing, for example, may identify information associated with frequency and phase shifts that may be indicative of the presence of moving objects or objects at a distance. The processing may include a calibration step to calibrate the data or processing steps based on conditions detected for a particular use of the device. Calibration may include removing or altering parts of the signal indicative of clutter, repeated mechanical movement, signal leakage, or reflections near or behind the device. Processing may also include calibration of the analysis steps, such as integration time.

[0077] To improve stationary object mapping and to reduce the subsequent dynamic range of the received signal data, leakage cancellation can be used in the calibration processing. Specifically, various components of the transmit-to-receive leakage signal can be adaptively located and removed from the received signal. Such components can generally be orders of magnitude higher than the highest reflected signal. Their cancellation can provide a reduced dynamic range of the subsequent signal data, and also can suppress the range sidelobes of the leakage signal which otherwise may obscure lower amplitude stationary targets.

[0078] In some implementations, the device uses a motion and/or location sensor to calibrate information from the reflected portions of the signal during or prior to processing. Specifically, motion or location information can be used to support motion compensation processing to factor out device motion. Also, adaptive processing of the radar return can be used by the device to estimate device motion. Such adaptive processing can be employed by using the phase change of stationary scattering present in the scene to estimate the sensor motion.

[0079] The device analyzes the data to determine if the reflected portions of the signal are associated with moving objects or entities (step 4d). The analysis of the data (step 4d) may include use of a short-time Fourier Transform to estimate the Doppler shift of the return signals as one of multiple Fourier Transformation integration times. In particular, the analysis may include using a low-pass filter to provide data for stationary object mapping and using a high-pass filter to provide data for moving target angle estimation. In various implementations, other techniques may be used to accomplish this estimation. In particular, processing techniques such as Maximum Likelihood Method, Maximum Entropy Method, or Music Method, may offer greater resolution for micro-Doppler detection using shorter observation times. Such methods can be used as parametric techniques to hypothesize a particular (often autoregressive) parametric signal model enabling greater resolution in the Doppler domain with shorter observation times.

[0080] Similarly methods such as Singular Spectrum Analysis (SSA) and Higher-order statistics based techniques (e.g., Bispectral Analysis) can also be used to better resolve very closely spaced independent target returns than is possible with direct Fourier methods. These methods can be considered in a tradeoff between greater computational cost than Fast Fourier Transform (FFT) methods versus improved resolution under certain circumstances. Moreover, other methods that focus on reducing the computational cost relative to the FFT methods can be used to create the frequency (Doppler) spectrum, such as, Discrete Cosine Transform, Fast Hartley Transform, and Walsh-Hadamard Transform. These methods may employ simpler basis functions for the orthogonal decomposition than the more complex exponentials in the FFT methods. Each of the above described processing techniques can be used in the analysis of the data (step 4d) and may be chosen depending on the specifics of the target application and desired specialization for optimizing implementation cost versus needed detection resolution and sensitivity.

[0081] The process can configure the transmitted waveform internal structure, bandwidth extent, and duration to better match and reveal certain target characteristics and fine-grained structure. For example, the detection and identification of small movements of machinery (e.g., clock mechanisms, slow speed rotating pumps) or human motions (e.g., voluntary and involuntary facial movements and life sign processes such as breathing, heart beat and blood flow within the arterial cavities) can be targeted by the analysis of the data (step 4d). These targets, when re-examined with the properly designed transmitted waveform, can reveal their nature in the form of very small displacements over time that impart micro-Doppler structure on the returned signals. For example, in various implementations, movement of 50-70 microns and less can be detected through adjustments to the transmit waveform characteristics and receiver processing algorithm parameters. These movements can be measured and various health parameters of the individual from which they were measured can be determined. This can provide remote monitoring of the individual for health or other purposes (e.g. pulse rate, respiratory rate). With the aid of a tag, other health parameters can also be determined and monitored remotely (e.g. temperature, blood pressure, oxygen saturation, glucose level, etc.), as well as a determination of individual location, position, and identification.

[0082] Results of the analyzed data are then displayed (step 4e). In some implementations, the results can be displayed using a series of indicators or lights or as a listing of monitored parameters (e.g. FIG. 10-11, and example 5). For example, movement detected as significant (e.g., from a running individual) can result in activation of a first light while movement detected as less significant (e.g., from an individual sitting and breathing) can result in activation of a second light. In some embodiments, only when a particular movement, position, or location, is unexpected (or out of a normal range) does a light or other alarm get activated, such as when the individual is laying on the floor in the shower, or when the individual's heart rate is elevated out of the normal range. In other implementations, a display screen is used to illustrate two or three dimension positions of movement with or without additional information about the movement. For example, a visual display of the relative location of multiple detected moving objects can be shown as locations on a three dimensional graph or representation of a space. The significance or level of movement of the detected moving objects can be indicated by, for example, size, shape, color, or animation of the indications. Additionally, the device can derive information of the area using information from the received reflections (e.g., derive existence of stationary objects such as walls) or by loading preexisting data (e.g., load a geographical map of an area or representation of the outlay of a building) and can populate the indications of detected movement upon the derived or loaded information. The tag can be used additionally to identify the individual and/or provide additional information to the system that can be used to assess the individual's status health or position-wise.

[0083] Other information can be shown using the display screen. For example, in some implementations, the device is configured to determine the relative positions of other devices. For example, the device can locate other devices by detecting a unique broadcast signature during transmission (e.g., a particular sequence of frequency steps) or by wireless network communications. Also, individuals without a scanner may include other RF identification tags that can be similarly located and identified. The device can display the position of other located devices/individuals on the display screen by rendering a unique indication. For example, such located other devices/individuals can be displayed with a first color indication while identified unknown moving objects can be displayed with a second color indication. In a military application, this can enable a unit of soldiers to, for example, identify whether a target in another room is likely a non-threat (e.g., a "friendly") or a threat (e.g., a "hostile"). In a fireman situation, this can enable fireman outside a building monitoring firemen within the building to locate movement in a building and determine whether the movement is from the monitored fireman or from another individual or other moving object. In a health monitoring environment, this can enable the person monitoring an individual to distinguish from the vital signs of a health worker in the room with the patient from the vital signs of the patient.

[0084] Also, devices can be configured to share results of analysis with other nearby devices using wireless communication. From this shared information, the device can display results computed from other devices. For example, if a first device determines there is a moving object three meters in front of it that is likely a non-threat it can transmit this determination to a second device. The second device receives this information and determines the location of the non-threatening object. For example, the second device may first determine that the first device is located, for example, four meters left of the device. Thereafter, the second device determines that the non-threatening object is five meters diagonally front and left of the device based on the first device's relative location to the second device and the non-threatening object's relative location to the first device, and renders an appropriate indication on the display screen.

[0085] The process is an example implementation of a process to sense moving entities using, for example, a stepped-frequency scanning device. Some implementations may include additional or alternative steps. For example, processing and analyzing the data (steps 4c and 4d) may be conducted together.

[0086] Another example of a process to detect moving entities including altering transmitted waveforms used by a scanning device comprises at least one of the following steps: 4a1) determine that a transmission waveform should be altered; 4b1) alter the transmission waveform; 4c1) transmit the altered waveform as a stepped-frequency signal; 4d1) detect reflected portions of the signal and use the detected reflected portions to detect objects. The process may be implemented with the device 150 of FIG. 1B or other devices. The process can be used along with or separate from other processes described herein. By altering the transmitted waveform, a device may be able to compensate for the effects of noise or interference, and may be able to avoid or overcome the presence of signal jamming.

[0087] Initially, it is determined that the transmission waveform should be altered (step 4a1). The determination may be made by a user or by the device. For example, in one implementation, the device includes an input option to randomize the waveform frequencies or to select alternative frequency stepping. In particular, if a previous scan yields poor results (e.g., the results seem incorrect to the user, such as excessive detections), the user can activate a manual alteration input (e.g., a button on the device). In response, the device is triggered to adjust the transmission waveform used in subsequent transmission. Also, a user may determine that alteration is needed prior to any transmission, such as, if the user suspects that an identifiable transmission may result in directed jamming. By using a manual alteration input to preemptively randomize the transmitted waveform, the coherent nature and wide bandwidth of the subsequent transmissions can be disguised or minimized, possibly preventing detection or jamming.

[0088] In various implementations, the device is configured to determine that the transmission waveform should be altered (step 4a1) without additional user input as a result of various conditions. For example, the device can be configured to trigger alteration of the transmission waveform in response to a determination of poor results during processing and analysis of data, such as, if saturation or degraded performance is detected (discussed below). In addition, the device can be configured to determine that the transmission waveform should be altered (step 4a1) in response to a determination that frequencies are jammed or otherwise have high levels of interference. In one implementation, the device detects signals present prior to transmission (prior to each transmission or during device power on). If a frequency is found to be unavailable due to jamming or interference, the device alters the waveform to remove frequency steps in or near the unavailable frequency.

[0089] The device proceeds to alter the transmission waveform (step 4b1). The altering may include removing specific frequencies, changing the step pattern of the frequency steps, randomizing frequency steps, or otherwise generating a non-uniformly spaced, monotonically ordered stepped-frequency waveform. The altering may include accessing a stored transmission waveform of a series of discrete stepped-frequencies for transmission, altering one or more of the discrete stepped-frequencies or order thereof, and storing the altered transmission waveform in permanent or temporary storage (e.g., random access memory) for use during subsequent transmission.

[0090] Thereafter, the altered waveform is transmitted by the device as a stepped-frequency signal (step 4c1). The frequency steps of the altered waveform can be transmitted in an order dictated by a quadratic congruential sequence. Also, in some implementations, two or more transmit antennas can be operated simultaneously using mutually orthogonal stepped-frequency transmit sequences, such as, for example Bellegardia Sequences or Quadratic Congruences. Reflected portions of the signal are detected and used to detect objects (step 4d1). Multiple receiving antennas can be used. The reflected portions of the signal can be processed to generate data associated with frequency and phase shifts, analyzed, and used to display results using, for example, the techniques described above with respect to steps 4c to step 4e as noted above.

[0091] FIG. 5 is a diagram 500A illustrating use of interferometric measurement with a scanning device 502A. An example of a process to detect moving entities using interferometric measurement with the device 502A may comprise at least one of the following steps: 5a) transmit a stepped-frequency signal; 5b) detect reflected portions of the signal using a first receiving antenna; 5c) detect the reflected portions of the signal using a second receiving antenna spaced from the first receiving antenna; 5d) detect the reflected portions of the signal using a third receiving antenna spaced from the first and/or second receiving antennal; 5e) process the reflected portions to generate data associated with frequency and phase shifts; 5f) analyze the processed data to determine location information of moving objects; 5g) display a multi-dimensional representation indicating the determined location information.

[0092] The description of FIG. 5 and the processes used therewith are directed to the use of multiple receiving antennas. By using multiple receiving antennas, the determined location of moving objects can be of greater specificity. For example, while a single receiving antenna generally enables determination of a linear distance between the device 502A and the object, using three receiving antennas can enable determination of a location in three spatial dimensions relative to the device 502A. The device 502A may be implemented as a part of the device 150 of FIG. 1B or other devices. The process described herein can be used along with or separate from other processes described herein.

[0093] Initially, the device 502A transmits a stepped-frequency signal (step 5a). The signal may be a stepped-frequency signal transmitted using a single transmit antenna 505A. The signal propagates outward from the device 502A and reaches a moving object 540A, where it is partially reflected. The reflected portions of the signal propagate back to the device 502A with a frequency change proportional to the magnitude with which the moving object was moving towards or away from the device 502A. As the reflected portions of the signal propagate, the phase changes with position while frequency remains constant. The reflected portions of the signal propagate past each of the first, second, and third receiving antennas 510A-530A.

[0094] The reflected portions of the signal are detected by the first receiving antenna 510A of the device 502A (step 5b). The first receiving antenna 510A is at a first location, and the reflected portions of the signal exhibit a first phase relative to the first location. The reflected portions of the signal are also detected by the second receiving antenna 520A of the device 502A (step 5c). The second receiving antenna 520A is at a second location which is spaced from the first location. The reflected portions of the signal are further detected by the third receiving antenna 530A of the device 502A (step 5d). The third receiving antenna 530A is at a third location which is spaced from the first and/or second locations.

[0095] In one implementation, the first and second receiving antennas 510A and 520A are separated along a first axis (e.g., horizontally) to create a first interferometric pair and the third receiving antenna 530A is separated from the first and/or second receiving antennas 510A and 520A along a second axis which is perpendicular to the first axis (e.g., vertically) to create a second interferometric pair. In addition, the back lobe of a rear facing antenna (not shown) can be used in conjunction with the first and second interferometric pairs which are forward looking in the diagram 500A to provide additional interferometric measurement capability to increase accuracy of angle of arrival estimation. Different implementations can place the receiving antennas 510A-530A differently, such that they are separated by multiple dimensions. Although discussed as three separate occurrences for simplicity, the detections (step 5b to step 5d) can be conducted nearly simultaneously (i.e., detection can be temporally separated only by the time of propagation by the reflected signal).

[0096] The reflected portions are processed to generate data associated with frequency and phase shifts (step 5e) using, for example, the techniques described above with respect to element 430A of FIG. 4A. The processed data is analyzed to determine location information of moving objects (step 5f). In the analysis, the spatial locations of the receiving antennas 510A-530A and the phase of the reflected portions as measured by the receiving antennas 510A-530A are taken into account to determine the physical position of the moving object 540A relative to the device 502A.

[0097] In particular, the device 502A uses the phase differences between reflected portions of the signal as received by the first and second receiving antennas 510A and 520A and the known physical locations of the first and second receiving antennas 510A and 520A (e.g., in this implementation, separated horizontally) to determine the azimuth angle-of-arrival of the reflected portions of the signal. Also, the device 502A processes the phase differences between reflected portions of the signal as received by the second and third receiving antennas 520A and 530A and the known physical locations of the second and third receiving antennas 520A and 530A (e.g., in this implementation, separated vertically) to determine the elevation angle-of-arrival. The device 502A uses azimuth and elevation interferometry of the data to determine the physical location of the moving object 540A in three spatial dimensions.

[0098] Finally, the device 502A displays a multidimensional representation indicating the determined location information of the moving object 540A (step 5g) using, for example, the techniques described above with respect to step 4e.

[0099] FIG. 6 is a diagram 600A illustrating use of multi-static motion detection with a scanning device 602A. An example of a process using the device 602A to detect moving entities using multi-static motion detection may comprise at least one of the steps of: 6a) transmit a first stepped-frequency signal with a first transmit antenna; 6b) transmit a second stepped-frequency signal with a second transmit antenna; 6c) transmit a third stepped-frequency signal with a third transmit antenna; 6d) detect reflected portions of the first, second, and third signals using a receiving antenna; 6e) analyze the processed data to determine location information of moving objects; and 6f) display multidimensional representation indicating the determined location information. The description of FIG. 6 and the process described using the elements of FIG. 6 are directed to the use of multiple signal transmissions. By using multiple transmissions, more precise identification of movement and location thereof can be provided. Moreover, the multiple transmissions can protect against degraded results due to jamming, interference, or noise. Additionally, some implementations conduct the transmissions in a sequence to enable faster refreshing of a display screen. The device 602A may be implemented as a part of the device 150 of FIG. 1B or other devices. The process described using device 602A can be used along with or separate from other processes described herein.

[00100] As shown in the diagram 600A, the three transmit antennas 610A-630A are part of a single device 602A. In one implementation, the transmissions occur on a single shared transmit antenna (not shown) to minimize device size and required components. The use of dedicated transmit antennas, however, can reduce circuit complexity and lower issues of interference. Moreover, for implementations employing interferometric measurement and the use of transceivers as shown in FIG. 7, separate antennas may be needed for receipt of signals, and therefore may be utilized for separate transmission as well.

[00101] Initially, first, second, third transmit antennas 610A-630A are used to transmit three signals. Specifically, a first stepped-frequency signal is transmitted with the first transmit antenna 610A (step 6a), a second stepped-frequency signal is transmitted with the second transmit antenna (step 6b), and a third stepped-frequency signal is transmitted with the third transmit antenna (step 6c). The transmissions of the three signals (step 6a to step 6c) can be conducted concurrently or spaced in time. Also, the three transmit antennas 610A-630A can each be a transmit antenna of separate devices, rather than from a single device 602A (as shown).

[00102] In some implementations, the transmissions of the three signals (step 6a to step 6c) are all conducted concurrently. In these implementations, the transmit frequencies are made to be different to minimize interference and to facilitate distinguishing between the reflected portions of the signals. For each concurrent transmission, the transmit antennas 610A-630A can each transmit a particular frequency within a predetermined series of frequency steps. Thereafter, each transmit antenna concurrently transmits the next respective frequency of the series. For example, if the frequency series consisted of frequencies F1, F2, and F3, the first transmission may be: F1 for the first transmit antenna 610A, F2 for the second transmit antenna 620A, and F3 for the third transmit antenna 630A. The next transmission can follow as F2 for the first transmit antenna 610A, F3 for the second transmit antenna 620A, and F1 for the third transmit antenna 630A. The physical separation for the three transmit antennas 610A-630A can be used during subsequent processing and/or analysis to account for difference in propagation distance of signals.

[00103] If multiple devices are used for transmission, a particular device can be used to so control transmission, detection, and processing. The devices can be networked together (using line or wireless communication) to control flow of information and commands. Specifically, a first device of the multiple devices can direct other devices when and what frequency to transmit, similar to how the device 602A directs the three transmit antennas 610A-630A. The first device can also detect reflected portions of each signal and conduct processing and analysis of the signal transmitted by each of the multiple devices. Also, the first device can receive position information of the other devices to be used during processing and analysis. Results of the processing can be communicated from the first device to each of the other devices, enabling the user of each device to perceive the results.

[00104] Reflected portions of the first, second, and third signal are detected using a receiving antenna 605A (step 6d) and the reflected portions are processed to generate data associated with frequency and phase shifts, using, for example, the techniques described above with respect to steps 4b and step 4c noted above. As reflected portions of multiple signals of different frequencies may be concurrently received on the same antenna, the signal received by the receiving antenna 605A can be filtered to separately extract the reflected portion of each transmission. For example, in the first transmission in the example above, the signal received by the receiving antenna 605A is filtered with an appropriate filter to extract signals near each of frequencies F1, F2, and F3. In one implementation, the signal received by the receiving antenna 605A is sent to a number of filters equivalent to the number of transmission (in this example, 3 filters), where each filter extracts signal near a particular frequency. In implementations directed to one-at-a-time transmissions, the signal received by the receiving antenna 605A is sent to a single adjustable filter which is adjusted to extract signals near a particular frequency according to the transmitted frequency.

[00105] The processed data is analyzed to determine location information of moving objects (step 6f). If multiple transmit antennas are used (as shown in the diagram 600A), the device 602A takes into account the known distance between the transmit antennas to account for different propagation distances of transmitted signals.

[00106] Implementations directed to concurrent transmissions can enable the determination of more precise identification of movement and its location. Using, for example, three transmissions can provide three separate data snapshots of a given scene. These snapshots may each have some differences due to signal noise, unwanted reflection, leakage, or other interference. By averaging the three data sets, the effect of such interference is reduced. Also, targeted or general signal jamming may be present on one, but not all, transmitted frequencies, resulting in very poor data. The device can selectively discard data from one or more transmitted frequencies. Therefore, the use of multi-static motion detection may overcome some effects of jamming.

[00107] Also, some implementations directed to one-at-a-time transmission enable a more rapid refreshing of data. In some implementations, the time required to complete the process comprising steps 4a through 4e can be too large to update a user of a quickly changing situation. By using multiple transmissions spaced in time according to the length of time required to complete the process, data presented to the user can be updated more often. If, for example, the process comprising steps 4a through 4e requires one half of a second to complete and three separate transmissions are spaced at a half second, data can be refreshed at approximately 6 hertz (depending on processing speed and other parameters, the time required to complete the process comprising steps 4a through 4e may be significantly different than one half of a second).

[00108] One-at-a-time refers to the start of transmission and does not preclude the possibility of an overlap between an ending of a first transmission and the start of a second transmission. Also, the order of the elements of process comprising steps 6a through 6g can be different than described. For example, reflected portions of the first signal can be detected using the receiving antenna 605A prior to the transmission of the second stepped-frequency signal with the second transmit antenna 620A.

[00109] Finally, the device 602A displays a multidimensional representation indicating the determined location information of the moving object 640A (step 6g) using, for example, the techniques described above with respect to step 4e noted above.

[00110] FIG. 7 is a diagram 700 illustrating use of transceivers to conduct interferometric measurement and multi-static motion detection with a scanning device. The device 702 may be implemented as a part of the device 150 of FIG. 1B or other devices. The device 702 includes first, second, and third transceivers 710-730. Each transceiver is configured to both transmit and receive stepped-frequency signals and is spaced from the other transceivers. Therefore, the device 702 is able to conduct multi-static motion detection as described in the process comprising steps 6a through step 6g of a moving object 740 through transmission by the transceivers 710-730 and to conduct interferometric measurement as described in the process comprising step 5a through step 5g of the moving object 740 through signal receipt by the transceivers 710-730. For simplicity, the diagram 700 illustrates the deflected signals but not the three transmitted signals.

[00111] In some implementations, the device 702 may use a mix of transceivers with transmit antennas or receive antennas. For example, a device 702 configured to use interferometric measurement as described in the process comprising step 5a through step 5g without the need for multi-static motion detection may require three receive antennas but only one transmit antenna. To minimize size, the device 702 can include a transceiver antenna used for all transmission and as a first receive antenna and two spaced receive antennas used as second and third receive antennas in interferometric analysis.

[00112] FIG. 8 is a diagram 800A illustrating use of SAR imaging with a scanning device 802A. An example process detects moving entities using SAR imaging with device 802A includes the steps: 8a) Activate synthetic aperture radar operation of a device; 8b) begin transmission of a stepped-frequency signal at a first location; 8c) move the device from the first location to a second location while transmitting; 8d) detect reflected portions of the signal during movement of the device from the first location to the second location; 8e) process the reflected portions to generate data associated with frequency and phase shifts; 8f) analyze the processed data to determine location information of moving objects; 8g) display a multidimensional representation indicating the determined location information. SAR imaging artificially enhances the effective aperture of the receiving antenna of a device. For example, if SAR data is properly constructed from moving the device a distance of a meter, the results data can correspond to the results obtain from a device with a receiving antenna spanning a meter. The device 802A may be implemented as a part of the device 150 of FIG. 1B or other devices. The process as noted can be used along with or separate from other processes described herein.

[00113] Initially, a SAR operation mode of the device 802A is activated. The activation may be as a result of input by a user to the device 802A to select one of multiple operation modes. For example, in one implementation, the device 802A includes an input option to specify that SAR will be used. In response, the device 802A is triggered to adjust operation according to the description below. In another implementation, SAR operation is the standard mode of the device 802A, and powering on the device 802A activates SAR operation.

[00114] Transmission of a stepped-frequency signal begins at a first location 810A. The transmission can begin as a result of user input. For example, the user may activate an input option (the same input option or another input option) to trigger the start of transmission. Also, the transmission may be triggered based upon movement of the device 802A such as that detected from an internal motion sensor. In one implementation, activating the SAR operation mode initiates device 802A monitoring of movement. When movement is deemed significant (e.g., motion of at least 100 millimeters is detected), transmission of the signal begins. Therefore, when ready, the user can ready the device 802A for SAR operation and begin the scan by beginning the motion of the device (as described below).

[00115] The device 802A is moved from the first location 810A to a second location 820A while transmitting the stepped-frequency signal and reflected portions of the signal are detected during movement of the device from the first location 810A to the second location 820A. The movement can be a lateral movement created by the user to move the device 802A from the first location 810A to the second location 820A. During the movement, the device 802A receives reflected portions of the signal. The reflected portions of the signal may be received and used for subsequent processing along with an indication of where or when the signal was received. Specifically, the device 802A can use time in conjunction with an assumed movement rate or can use measurements from an internal motion sensor to determine the location of the moving antenna at the time reflected portions are detected.

[00116] Also, in some implementations, an internal motion sensor is used to provide dynamic SAR scanning. Specifically, the device 802A uses the start and stop of motion to trigger the start and end of transmission/detection. Therefore, a user with ample room to obtain a large aperture can move the device across a longer distance while a user not able to move the device a full meter can nevertheless use space less than a meter to obtain some imaging improvement.

[00117] Thereafter, the reflected portions are processed to generate data associated with frequency and phase shifts. The processing can use techniques similar to those discussed elsewhere herein, for example, step 6e as noted above. The reflected portions may be received and processed into discrete packets of data associated with frequency and phase shifts. The packets can be associated with a relative position in the movement. Implementations with an internal motion sensor can use motion information to trigger generation of packets at specific physical intervals and record the location of each packet based on sensed motion. For example, in one implementation, a packet is recorded every half wavelength (e.g., at approximately every 2.5 inches) across one foot of lateral device motion based upon internal motion sensing. Implementations not employing motion sensors can be configured to assume movement of a particular speed for the purposes of packet location determination, and the user can be trained to move the device 802A at approximately the assumed speed.

[00118] The processed data is analyzed to determine location information of moving objects (step 8f) and a multidimensional representation indicating the determined location information is displayed (step 8g), using, for example, the techniques described above with respect to steps 4d and 4e as described above.

[00119] FIG. 9 is a flow chart of an example of a process 900A to analyze data associated with frequency and phase shifts generated by a scanning device. In various implementations, the process 900A is carried out with the device 150 of FIG. 1B and can be used to perform any of steps 4d, 4d1, 5f, 6f, or 8f. For brevity, however, the process 900A is described with respect to step 4d.

[00120] The process 900A receives processed IQ data that may be generated, for example, by step 4c noted above, and with the circuit 300 of FIG. 3. As shown, the process 900A involves multiple signal processing paths, degraded performance processing (910A), overt movement processing (925A), and subtle movement processing (975A). For simplicity, the signal processing paths are discussed separately, though the different types of processing may be concurrently carried out on the same input signals. Also, paths shown are examples only. Other implementations may conduct processing along a single path configured to process overt or subtle movement. Each processing path may be associated with a specific type of result displayed from the output generator (965A). In various implementations, in both overt movement processing (925A) and subtle movement processing (975A), phase and/or frequency data for each transmitted frequency is first used to develop a current picture of an environment, and is then compared against further phase and frequency data to determine differences.

[00121] The process 900A incorporates coherent integration gain and robust detection algorithms, to provide enhanced range of movement detection, higher probability of detection (Pd), and a lower probability of false alarm (Pfa). The process 900A begins when IQ data is input to be processed (905A). The input IQ data can be the output of the mixer 350 of the circuit 300 of FIG. 3. In some implementations, the IQ data is generated using a single transmit antenna and a single receive antenna. In other implementations, the IQ data is generated using multiple transmit antennas for interferometric processing and/or multiple receive antennas for multi-static processing. Accordingly, the process 900A can be used to implement portions of the processes comprising any of the steps 5a to 5g and/or comprising any of the steps 6a to 6f.

[00122] In various implementations, the user inputs one or more commands associated with one or more of overt movement processing (925A), subtle movement processing (975A), or both. For example, a user wishing to target only subtly moving objects (e.g., the cardio-pulmonary function of an individual sleeping or in a coma), may activate an input option to trigger the device to conduct subtle movement processing (975A) where it otherwise would not occur. In various implementations, a single command may be pressed, which may, depending on the reflected signal, trigger overt moving processing (925A), subtle movement processing (975A), or both.

[00123] IQ data is input to a calibrator (935A) and to a saturation detector (915A). The saturation detector (915A) sends data to a degraded performance detector (920A), which monitors for situations including detection of A/D converter saturations or unusually high signal levels that may arise from the transmitted signal reflecting off metal objects buried within or behind walls, detection of significant increases in the noise floor resulting from intentional or unintentional jamming, and detection of significant signal energy across all range cells associated with excessive movement of the antenna. If such situations are detected, the degraded performance detector (920A) can determine that the transmission waveform of subsequent transmission should be altered according to step 4a1 noted above. Also, data from the degraded performance detector (920B) can be sent to the output generator (965A) to trigger a visual indication or an alert to specify the detection of a degraded signal. The alert may signify to the user that processing results may be less reliable. Degraded performance processing (910A) need not interrupt other processing.

[00124] In overt movement processing (925A), the IQ data may first be sent through the calibrator (935A). Calibration can be used to minimize the effects of non-ideal transceiver hardware, such as transmit-to-receive signal leakage, unwanted device movement, interference, or other adverse effects upon the IQ data or collection thereof. Target detection performance may be improved as a result of cleaner range and Doppler profiles. Calibration can provide for adjustment of the collection of data, by, for example triggering the determination that the transmission waveform of subsequent transmission should be altered according to step 4a1 noted above. Calibration can also provide for adjustment of collected data, to for example, compensate for direct-current (DC) offset errors, IQ gain and phase imbalance, and gain and phase fluctuation across frequency which may be caused, for example, by transmit-to-receive signal leakage or unwanted device movement. In various implementations, calibration can be conducted at other positions within the process 900A. Hardware support for calibration can include use of an internal motion sensor and signal processor, solid state RF switches in the receive and transmit antenna front end(s) that enable the receiver input to be switched from the antenna to either resistive load or to a reduced power sample of the transmit signal. Calibrated data may be used in overt movement processing (925A) and subtle movement processing (975A).

[00125] The overt movement processing (925A) can be optimized for rapid detection of moving individuals. Processing delays associated with filtering and coherent integration can be short, enabling quicker display/alert of indications of detected movement, for example, within less than a second of the event in some implementations. The overt movement processing (925A) can begin with the data output from the calibrator (935A) input to the moving target indication (MTI) filter (940A) to eliminate or flag strong returns from stationary clutter, or returns from objects within a proximity from the device (e.g., objects on the same side of a wall as the device). Flagged returns from the MTI filer (940A) can be used by the output generator (965A) to identify flagged objects accordingly. For example, in one implementation, objects flagged as stationary are presented with a characteristic (e.g., a color or uniquely shaped icon) which differs from objects not flagged as stationary and object flagged as likely repeated mechanical movement are similarly presented with a different characteristic. Each transmit frequency may be processed by a separate filter having a bandpass response that passes signals from separate target velocities. Separate filters may enable detection of short duration movements from the arms and legs of stationary individuals as well as the detection of the main body movement, such as walking and running.

[00126] The data output from the MTI filter (940A) is input to the high range resolution (HRR) processor (945A). In one implementation, the HRR process (645A) uses an inverse fast fourier transform (IFFT) to transform the ensemble of returns from the received signal to HRR profiles. In other implementations, other transforms may be used. Depending on the characteristics of the results, the HRR process (945A) results may be input to the degraded performance detector (920) as well as the Doppler processor (950A). The Doppler processor (950A) may provide additional coherent integration gain to further improve the signal-to-noise ratio. A region detector (955A) then selects a Doppler bin with amplitude regions from range resolution cells.

[00127] The region amplitudes are passed on to a Range constant false alarm rate processor (CFAR) (960A). The Range CFAR (960A) is a cell-averaging constant false alarm rate (CA-CFAR) detector and operates along the HRR range cells output from the region detector (955A). The range cells are compared to the surrounding cells. A detection may be sent to the output generator (965A) if calculated parameters of the cell under test are greater than a predetermined amount.

[00128] Subtle movement processing (975A) is optimized for detection of stationary individuals, such as individuals whose only significant movement is that caused by respiratory and/or cardiac function. Subtle movement processing (915A) includes the calibrator (935A), the HRR processor (945A) and the Doppler processor (950A), but with longer integration times. A longer integration time provides fractional-hertz Doppler resolution to resolve the carrier modulation sidebands associated with breathing. The HRR processor (945A) can be used directly on the calibrated radar data, bypassing the MTI filters that may otherwise remove the respiration sidebands.

[00129] In subtle movement processing (975A), the output of the Doppler processor (950A) is sent to a Doppler CFAR processor (980A). The Doppler CFAR processor (980A) may be applied across the Doppler processor (950A) output to identify portions of the spectrum that are significantly above the noise floor. Values selected by the Doppler CFAR processor (980A) may be input to the spectrum variance estimator (985A) where the power-weighted second-moment of the spectrum is determined. If the calculated spectrum variance is within limits typical of respiration, the output generator (965A) may declare detection of subtle movement.

[00130] The output generator (965A) receives the results of the analysis of the IQ data from one or more of the overt movement processing (925A), subtle movement processing (975A), and the degraded performance processing (910A). For example, IQ data may be analyzed according to each processing path, generating multiple sets of results. The output generator (965A) may give priority, such that, if the same object is identified as overt and subtle movement, the output generator (965A) considers the object overtly moving. The output generator (965A) may perform additional clean-up of the detection map, including, for example, removal of detections beyond a range, and encoding the detection as either near or far. In some implementations, the output generator (965A) constructs a graphic user interface (GUI) to render the results for display to the user. The GUI can show a two or three dimensional representation of the detected objects as described with respect to the display screen 119 of FIG. 1 and/or step 4e noted above.

[00131] The output generator (965A) can output results of signal processing to a SAR processor (990A). The SAR processor (990A) is used as a feedback loop in implementing portions of the process described having steps 8a to 8g. Specifically, the SAR processor (990A) receives the output of the output generator (965A) and outputs SAR processing data as further IQ data for subsequent processing using the process 900A to provide a radar image with a synthetic aperture.

[00132] The above process 900A is an example and other processing techniques could be used along with or separate from elements of the process 900A. For example, alternate techniques discussed in FIG. 4A, such as Maximum Likelihood Method, Maximum Entropy Method, or Music Method, may offer greater resolution for micro-Doppler detection using shorter observation times. Also, methods such as Singular Spectrum Analysis (SSA) and Higher-order statistics based techniques (e.g., Bispectral Analysis) can also be used to better resolve very closely spaced independent target returns than is possible with direct Fourier methods. Further, other methods that focus on reducing the computational cost relative to the FFT methods can be used to create the frequency (Doppler) spectrum, such as, Discrete Cosine Transform, Fast Hartley Transform, and Walsh-Hadamard Transform.

[00133] An example of a process to cancel transmit-to-receive leakage signal with a scanning device may comprise at least one of the following steps: 9b1) begin stepped-frequency signal transmission and monitor for transmit-to receive leakage signal; 9b2) identify a transmit-to-receive leakage signal; 9b3) generate a cancellation waveform configured to remove the effects of the identified transmit-to-receive leakage signal; 9b4) if there is additional transmit to leakage signal, repeat steps 9b2, 9b3 until there is no additional transmit-to-receive leakage signal, and if there is no additional transmit-to-receive leakage signal, proceed to step 9b5) apply one or more cancellation waveforms to remove effects of transmit-to-receive leakage signal of subsequent transmissions; 9b6) process data associated with frequency and phase shifts of subsequent transmission; 9b7) analyze the processed data; and 9b8) display results of the analyzed data. This processing approach can be used to adaptively locate and remove various components of the transmit-to-receive leakage signal, which generally are orders of magnitude higher in amplitude then the highest reflected portions of signal intended to be detected. This cancellation can reduce the dynamic range of the signal data and also can suppress the range sidelobes of the leakage signal which otherwise may obscure lower-amplitude stationary targets. A reduction of dynamic range can allow for increased magnification of data for better separation between noise and targets without generating significant artifacts that would otherwise be generated by the increased magnification. The process may be implemented as a part of the process 900A of FIG. 9 and/or the process comprising steps 4a to 4e. For example, the process 900B can be used as part of the calibrator (935A) in FIG. 9. Also, the process 900B may be performed using the device 150 of FIG. 1B or other devices.

[00134] The device begins stepped-frequency signal transmission and monitors for transmit-to-receive leakage signal (step 9b1). The monitoring may begin concurrently with the transmission or just before or after the transmission. In one implementation, the monitoring begins prior to transmission. Thereafter, the change in received signals is used to determine the presence of transmit-to-receive leakage signal according to the techniques described below.

[00135] From the monitoring, a transmit-to-receive leakage signal is identified (step 9b2). The identification can be based upon various characteristics in signal received by one or more receive antennas that are indicative of transmit-to-receive leakage. For example, due to the proximity of the receive antennas to the transmit antennas, transmit-to-receive leakage signal can be the strongest received signal within a short delay from transmission. Specifically, transmit-to-receive leakage can occur at effectively zero distance from the device. Therefore, signal reflected from locations within a short distance (e.g., less than one foot) can be identified as transmit-to-receive leakage (step 9b2).

[00136] Amplitude can also be used to identify transmit-to-receive leakage signal. In particular, transmit-to-receive leakage signal can dominate the dynamic range with an atypically high amplitude (e.g., several orders of magnitude greater than the highest amplitude reflected signal). This effect is a result of the differing paths of signals. Specifically, because the transmit-to-receive leakage signal often is from a direct path and signals reflected from moving objects often move through an attenuating medium (e.g., a wall) there can be a significant difference in amplitude between transmit-to-receive leakage signal and signal reflected from moving objects.

[00137] Another characteristic that can be used to identify transmit-to-receive leakage signal is phase change. Generally, transmit-to-receive leakage signal exhibits no Doppler shift. The lack of a Doppler shift is because transmit-to-receive leakage signal is reflected from the device and received at the device. Therefore, the transmission location and receive location have no difference in net movement so long as they are mechanically connected.

[00138] A cancellation waveform configured to remove the effects of the identified transmit-to-receive leakage signal is generated (step 9b3). The cancellation waveform is configured to offset the effect, thereby effectively removing the identified transmit-to-receive leakage signal. In particular, a signal profile which is the inverse of the profile of the identified transmit-to-receive leakage signal can be created. This cancellation waveform can effectively zero out the transmit-to-receive leakage signal.

[00139] These techniques can be applied iteratively to maximize the reduction of interference caused by transmit-to-receive leakage. For example, after generating the cancellation waveform, the device determines whether there is additional transmit-to-receive leakage signal (step 9b4). If there is additional transmit-to-receive leakage, the process identifies and generates a cancellation waveform to remove effects of the additional transmit-to-receive leakage signal (step 9b2 and step 9b3). The iteration can be used to fine-tune the removal of a particular signal leakage path or to remove signal from multiple leakage paths. For example, signal from a separate leakage path may travel further before reaching the receive antenna and may not have the same amplitude or delay. Multiple cancellation waveforms can be generated, or a single cancellation waveform can be adjusted with each iteration.

[00140] The one or more cancellation waveforms are applied to remove the effects of transmit-to-receive leakage signal of subsequent transmissions (step 9b5). For example, the cancellation waveform can reflect the signal profile of the identified transmit-to-receive leakage signal and may be stored in memory and used during calibration processing of later data to effectively remove subsequently occurring transmit-to-receive leakage signal. In various implementations, the one or more cancellation waveforms are applied to all subsequent transmission while the device is powered on. In other implementations, the process 900B is repeated at fixed intervals of time or upon detection of poor data, such as, for example, by the saturation detector (915A) or the degraded performance detector (920A) of FIG. 9. Thereafter, data associated with frequency and phase shifts of the subsequent transmission is processed, the processed data is analyzed, and results of analyzed data are displayed (960B-980B) using, for example, the techniques described above with respect to steps 4c) to 4e) noted above.

[00141] An example of a process to compensate for motion occurring during operation of a scanning device may comprise at least one of the following steps: 9c1) begin stepped-frequency signal transmission; 9c2) detect reflected portions of the signal and accompanying motion data; 9c3) process the reflected portions to generate data adjusted for device motion associated with frequency and phase shifts; 9c4) analyze the processed data; and 9c5) display results of the analyzed data. This processing approach can be used to enable the operation of the device while it is being moved intentionally or unintentionally. Specifically, input from a motion sensor is used to facilitate the adjustment of data to offset the effect of device movement. The process may be implemented as a part of the process 900A of FIG. 9 and/or the process comprising steps 4a through 4e. For example, the process can be used as part of the calibrator (935A) in FIG. 9. Also, the process may be performed using the device 150 of FIG. 1B or other devices.

[00142] The device begins stepped-frequency signal transmission (step 9c1) and reflected portions of the signal and accompanying motion data are detected (step 9c2). Device movement can contribute to or otherwise alter the phase change of the reflected portions created by the movement of the reflecting object. Specifically, if the device is moving towards a stationary object (e.g., due to unintentional device movement), the reflected portion of the signal can exhibit a Doppler shift similar to what would be exhibited if, instead, the object had been moving towards the stationary device. The movement information enables adjustment for phase changes resulting from this device movement. In various implementations, as reflected portions of the signal are received and sent for processing, the device receives movement information from an internal inertial sensor. In other implementations, the device uses a GPS sensor to derive device movement alone or in conjunction with an internal inertial sensor.

[00143] The reflected portions are processed with the movement information from the internal motion sensor to generate data adjusted for device motion and associated with frequency and phase shifts (step 9c3). In one example, processing includes generating a packet of data for received reflections of each frequency step of a sequence of frequency steps in the transmitted stepped-frequency signal and associating motion information with each packet. In particular, if an internal inertia sensor is used, the output of the sensor can be sampled once for each packet to determine acceleration of each of three axes. This acceleration information can be accumulative and can be integrated across multiple packets for determination of velocity and direction of movement. From the determination of velocity and direction of movement, the generated data can be adjusted to reverse the Doppler effect resulting from the motion of the device with respect to the detected reflections. Also, if a GPS sensor is used, the position as determined by the sensor can be sampled once for each packet. This position information can be used to determine velocity and direction of movement by comparing previous position information.

[00144] The processed data is analyzed (step 9c4). The motion determined by the motion sensor can be used during analysis to compensate or offset the perceived Doppler shift (and thus the perceived motion) of an object detected by the device. Thereafter, results of analyzed data are displayed (step 9c5) using, for example, the techniques described above with respect to step 4e noted above.

[00145] Alternatively or in conjunction, adaptive processing of the radar return can be used by the motion sensor 190 and/or the signal processor 175 to estimate the sensor motion. The latter approach can be employed to utilize the phase change of stationary scattering present in the scene to estimate the sensor motion.

[00146] An example of a process to compensate for motion occurring during operation of a scanning device using adaptive processing may comprise any of the steps of: 9d1) transmit a stepped-frequency signal and detect reflected portions of the signal; 9d2) process the reflected portions to generate data associated with frequency and phase shifts; 9d3) identify phase change of reflections from stationary objects or scattering; 9d4) derive device motion from the identified phase change; 9d5) adjust the processed data according to the derived device motion; 9d6) analyze the adjusted data; 9d7) display results of the analyzed adjusted data. This processing approach can be used to enable the operation of the device while it is being moved intentionally or unintentionally without the use of a motion sensor. Specifically, the device analyzes data for the appearance of movement of stationary objects and uses the apparent movement to derive and compensate for the actual movement of the device. The process may be implemented as a part of the process 900A of FIG. 9 and/or the process as described in steps 4a through 4e. For example, the process can be used as part of the calibrator (935A) in FIG. 9. Also, the process may be performed using the device 150 of FIG. 1B or other devices. Finally, the process can be used in conjunction with an internal motion sensor as described in the process comprising steps 9c1 to 9c5 to further minimize the effects of device motion.

[00147] The device transmits a stepped-frequency signal and detects reflected portions of the signal (step 9d1). The reflected portions are processed to generate data associated with frequency and phase shifts (step 9d2). As discussed above, the phase of reflected portions of the signal may exhibit a Doppler shift based on the relative movement of the object towards or away from the device. If the device is moving towards a stationary object, the reflected portion of the signal can exhibit a Doppler shift similar to what would be exhibited if, instead, the object had been moving towards the stationary device.

[00148] The device identifies a phase change of reflections from stationary objects or scattering (step 9d3). In one implementation, the identification of the phase change can be based upon perceiving newly occurring movement (or a phase change indicative thereof) from a reflection from a previously stationary object. For example, the device can identify non-moving objects or objects of repeated mechanical movement and store the identification in memory. Thereafter, the device can compare the stored identification of the prior identified stationary object with the object's apparent movement during a subsequent transmission. From this comparison, the device can identify a phase change of reflections from stationary objects or scattering (step 9d3).

[00149] Also, in various implementations, the device can identify the phase change by analyzing a commonality in the data of reflected portions of the signal last transmitted. Specifically, the device can look for consistent movement or a pattern of movement of scattering or objects which reflect the transmission. For example, if the majority of reflected portions of the signal indicate movement (i.e., exhibit a phase change), the device can determine that the phase change of the reflected portions of the signal is a phase change of stationary objects. Finally, some implementations use a combination of the two approaches described above. For example, the device can first determine if there is common movement for a current set of objects, and, if so, compare the prior and current movement of specific objects to identify the phase change of reflections from stationary objects (step 9d3).

[00150] Next, the device derives device motion from the identified phase change (step 9d4). Specifically, the device determines what motion of the device would produce the identified phase change of the stationary objects. For example, in some implementations which generate a packet of data for received reflections of each frequency step, an adjustment is associated with each packet indicating the derived motion. The derived motion can be both a velocity and direction. To derive both velocity and direction, the device may process the perceived motion towards and away from multiple objects of different physical locations. This may include interferometric processing techniques to determine movement of the device in three spatial dimensions.

[00151] Thereafter, the processed data is adjusted according to the derived device motion (step 9d5). The adjustment can include altering frequency data to counteract the effect of the motion derived to have occurred for the device. Finally, the adjusted data is analyzed (step 9d6) and results of the analyzed adjusted data are displayed (step 9d7) using, for example, the techniques described above with respect to step 4e as described above. The adjustment may be conducted later in processing only for specific objects of significance or may be conducted earlier in processing on the data used to determine the existence of moving objects.

[00152] In one implementation, a scanning system employs a through-wall-detection radar device to detect an individual. The device includes a light-weight (e.g., a few pounds or less), portable, dedicated through wall device for detection through walls. Particular implementations of the scanning system are configured to detect both moving and stationary (breathing) individuals and can be useful in a variety of situations. For example, an individual buried under structural debris can be located with relative spatial position or distance and angle, which may be critical to a life saving operation. Also, in the case of hostage situations, the scanning system may be used to determine the position of individuals from certain locations, which may dictate the rescue operation methodology.

[00153] A particular implementation employs radar device in a miniaturized scanning system unit that fits into a pouch, and may operate for 180 twenty-second cycles and otherwise remain on standby during a 16 hour period running on eight disposable AA batteries. Other implementations use different batteries. For example, one implementations uses six CR123 type camera batteries rather than eight AA batteries. The scanning system detects moving targets particularly well through non-metallic materials (e.g., cement blocks, reinforced concrete, adobe, wallboard and plywood).

[00154] The scanning system may employ coherent, stepped-frequency continuous wave (SFCW) radar that provides excellent through wall detection performance. Detection is realized through range-Doppler processing and filtering to isolate human motion.

[00155] In various implementations, data from a SFCW radar may be processed as an ensemble of fixed-frequency CW radars, allowing for the optimum detection of the Doppler shift of a moving target over time via spectral analysis. The stepped-frequency radar data may also be processed to compress the bandwidth and obtain a high range resolution profile of the target. For example, the data may be processed to remove stationary or fixed time delay data, leaving the moving target data to be evaluated in both the range and Doppler (velocity) dimensions. A coherent frequency-stepped radar may have an advantageous signal gain when computing the range and Doppler values of moving targets. Pulse type or frequency chirp type radars may not be able to achieve the same integrated signal gain as stepped-frequency radar, due to a non-coherent nature.

[00156] Another property of a SFCW radar is the ability to operate in environments that exhibit high radio frequency interference (RFI). Short pulse and frequency chirp radar devices maintain a wider instantaneous receive bandwidth, enabling more RFI into a processing electronics chain and reducing the signal to noise/interference level, which may reduce sensitivity and may degrade detection performance.

[00157] In one implementation, the SFCW radar device enables detection of subtle and overt movement through walls. The SFCW radar device can use processes that operate on hardware that is generally commercially available. The architecture of the SFCW radar device generally is less susceptible to jamming (intentional or unintentional) than other radar architectures. Additionally, the reduced bandwidth enables implementation of more highly integrated RF technology, resulting in a reduction in device size, weight and DC power.

[00158] With respect to the antenna, the antenna elements can be miniaturized (scaled) versions of the AN/PSS-14 cavity-backed spiral design. The miniaturized tactical antenna supports the selected frequency range (the upper end of the AN/PSS-14 operating range, which improves performance against rebar) and packaging constraints.

[00159] The RF Electronics can generate the frequency-stepped radar waveform, amplify the signal for transmission, receive energy reflected off targets using a low-noise front end, and generate coherent (in-phase and quadrature, or I & Q) signals used in the detection process. The transceiver electronics feature a reduced bandwidth, which enables a single voltage controlled oscillator (VCO) implementation compared to a more complex two VCO design. Further device miniaturization can be achieved through implementation of a direct down-conversion (homodyne) receiver.

[00160] A brassboard homodyne receiver has shown that significantly increased detection range in through wall applications is achievable compared to the phase-noise limited AN/PSS-14 super-heterodyne architecture. The reduced bandwidth of the single-board TX/RX can provide sufficient range resolution capability to support detection and can avoid the National Telecommunications and Information Administration (NTIA)/Federal Communication Commission (FCC) restrictions associated with ultra wideband (UWB) radars. The transmit power, coupled with the gain of the antenna, can result in a low radiated power (approximately the same as cell phones), making the device safe for human exposure. Some implementations use a super-heterodyne receiver with common transmit and receive local oscillators and VCOs. The super-heterodyne implementations can reduce phase noise as compared to the homodyne implementations. The digital signal processor (DSP) hosts the motion detection algorithms. The scanning system signal processing algorithm incorporates coherent integration gain and robust detection algorithms, achieving superior performance with greater detection range, higher probability of detection (Pd), and lower probability of false alarm (Pfa). Particular implementations may be used to scan through damp concrete blocks and rebar, so as to permit ready detection of moving individuals.

[00161] The device also can include power supply circuitry needed to convert 6V battery power for the electronics. Bottoms-up power consumption calculations show that a set of disposable AA alkaline batteries may provide 180 twenty-second operating cycles. The low power, compact, high-performance direct-conversion radar transceiver can be realized through use of PF Monolithic Microwave Integrated Circuits (MMICs) and the RF integrated circuits available. An ultra-low phase noise Temperature Compensated Crystal Oscillator (TCXO) housed in a miniature surface-mountable package can be used as a reference to a synthesizer chip with a VCO integrated on the chip. Loop response time and phase noise can be achieved and optimized via an external loop filter, creating a stable, fast-locking signal source with low divider noise.

[00162] The signal source is then amplified by high-efficiency monolithic amplifiers with integrated active biasing circuitry and on-wafer DC blocking capacitors. This approach minimizes part count and current consumption. This low-noise VCO is also used in the demodulation of the received radar return, which provides considerable phase noise cancellation due the oscillator coherency. With much lower phase noise riding on returned signals (including near-wall reflections), the receiver sensitivity can be predominantly limited by thermal noise, enabling increased detection range compared to the AN/PSS-14 radar receiver. This also enables an increase in transmit power for increased range.

[00163] The direct-conversion quadrature demodulator can include polyphase filters and ensure quadrature accuracy across the entire bandwidth. Pre-amplification of the LO and integrated variable gain control of the demodulated signal can allow for efficient use of circuit board real estate and provide the device with signal conditioning flexibility to maximize signal dynamic range at the analog-to-digital (ADC) inputs.

[00164] The digital signal processor (DSP) is used to process IQ data from the radar transceiver to determine if objects are in motion and, if so, to alert the user. The DSP can have many features for power management, including dynamic frequency control, dynamic core voltage control, and the capability of turning off unused sections of the IC. These power management features make this DSP an excellent choice for battery operated scanning systems. Operating the scanning system at half the frequency and a core voltage of 1V allows lowering of the power and can enable a programmable performance upgrade for the future. A clock frequency is provided by the RF transceiver board via a Low-voltage differential signaling (LVDS) differential clock driver. This helps protect signal integrity and reduces electromagnetic interference (EMI) caused by the fast clock edge rates.

[00165] In various implementations of scanning system, the design features 8 M bytes of synchronous dynamic random access memory (SDRAM) for fast program access and enough storage for 60 seconds of captured data per operating cycle. In addition, 4 M bytes of flash memory are used for booting up the DSP and for non-volatile storage. A universal serial bus (USB) interface is used as a test port, and will only be powered up for debugging and data collection. An ADC includes an 18 bit ADC that allows a 15 dB increase in signal-to-noise ratio (SNR) to take advantage of the increased dynamic range and sensitivity. Differential inputs improve common-mode noise cancellation, allowing for a more sensitive detector. The op-amps are selected for low power, low noise performance as amplifiers and active filters. A 16 bit DAC is used to cancel the DC offset from the incoming IQ signals from the RF Electronics.

[00166] Serial communication protocol (SPI) is used to communicate with the ADC, digital-to-analog converter (DAC), and RF phase-locked loop (PLL), which helps reduce I/O requirements and EMI.

[00167] The compact scanning system package enables single-handed operation while providing robust protection for the intended application. The unit may also be attached to the forearm or upper arm via straps. The housing layout is able to be configured with three circuit card assemblies (CCA), which enables an optional integrated battery recharging circuit, such as a generally commercially available integrated battery recharging circuit. The miniature cavity-backed spiral antennas each contain a planar feed assembly that connects directly to the RF CCA. The Digital CCA contains the DSP as well as the power supply (PS) circuitry.

[00168] A scanning system unit and accessories can fit into a small case for storage and transportation. The packaging may provide protection against transportation shock and vibration, environmental protection, and facilitates safe storage and case of handling while in daily use by users (e.g. hospital personnel or rescuers). The case includes compartments for storing arm straps, extra batteries, and an optional vehicle-compatible battery recharger.

[00169] To deploy, the operator may hold the device by the straps or by the sides of the unit, affix the unit to either arm via the straps (forearm or upper arm), or mount the device to a pole or tripod (pole/tripod not provided with unit). A standard video camera mount may be connected to the bottom of the unit to facilitate mounting to a tripod or pole. The housing design also features raised stiffener ridges on the front that may facilitate temporary wall mounting using putty. Other implementations may not include the straps, enabling users to operate the device without connecting it to their person.

[00170] The housing is made of impact-resistant ABS plastic to help provide protection if the case is dropped or collides with hard objects that may occur during training exercises or during operation, such as on a battlefield or in a rescue operation. The external design of the housing incorporates human factor features to simplify operation in difficult environments. A rubber shield protects the front of the unit. Rubber grip pads are also provided in four areas to facilitate slip-free handheld operation. Multiple SCAN switches support a variety of operational situations.

[00171] The battery holder assembly features all eight batteries in the same orientation for easy installation under low light/time critical conditions. The total power draw from batteries can be 2.2 W. In one implementation, four batteries are connected in series, and 2 sets of 4 batteries in parallel. This provides 6V and divides the power by the 2 battery sets. During run time the individual battery voltage is allowed to decay from 1.4V to 0.9V, providing approximately 1 hour of operation time.

[00172] The device can include light emitting diodes (LEDs) recessed to provide shadowing to enhance daytime vision with or without a display screen (not shown).

[00173] In Standby mode the circuitry is placed in a power-save mode, and activation of any one of three SCAN pressure switches (one front, two bottom) initiates immediate sensor operation. The device returns to standby mode when the SCAN button is released. Other implementations may include other interface arrangements. For example, a combination of two SCAN switches could be simultaneously pressed (but not held) to enable timed operation, such as when the unit is temporarily adhered to or leaned against a wall, or mounted to a tripod, for hands-off operation.

In one implementation simplifying design, four color LEDs are used to provide indications to the operator without a display screen. The yellow STANDBY LED indicates power status: steady illumination indicates power is on; flashing LED indicates low battery power. The red FAULT LED indicates one of several conditions: steady illumination indicates that the device is unable to make an accurate measurement due to metal blockage, electromagnetic interference (e.g., jamming), or excessive motion of the sensor; flashing illumination indicates a built-in-test (BIT) failure. The green SCANNING LED remains illuminated while the unit is operating to detect motion. The blue DETECT LED indicates that motion has been detected. Steady illumination indicates individual motion detection at a closer distance. A flashing DETECT LED indicates individual motion detection at a farther distance. A change in color for the blue DETECT (to Magenta) indicates that subtle movement has been detected.

[00174] The device may be powered on and placed in standby mode by momentarily pressing the STDBY switch. The device may be powered off by simultaneously pressing the STDBY and OFF switches. This may prevent accidental power-down during normal operation should the OFF switch get accidentally bumped. In STDBY mode, circuitry is activated in power-save mode, and the device may be immediately operated by pressing one of the SCAN switches. The front SCAN switch may be activated by pressing and holding the device scanning system against the wall to be penetrated. One of two bottom SCAN switches may be activated by squeezing with the thumb (normal device orientation) or index finger (inverted orientation), or by pressing the device against the knee or thigh when in a kneeling position.

[00175] When any SCAN switch is depressed, the green SCAN LED may illuminate, and may remain illuminated as long as the SCAN switch is depressed. This may alert the operator that the device is operational (i.e., that the SCAN switch is properly depressed). A blue DETECT LED may be used to alert the operator of detected individuals. The device may also be programmed to detect subtle movement. This mode may be initiated by pressing any SCAN switch twice in rapid succession. The green SCAN LED may pulsate slowly when this mode is active. The blue DETECT LED may illuminate when slow movement (respiration) is detected. Some implementations use alternative manners of communicating information to users. For example, one implementations uses a light emitting diode screen to render a two digit number to express a distance of detected moving objects. Other implementations use more sophisticated screens (e.g., more advanced light emitting diodes, organic light emitting diodes, etc.) to render three dimensional representations and more complex information.

[00176] Some implementations not employing interferometric processing can have conical radiation patterns so the device may be arbitrarily oriented (within the plane of the wall); i.e., when held against the wall, the unit may be oriented horizontally, vertically, or in any other position without impacting operational performance. The device may also be held off the wall (standoff), provided it is held still during SCAN operation.

[00177] Although the techniques and concepts have generally been described in the context of a handheld stepped-frequency scanning device and/or scanning system, other implementations are contemplated, such as a vehicle-mounted stepped-frequency device.

[00178] In one general aspect, sensing moving entities includes transmitting a stepped-frequency radar signal including multiple frequencies through a wall from a first side of the wall to a second side of the wall, detecting reflected portions of the radar signal that are reflected by entities located beyond the second side of the wall, processing the reflected portions to generate processed data including information associated with frequency shifts between the transmitted signal and the detected signal, and analyzing the processed data to determine if reflected portions are associated with moving entities.

[00179] Implementations may include one or more of the following features. For example, analyzing the processed data may include calibrating the processed data, such as by compensating for reflections near or behind the device. Calibration may be performed for each separate attempt to sense moving entities.

[00180] Analyzing the processed data may include removing information associated with reflections from stationary objects or from objects within a proximity to the device. Analyzing the processed data also may include performing a Fourier transform on information associated with the processed data, and degraded performance may be detected based on whether results of the Fourier transform satisfy a condition. Similarly, a first Fourier transform with a first integration time and a second Fourier transform with a second integration time longer than the first integration time may be performed on the same information associated with the processed data, and degraded performance may be detected based on whether results of the first Fourier transform satisfy a first condition and results of the second Fourier transform satisfy a second condition different from the first condition. Analyzing the processed data may include analyzing frequency and phase shifts between the transmitted signal and the detected signal to determine movement of objects at a distance.

[00181] In another general aspect, a system for sensing moving entities includes a stepped-frequency radar transmitter coupled to a transmit antenna to transmit a stepped-frequency radar signal, a receive antenna configured to detect reflected portions of the radar signal, and a processor operable to process, for a multiple frequencies, the reflected portion of the radar signal from the receive antenna and to analyze the processed data to determine the presence of moving entities on an opposite side of a wall from a side of the wall on which the system is located.

[00182] Implementations may include one or more of the following features. For example, the system may include a demodulator which receives both the stepped-frequency radar signal and a reflected portion of the radar signal, and outputs in phase and out of phase data. The system may be configured to be operable using AA batteries.

[00183] The processor may be configured to remove information associated with signal reflection from stationary objects or from objects within a proximity to the device. The processor also may be configured to perform a first Fourier transform with a first integration time and a second Fourier transform with a second integration time longer than the first integration time on the same information associated with the processed data.

[00184] In general, in some aspects, a method for monitoring at least one entity (a single patient, and/or several patients, for example) based on movement includes transmitting a stepped-frequency radar signal from a first location and detecting reflections of the transmitted signal with an antenna. This may be done, for example, through a wall. This may be done while the antenna is in motion. The method may also include determining one or more characteristics of motion of a system which includes the antenna during the detection of reflections of the transmitted signal. The method may further include generating data including information associated with frequency and phase shifts between the transmitted signal and the reflections of the transmitted signal detected with the antenna while the antenna is in motion. The method additionally may include analyzing the generated data to determine information associated with the entity or entities. The analyzing includes using the determined one or more characteristics of the motion of the system to compensate for the effect of the motion of the system on the phase shifts between the transmitted signal and the reflections of the transmitted signal.

[00185] This and other implementations can optionally include one or more of the following features, which also may optionally be in any combination. In the method, determining the one or more characteristics of the motion of the system during the detection of reflections of the transmitted signal can include receiving an indication of the one or more characteristics of the motion of the system from a motion sensor included within the system. Receiving an indication of the one or more characteristics of the motion of the system from the motion sensor can include receiving information from a global positioning system sensor. Receiving an indication of the one or more characteristics of the motion of the system from the motion sensor can include receiving information from an inertial sensor. Receiving information from an inertial sensor can include sampling one or more outputs of the inertial sensor indicating a current state of acceleration in each of three spatial dimensions.

[00186] Also, generating the data can include generating packets of data which each include information associated with the received indication of the one or more characteristics of the motion of the system along with the information associated with frequency and phase shifts. Using the determined one or more characteristics of the motion of the system to compensate for the effect of the motion can include deriving the motion of the system from the received indication of the one or more characteristics of the motion of the system from the motion sensor, altering the generated data to reverse the Doppler shift of the detected reflections resulting from the derived motion of the system, and analyzing the altered data to determine the information associated with the moving object located beyond the second side of the wall.

[00187] The method can also include identifying a phase change of detected reflections of the transmitted signal from stationary objects or scattering and the one or more characteristics of the motion of the system can be determined based on the identification of the phase change of detected reflections of the transmitted signal from stationary objects or scattering. Identifying the phase change of detected reflections of the transmitted signal from stationary objects or scattering can include determining that the detected reflections are reflected from an object that had previously reflected transmission which was not indicative of movement. Identifying the phase change of detected reflections of the transmitted signal from stationary objects or scattering can include identifying phase changes indicative of a consistency of movement or a pattern of movement of scattering or objects. Using the determined one or more characteristics of the motion of the system to compensate for the effect of the motion can include deriving the motion of the system from the one or more characteristics of the motion of the system, altering the generated data to reverse the Doppler shift of the detected reflections resulting from derived motion of the system, and analyzing the altered data to determine the information associated with the moving object located beyond the second side of the wall.

[00188] Further, transmitting the stepped-frequency radar signal can include beginning transmission of the stepped-frequency radar signal at a first system location and moving the system during transmission of the stepped-frequency radar signal from the first system location to a second system location. Detecting reflections of the transmitted signal with the antenna while the antenna is in motion can include detecting reflections of the transmitted signal during the movement of the antenna from the first system location to the second system location. Analyzing the generated data can include determining the information associated with the moving object located beyond the second side of the wall based upon the reflections detected during the movement of the antenna from the first system location to the second system location.

[00189] Moreover, generating the data can include generating data for detected reflections which includes information associated with frequency and phase shifts and associated with the one or more characteristics of the motion of the system determined during the detection of reflections of the transmitted signal. Analyzing the generated data can include generating a synthetic aperture radar image using the data including information associated with frequency and phase shifts and associated with the one or more characteristics of the motion of the system. Determining the one or more characteristics of the motion of the system during the detection of reflections of the transmitted signal can include sampling output of an inertial sensor within the system. Generating the data can include generating a packet of data for reflections received at each of multiple system locations between the first and second system locations, each packet including the information associated with frequency and phase shifts, and output of the sampled inertial sensor at the time the reflection was detected.

[00190] In addition, the method can include identifying a transmit-to-receive leakage signal resulting from the transmission of the stepped-frequency radar signal, generating a cancellation waveform configured to remove effects of the identified transmit-to-receive leakage signal, and using the generated cancellation waveform to remove effects of transmit-to-receive leakage signal of subsequent transmissions. The method can also include, after transmitting the stepped-frequency radar signal, determining the stepped-frequency radar signal should be altered, generating an altered stepped-frequency radar signal such that the order of the transmitted frequencies is changed or such that one or more of the transmitted frequencies is removed, and transmitting the altered stepped-frequency radar signal. Determining the one or more characteristics of the motion of the system can include determining one or more characteristics of the motion of the antenna.

[00191] In other implementations, some aspects include a system for detecting entities based on movement. The system includes transmission circuitry configured to enable transmission of a stepped-frequency radar signal and an antenna configured to detect reflections of the transmitted signal. The system also includes receiving circuitry configured to receive detected reflections from the antenna and to generate data including information associated with frequency and phase shifts between the transmitted signal and the reflections of the transmitted signal. The system further includes a processor configured to receive the generated data from the receiving circuitry and to analyze the generated data to determine information associated with a moving object located at a side of a wall different than a side of the wall of which the system is located. The analyzing includes using one or more characteristics of motion of the system to compensate for the effect of the motion of the system on the phase shifts between the transmitted signal and the reflections of the transmitted signal.

[00192] This and other implementations can optionally include one or more of the following features, which also may optionally be in any combination. The receiving circuitry can be a part of the processor. The system can includes a motion sensor configured to determine the one or more characteristics of the motion of the system and, to generate the data, the receiving circuitry can be configured to receive an indication of the determined one or more characteristics of the motion of the system from the motion sensor. The motion sensor can be a global positioning system sensor. The motion sensor can be an inertial sensor. The inertial sensor can be configured to output a current state of acceleration in each of three spatial dimensions. To generate the data, the receiving circuitry can be configured to generate packets of data which each include information associated with the received indication of the determined one or more characteristics of the motion of the system along with the information associated with frequency and phase shifts.

[00193] Also, to use the one or more characteristics of the motion of the system to compensate for the effect of the motion, the processor can be configured to derive the motion of the system from the received indication of the one or more characteristics of the motion of the system from the motion sensor, alter the generated data to reverse the Doppler shift of the detected reflections resulting from the derived motion of the system, and analyze the altered data to determine the information associated with the moving object at the side of the wall different than the side of the wall of which the system is located. To use the one or more characteristics of the motion of the system to compensate for the effect of the motion, the processor can be configured to identify a phase change of detected reflections of the transmitted signal from stationary objects or scattering and determine the one or more characteristics of the motion of the system based on the identification of the phase change of detected reflections of the transmitted signal from stationary objects or scattering.

[00194] Further, to identify the phase change of detected reflections of the transmitted signal from stationary objects or scattering, the processor can be configured to determine that the detected reflections are reflected from an object that had previously reflected transmission which was not indicative of movement. To identify the phase change of detected reflections of the transmitted signal from stationary objects or scattering, the processor can be configured to identify phase changes indicative of a consistency of movement or a pattern of movement of scattering or objects. To use the determined one or more characteristics of the motion of the system to compensate for the effect of the motion, the processor can be configured to derive the motion of the system from the one or more characteristics of the motion of the system, alter the generated data to reverse the Doppler shift of the detected reflections resulting from the derived motion of the system, and analyze the altered data to determine the information associated with the moving object at the side of the wall different than the side of the wall of which the system is located.

[00195] Moreover, the transmission circuitry can be configured to enable the transmission of the stepped-frequency radar signal to begin at a first system location and to continue during movement of the system from the first system location to a second system location. The receiving circuitry can be configured to receive the detected reflections of the transmitted signal during the movement of the system from the first system location to the second system location. The processor can be configured to determine the information associated with the moving object located at the side of the wall different than the side of the wall of which the system is located based upon the reflections detected during the movement of the system from the first system location to the second system location. To generate the data, the receiving circuitry can be configured to generate data for detected reflections which includes information associated with frequency and phase shifts and information associated with the characteristics of the motion of the system. To analyze the generated data, the processor can be configured to generate a synthetic aperture radar image using the data including information associated with frequency and phase shifts and information associated with the one or more characteristics of the motion of the system.

[00196] In addition, the system can include an inertial sensor configured to determine the one or more characteristics of the motion of the system and to generate the data, the receiving circuitry can be configured to sample output of the inertial sensor and to generate a packet of data for reflections received at multiple system locations between the first and second system locations, each packet including the information associated with frequency and phase shifts, and output of the sampled inertial sensor at the time the reflection was detected. The processor can be configured to identify a transmit-to-receive leakage signal resulting from the transmission of the stepped-frequency radar signal, generate a cancellation waveform configured to remove effects of the identified transmit-to-receive leakage signal, and use the generated cancellation waveform to remove effects of transmit-to-receive leakage signal of subsequent transmissions. The processor can be configured to, after the transmission of the stepped-frequency radar signal, determine the stepped-frequency radar signal should be altered, enable generation of the altered stepped-frequency radar signal such that the order of the transmitted frequencies is changed or such that one or more of the transmitted frequencies is removed, and enable the transmission circuitry to transmit the altered stepped-frequency radar signal. To use the one or more characteristics of motion of the system, the processor can be configured to use one or more characteristics of motion of the antenna.

[00197] In other implementations, some aspects include a system for detecting entities based on movement. The system includes transmission circuitry configured to enable transmission of a stepped-frequency radar signal and an antenna configured to detect reflections of the transmitted signal. The system also includes receiving circuitry configured to receive detected reflections from the antenna and to generate data including information associated with frequency and phase shifts between the transmitted signal and the reflections of the transmitted signal. The system further includes processing means to receive the generated data from the receiving circuitry and to analyze the generated data to determine information associated with a moving object located at a side of a wall different than a side of the wall of which the system is located. The analyzing includes using one or more characteristics of motion of the system to compensate for the effect of the motion of the system on the phase shifts between the transmitted signal and the reflections of the transmitted signal.

[00198] Processing algorithms and characteristics of the transmitted signals can be programmed and configured in the signal processing unit and transmitter/receiver device to detect a patient's macro motions (*e.g.*, walking, exercising, eating, and the like) as well as micro motions (*e.g.*, voluntary and involuntary facial movements and life sign processes such as breathing, heart beat and blood flow within the arterial cavities) and via analysis of the received data. In some embodiments, by processing and sensing very small Doppler shifts in a reflected signal, a central processing unit can detect and determine accurate and repeatable real-time measurements of patient physiological variables including, for example, a patient's vital signs. Vital signs as used herein include one or more of the following: heart rate, heart rhythm, breathing rate and breathing rhythm. In some embodiments, both macro and micro motions can be detected simultaneously using various processing algorithms and characteristics of the transmitted signals.

[00199] The processing algorithms transmitted signals can be configured in the signal processing unit and transmitter device to determine a patient's position, *e.g.*, standing upright, sitting, lying flat, or a combination thereof. In certain embodiments, the directionality of a patient can be identified such that the system can distinguish whether a patient is lying face down, on the side or face up, or 45 degrees from the bed based on the micro motion data. In certain instances, detection and determination of a patient’s position includes a patient’s directionality.

[00200] In some configurations, the signal processing unit and transmitter/receiver device is configured to detect and determine one of the following: patient's location, movement, position or vital signs. In other configurations, the signal processing unit and transmitter/receiver device is configured to detect and determine two of the following: a patient's location, movement, position or vital signs. In some other configurations, the signal processing unit and transmitter/receiver device is configured to detect and determine three of the following: a patient's location, movement, position or vital signs. In yet other configurations, the signal processing unit and transmitter/receiver device is configured to detect and determine all of the following: a patient's location, movement, position or vital signs.

Patient Identification Tags

[00201] In various embodiments, incorporated into the remote patient monitoring system is a tag that is in close proximity to or worn by a patient allowing for identification and tracking of a patient relative to other patients within the field of vision of the monitoring system. A tag can serve as a means to discriminate patients from each other and, in some embodiments, may encode specific patient information such as medical record number and date of birth. In other embodiments, the tag may be anonymous whereby individual tags are associated with patient rooms and the patient, once assigned to a room, receives the associated room tag. Associated room tags may be advantageous in reducing manufacturing costs, i.e., a single tag for each room may be produced at large volume as opposed to providing an individualized tag for each new admitted patient.

[00202] The tag, in various configurations, incorporates any identification technology that can be detected by the patient monitoring system, including, *e.g.*, radio-frequency identification (RFID). RFID tags used herein can be entirely passive, battery assisted passive (BAP) or active. Thus, the tag may or may not comprise a battery, depending on the embodiment. The tag may comprise data collectors and/or circuitry and logic in the circuitry to collect, transform, and/or transmit data in raw form and/or transformed form to the device. The tag may also and/or alternatively be powered by the transmitter signal itself, or powered in another manner altogether as known to one of skill in the art.

[00203] Tags can be implemented in any format including, but not limited to, necklaces, bracelets, rings, clothing, shoes, cards, fobs, keys, and other items that are either in close proximity to or worn by the patient. In some embodiments, the tag is in a form of a wearable, disposable patch that is applied to an area of the body that is not easily reach by the patient (*e.g.*, the middle of the back). A patch allows the tag to be worn by the patient throughout the entire admission. Generally, patches are about 1 to about 2 cm in diameter or less and would not interfere with daily life activities such as eating and bathing as well as clinical procedures.

[00204] In addition to patient identification, tags, in certain instances, can serve to increase functionality in the described patient monitoring system. In some embodiments, the use of multiple tags enhances the detection of the position of the patient. Multiple tags include two, three, four, five and up to ten tag systems. For example, a four tag configuration in a patch format with a patch on a patient's upper back, lower back and one on each mid leg would allow better resolution as to whether a patient is upright, sitting down or lying flat. A multiple tag system, in some configurations, can also increase accuracy in the detection of a patient's movement, location, vital signs, or a combination thereof.

[00205] Tags may also and/or alternatively provide additional details to be used to determine various health parameters of the individual that may be monitored. These details may be used in conjunction with information detected by the device to determine or more accurately determine a particular health parameter, or may alone provide information on a health parameter which may be shown on the device or on a monitoring station. For example, the tag may take glucose readings from a glucose monitor connected to the patient. The glucose monitor may be incorporated into the tag itself or be remotely connected or directly connected to the tag, depending on the embodiment. The tag may provide a glucose reading to the device for display on the device. In another example, the tag may take a reading of the individual, which is transmitted to the device. The device then uses the reading in conjunction with another parameter detected by the device itself to determine and/or display a monitored parameter. Thus, a measurement of the individual requiring contact may be combined with a measurement of the individual which may be taken remotely by the device in order to monitor the individual. The device may, for example, detect that a patient has slow heart rate, while the tag identifies the patient as patient “X” and determines that patient “X” is in the bathroom. Alone, the tag might only identify the patient, and alone, the device might only identify a slow heart rate, depending on the embodiment. A slow heart rate alone might otherwise be associated with a sleeping patient and not alarm anyone, but together with the patient’s identity and location from a tag (or other parameters monitored by the tag), the device can alert a caregiver through an alarm notification that patient “X” is exhibiting a slower than expected heart rate for someone who is awake and in the bathroom, for non-limiting example.

Portable Monitoring Devices

[00206] Provided in some embodiments of the patient monitoring system is the use of one or more portable monitoring devices. These devices can receive information from the signal processing unit and display one or more patient's vital signs, location, position and movement. The portable monitoring devices can exist in various forms including but not limited to hand-held devices to be carried by healthcare practitioners and staff, wearable forms, table-top units and/or wall-mounted units. In certain configurations, the signal processing unit is integrated into the portable monitoring devices. In other configurations, the signal processing unit is separated from the portable monitoring devices.

[00207] The portable monitoring devices can communicate with the signal processing unit by any known communications method or protocol. For moveable portable monitoring devices such as wearable and hand-held devices, generally wireless protocols can be used (*e.g.*, IEEE 802.11 WiFi, infrared, Bluetooth and the like). Stationary portable monitoring devices such as table-top units and/or wall-mounted units can communicate via wired or wireless protocols. In various configurations, the communications between the signal processing unit and the portable monitoring devices are encrypted to provide security and authenticity of the patient data as well as maintain patient privacy. Portable monitoring devices and signal processing units are not limited by distance. For example, portable monitoring devices and signal processing units may be located in the same location such as a patient ward, or offsite in different buildings and/or in different cities.

[00208] The portable monitoring devices can output the patient information visually in the form of tables, graphs, symbols, two-dimensional or three-dimensional representations, any combination thereof, or other forms of display. In some embodiments, the portable monitoring devices can also provide a notification when one or more of a patient's vital signs, location, position and movement fall or trend outside a predetermined set of ranges of acceptable parameters. For example, if a patient's heart rate is outside the 'safety' range, an alarm is signaled and a healthcare practitioner is informed to go to bedside to review the patient. Alarm notifications may be visual in the form of blinking lights and the like; aural as a series of beeps, rings and the like; tactile, *e.g.*, vibrations, or any combination thereof. Alarm notifications can also be elicited according to severity and degree of the information outside one or more given parameters.

Predetermined Parameters

[00209] In some embodiments, predetermined set of ranges of acceptable parameters for vital signs, location, position and movement are unique and tied to individual patients. Vital sign ranges can be defined during admission of a patient and may be adjusted throughout the course of the patient's admission. Likewise, location, position and movement parameters can be mapped out upon admission of a patient and are based on allowable 'patient care areas' within which a patient resides throughout admission.

[00210] Discrete patient care areas can be described as a virtual realm with boundaries that defines the location that a patient may freely move within and is based on their individual risk factors such as stability while mobilizing (*e.g.*, risk of falling), level of confusion or delirium (*e.g.*, dementia and alcohol/drug withdrawal), and likelihood of taking part in dangerous activity (*e.g.*, illicit drugs or aggressive behavior) to name a few. For instance, some patients have freedom to roam around a hospital while others require accompaniment by staff to use the bathroom. Setting boundaries for a patient's care area and allowing for continuous, remote surveillance of the patient can be important in avoiding adverse patient events such as un-witnessed falls and roaming because of a confused state as often occurs with dementia patients.

[00211] Exemplary patient care area parameters include areas for patients who are not allowed to wander from their room. Larger area parameters include the patient room and common room areas or the entire ward if the patient is free to roam beyond the confines of his or her room. Smaller area parameter could simply be mapped to the patient's bed if the patient is immobilized and confined to the bed with a high risk of falling.

[00212] In some embodiments, initial predetermined set of ranges can be inputted and recorded at the signal processing unit, the portable monitoring device, both and/or other locations. Likewise the predetermined set of ranges can be changed at signal processing unit, the portable monitoring device, both and/or other locations. Discrete patient care areas can be mapped out, in some embodiments, with a hand held device that when positioned, for example, in a corner of a room communicates the coordinates of the point with the signal processing unit. By repeating this process at one or more boundary points in a discrete patient care area, a three-dimensional box or volume may be mapped out to produce a virtual room that the patient exists within throughout his or her admission and permitted to occupy and move around. In certain instances, the mapping function can be integrated into a portable monitoring device. In other instances, a separate hand held device from a portable monitoring device is used to map discrete patient care areas. Patient care areas can also be changed or modified by expanding or limiting the allowable areas for a patient during the course of his or her admission.

[00213] In some configurations, comparison of a patient's current vital signs, location, position, movement, or combinations thereof to a given set of predetermined ranges can be analyzed by a signal processing unit and the subsequently relayed to a portable monitoring device. In other configurations, a signal processing unit relays only the patient's current vital signs, location, position, movement, or combinations thereof to a portable monitoring device that subsequently analyzes and compares a patient's current vital signs, location, position, movement, or combinations thereof to a given set of predetermined ranges. In yet other configurations, both a signal processing unit and a portable monitoring device have capability to analyze and compare a patient's current vital signs, location, position, movement, or combinations thereof to a given set of predetermined ranges.

Additional Physiological Monitoring Devices

[00214] In some aspects, additional physiological monitoring devices in the form of small integrated circuits can be included in the disclosed patient monitoring systems. For example, small integrated circuits can be worn by and/or attached to the patient and can measure, amplify, and filter biopotential signals such as ECG, EEG, EMG, oxygen saturation, temperature, blood pressure, glucose, action potentials and local field potentials. The biopotential signals can be recorded and transmitted in real-time thereby offering real-time telemetry readings of, for instance, cardiac electrical activity.

[00215] The small integrated circuits can have low power requirements and in certain configurations, can use an external power source such as a battery. In other configurations, the small integrated circuits utilize the transmitted radar signals as a remote power source. In one non-limiting example, an ECG signal is recorded and transmitted so long as the radar signal is detected by the integrated circuit. In certain embodiments, the small integrated circuits are incorporated into the patient identification tags. Incorporation into the patient identification tags can reduce the number and complexity of items a patient would wear for remote monitoring. In other embodiments, the small integrated circuits are separate and distinct from the patient identification tags as some patients may not require monitoring of certain biopotential signals.

Applications

[00216] Applications for utilizing a remote patient monitoring and surveillance system include, in certain embodiments, continuous surveillance of patients enabling early intervention if physiologic variables such as heart rate and breathing become irregular and unsafe; early warning systems in preventing falls by alerting staff of positional and location changes in patient's at high risk of falling (*e.g.*, debilitated, confused, stroke patients, etc.); detection of movement related to conditions in need of medical attention (*e.g.*, repetitive movements, shaking, seizures, spasms); and the improvement of nursing efficiencies by enabling multiple, simultaneous, and real-time patient monitoring in areas that typically have staffing limitations.

[00217] The remote patient monitoring and surveillance system may be adapted to skilled nursing facilities and rehabilitation centers, assisted living facilities for those with progressive dementia and debilitation, and as well as home based units for persons who live independently but prefer the safety net of being monitored remotely, or may be used in any patient setting, including a hospital or other care setting (e.g. urgent care center, doctor's office, outpatient facility).

[00218] Home based implementations include monitoring of chronically ill patients such as those suffering heart failure, COPD, and/or other diseases or medical conditions. Unwanted changes in physiology can be viewed remotely with treatment intervention before the patient becomes critically ill and requires hospital admission. Similarly, the remote patient monitoring and surveillance system may be used to monitor patients that are at high risk of complications but not critically ill. Such sub-acute patient populations include, but are not limited to, the elderly, individuals with dementia, inherently high risk patients with multiple health problems and stroke rehabilitation patients at risk for aspiration and sudden deterioration of death.

[00219] In one aspect of the patient monitoring system is that information acquired on the patient seamlessly integrates with existing hospital information technology infrastructure.

Examples

Example 1

[00220] FIG. 4A shows a signal processing unit **2** in close proximity of a transmitter device **6** along with a separate receiver **12**. A single antenna **8** is attached to the transmitter device and is depicted for simplicity, although multiple antennas may be used in the transmitter. An omni-directional signal **10** is transmitted and partially reflected by a patient **18** that is wearing a circular identification tag **20**. The partially reflected signal

16 is received by receiving antenna **14**. The signal processing unit **2** is configured to receive the frequency and phase information from both the transmitter and receiver device and is able to process the data to provide the vital signs, location, position and movement of patient **18** based on frequency and phase shifts between the transmitted signal and reflections of the transmitted signal. The circular identification tag **130** further provides the identity of patient **18** when receiving the transmitted signal and reflecting an identification signal. Here, the signal processing unit is connected to an optional monitor **4** which outputs the vital signs, location, position and movement of patient **18** along with his identity. Other configurations may exclude a monitor and relay the patient information directly to portable monitoring units.

Example 2

[00221] FIG. 4B depicts a two patient room monitoring set up with two patient rooms **26** and **32** with adjoined bathrooms **28** and **34** respectively. In the middle of both patient rooms, is transmitter radar device **22** which transmits an omni-directional signal **24** into both patient rooms. In the patient rooms, patient **30** is lying on the ground of bathroom **28** while patient **36** is slightly on the bed in an abnormal position. Both patients are wearing circular patient information tags.

Example 3

[00222] FIG. 10 is a display of two exemplary portable monitoring devices, **38** and **42**. The portable monitoring device is configured to have a visual display **40** and **44**. Display **40** and **44** displays information in four graphical panels that includes heart rate (HR), breathing rate (RR), position, and location of the two patients **30** and **36** of FIG. 4B as well as their identities, 'A' and 'B'. In display **40**, Patient A's heart rate, breathing rate, position and location are all outside of normal predetermined ranges which triggers an alarm on all four panels. In display **44**, Patient B has a heart rate, breathing rate and location within normal predetermined ranges, however has an abnormal position of 45 degrees that is at risk of falling from the bed which triggers an alarm.

Example 4

[00223] FIG. 11 is a display of exemplary portable monitoring device **46**. The portable monitoring device is configured to have a display **48**. Display **48** displays information of both patients **30** and **36** of FIG. 4B in text format simultaneously that includes heart rate (HR), breathing rate (RR), position, and location as well as their identities, 'A' and 'B'. FIG. 11 contains the same information as FIG. 10 in a different format.

Example 5

[00224] In a four patient ward, a patient monitoring system is configured to monitor patients C-F. Patient C is a 66 year old male admitted with nausea and vomiting. Patient D is a 78 year old female admitted with chest pain. Patient E is a 85 year old male admitted with confusion. Patient F is a 44 year old female admitted with overdose. A portable monitoring device receives information on patients C-F from the signal processing unit and renders the information into the following table:

	Patient C	Patient D	Patient E	Patient F
Heart Rate	88	**22**	65	**177**
Breathing Rate	20	**4**	16	**36**
Position	Flat above floor	Flat above floor	Standing	**Flat on floor**
Location	Bed	Bed	**Hall**	**Bath**

[00225] Table values surrounded in asterisks, **, indicate an alarm notification. The above table shows that Patient C currently lying in bed with vital signs within a normal range. Patient D is lying in bed with critically low heart and breathing rates. Patient E has normal vital signs and position, however an alarm triggers his position in the hall due to his location parameter being limited to only his room. Patient F has alarm notifications on all parameters due to lying in the bath with an above normal heart and breathing rate.

[00226] Additional monitoring parameters may include detecting the direction of the position, e.g., flat on back or flat on the face in the case of Patient F as well as movement speed and direction of Patient E.

Example 6

[00227] A through-wall radar may be used for constant monitoring of people in environments where knowledge of their location is a safety issue. By itself, the device can locate (in range) faintly moving targets such as sleeping people in its field of view, but it cannot alone positively identify particular individuals. An RFID (Radio Frequency Identification) tag may be added to the device to provide identity verification.

[00228] In some embodiments, the radar is a hand-held, battery operated device that includes a homodyne microwave transceiver that operates in an FCC-allocated radiolocation (radar) frequency band (3.1-3.4 GHz) and a DSP-based (digital signal processing-based) computer that runs the target identification algorithm. (http://www.ntia.doc.gov/osmhome/allochrt.pdf) The transceiver generates its frequencies from a voltage controlled oscillator (VCO) that has a tuning range of 3100-3600 MHz (3.1-3.6 GHz). Frequencies beyond this range require changing the VCO and passive filters in the transceiver, and frequencies outside this operating band may require alternative transmit and receive filters.

[00229] The transceiver samples each of two receive antennas at each of 120 frequency steps that are utilized at a rate of just under 7 kHz (i.e. at most 7kHz, 5-7kHz, 6-7kHz, 6.5-7kHz, 6.7-7kHz), an overall sample rate of about 14 kHz, (i.e. 14+/- 1kHz, or 14+/- 5kHz). In another embodiment, the transceiver samples each of two receive antennas at each of at least 50 frequency steps that are utilized at a rate of at most 10 kHz. In another embodiment, the transceiver samples each of two receive antennas at each of at least 50 frequency steps that are utilized at a rate of at most 7 kHz. In another embodiment, the transceiver samples each of two receive antennas at each of at least 75 frequency steps that are utilized at a rate of at most 10 kHz. In another embodiment, the transceiver samples each of two receive antennas at each of at least 75 frequency steps that are utilized at a rate of at most 7 kHz. In another embodiment, the transceiver samples each of two receive antennas at each of at least 100 frequency steps that are utilized at a rate of at most 10 kHz. In another embodiment, the transceiver samples each of two receive antennas at each of at least 100 frequency steps that are utilized at a rate of at most 7 kHz. In another embodiment, the transceiver samples each of two receive antennas at each of at least 120 frequency steps that are utilized at a rate of at most 10 kHz. In another embodiment, the transceiver samples each of two receive antennas at each of at least 120 frequency steps that are utilized at a rate of at most 7 kHz. In another embodiment, the transceiver samples each of two receive antennas at each of at least 150 frequency steps that are utilized at a rate of at most 10 kHz. In another embodiment, the transceiver samples each of two receive antennas at each of at least 150 frequency steps that are utilized at a rate of at most 7 kHz. In another embodiment, the transceiver samples each of two receive antennas at each of at least 200 frequency steps that are utilized at a rate of at most 10 kHz. In another embodiment, the transceiver samples each of two receive antennas at each of at least 200 frequency steps that are utilized at a rate of at most 7 kHz. In another embodiment, the transceiver samples each of two receive antennas at each of at least 200 frequency steps that are utilized at a rate of at most 5 kHz. In another embodiment, the transceiver samples each of two receive antennas at each of at least 200 frequency steps that are utilized at a rate of at most 20 kHz. In another embodiment, the transceiver samples each of two receive antennas at each of at least 50 frequency steps that are utilized at a rate of at most 5 kHz. In another embodiment, the transceiver samples each of two receive antennas at each of at least 50 frequency steps that are utilized at a rate of at most 20 kHz.

[00230] If two samples are allowed per symbol period, the device receiver could be pressed into service receiving digital data at a symbol rate of about 7000 symbols per second (i.e. 7000 +/- 500, 500-9000, 6500-7500, 6000-8000, 6750 to 7250, 6900-7100 or 6950-7050 symbols per second) , although QAM or other sophisticated coding could increase the number of bits per symbol received to achieve higher throughput, such as 10k symbols per second, 14k symbols per second, 15k symbols per second, 20k symbols per second, 21k symbols per second, less than 27k symbols per second, at most 27k symbols per second, 35k symbols per second, or 70k symbols per second, at most 100k symbols per second, at most 120k symbols per second, at most 125 symbols per second, or at most 128 symbols per second.

[00231] Commercially available RFID tags all operate in one of several unlicensed Industrial Scientific and Medical (ISM) frequency bands. There are no ISM bands that are within the tuning range of the VCO used in the device radar system described above in this Example. In Florida, the credit card-sized passive Sunpass Mini transponder sticker, a TransCore eGo Plus tag, operates in the 915 MHz band (considered within an ISM band). More common tags, like those used to track books in libraries, work at the 13 MHz HF band. Some work at 125 kHz, and are classified as LF devices. Wavetrend's Domino L-TG100 active tag operates at 433 MHz and the similar GAO active tag and has an operating bandwidth of 1 MHz, implying a relatively high data rate. Thus operation within the ISM or within a band outside of an ISM bands is contemplated, including in the VCO range of 3.1-3.6 GHz or in another range outside of the VCO range of 3.1-3.6 GHzPassive tags, which are energized by the reader and have no power supply of their own, have a limited reading range due to their inherently low-power nature. Nevertheless, passive tags may be used depending on requirements of the reader and application for which the tag is used. Moreover, as the ability for passive tags to be powered remotely improves, such tags themselves may be more sophisticated in complexity and range. Alternatively, active tags usually operate off button cell batteries and have a limited shelf life. They may also be larger but have greater reading ranges due to their relatively high transmit power. A combination of active and passive tags may be used to increase the overall life of the tag. For example, for activities that require low power or of simple complexity, the tag may run on power received from the reader device itself, whereas for more complex activities, the battery power may be used.

[00232] RFID tags use simple on/off type keying system at data rates of 27 to 128 kilobits per second, faster than the device sample rate in this Example, where ones and zeros are encoded as either the absence or presence of a level shift halfway through the symbol period. The ISM frequencies utilized and (moderately) high data rates make it unlikely that a system described in this Example could be pressed into service as a reader for current commercial RFID tags. Nevertheless, in some embodiments, such RFID tags may be utilized and a reader as described herein could be adapted to be compatible with such RFID tags.

[00233] An analogous situation, where identity is as important as location, air traffic control has for many years made use of secondary radar using transponders in aircraft that respond to repeated interrogation from ground-based systems with antennas co-located with primary "skin paint" ATC radar antennas. Making use of frequencies allocated for aeronautical radionavigation, the Air Traffic Control Radar Beacon System (ATCRBS) ground station transmits a special three-burst interrogation at 1030 MHz that is received by the aircraft-mounted transponders. Depending on the timing of the interrogation bursts, the transponder replies on 1090 MHz with either the selected four-digit octal identification code ("Mode A" or "Mode 3/A") or the aircraft altitude, encoded as a four-digit octal number ("Mode C").

[00234] There is no collision detection or other interference-avoiding mechanisms used; all aircraft in the illuminated search volume will respond to the ATCRBS interrogation signal. A “more recent” version of the ATCRBS system, known as Mode S provides for addressing and interrogating individual aircraft, not just all aircraft at which the radar antenna is pointing, reducing over-the-air traffic on the allocated communication frequencies.

[00235] IEEE 802.11 wireless networking uses a similar system for collision (two nodes transmitting at the same time) avoidance as wired Ethernet networking-- Carrier sense multiple access with collision avoidance (CSMA/CA). Before a node transmits, it monitors the communication channel and waits for a duration of channel inactivity before commencing its transmission. If the channel is or becomes busy, the node waits a random period of time before attempting to use the channel again.

[00236] While CSMA/CA works well for environments where many nodes are present and each node on the network can independently initiate communication with other nodes. Other wireless options, such as Bluetooth or ZigBee are aimed at more master/slave type topologies, but operate in the 2.4 GHz ISM band and have data rates that are beyond the device receiver’s capabilities (i.e. of the device noted in this Example). Nevertheless, in some embodiments, the device receiver could be adapted to operate to receive data at rates noted herein, or outside the rates noted in this Example.

[00237] FCC acceptance of a device as described herein requires its continued operation in a radiolocation (radar) allocation; moving to an ISM band is possible, but may expose the radar to interfering signals that may degrade its detection performance. An alternative route would be to design transponder tags that are designed for the device hardware compatibility as described herein.

[00238] First the device tag operates in the device’s 3.1-3.4 GHz frequency range. The tags could be made physically small. Similar to other active (powered) tags, the tag in some embodiments would utilize a button cell battery. Although passive tags are desirable for low-cost and reliability, the device power output precludes the operating range required in some embodiments. For example, a one-inch square tag located three meters from the device transmit antenna would receive only -42 dBm (about 60 micro-watts) of power.

[00239] Like ATCRBS, the tag in some embodiments utilize a simple message system and a data rate of no more than 7 kilobits per second. If a 32-bit integer is used as the tag code, more than four billion distinct tags would be possible. Coding that 32-bit number in, for example, a forty-bit transmission, and assuming simple on-off keying modulation would require a transmission period of six milliseconds. In some embodiments, thus, the identification can be transmitted in 6 milliseconds, at most 6 milliseconds, about 6 milliseconds, 4-8 milliseconds, 10 milliseconds, at most 10 milliseconds, at most 25 milliseconds, at most 30 milliseconds, at most 50 milliseconds, at most 100 milliseconds, or about 10 milliseconds. As used with regard to transmission speed, the term “about” means a variation of 5%, 10% or 25% of the given time.

[00240] In some embodiments, the tag provides no more than four meters of detection range, enough to cover a normal-sized room. A link budget analysis may provide the actual transmit power required. In some embodiments, the tag provides at least 1 meters of detection range, at least 2 meters of detection range, at least 3 meters of detection range, at least 4 meters of detection range, at least 5 meters of detection range, at least 6 meters of detection range, at least 7 meters of detection range, at least 8 meters of detection range, at least 9 meters of detection range, at least 10 meters of detection range, at least 12.5 meters of detection range, at least 15 meters of detection range, at least 17.5 meters of detection range, at least 20 meters of detection range, at least 25 meters of detection range, at least 30 meters of detection range, at least 40 meters of detection range range, at least 50 meters of detection range, and/or at least 100 meters of detection range.

[00241] Borrowing from 802.11, the tag in some embodiments provides simple collision avoidance by waiting a random number of transmit periods before transmitting. Multiple interrogation/response events would overcome random interference from multiple tags transmitting at once.

[00242] The device software may be modified such that periodically, that stepped-frequency continuous wave (SFCW) signal normally produced is stopped and a single frequency is produced. On-off keying the single frequency tone would then be used to trigger the tags in the room (i.e. the tags that are within range). After waiting for a preset period to receive all the tag replies, the normal radar signal is restored and target (i.e. subject or patient) detection resumes.

[00243] In some embodiments, nevertheless, the radar includes a transceiver that operates in any one or more of the ULF (ultra low frequency) 300-3000Hz, VLF (very low frequency) 3-30 kHz, LF (low frequency) 30-300 KHz, MF (medium frequency) 300-3000 kHz, HF (high frequency) 3-30 MHz, VHF (very high frequency) 30-300 MHz, UHF (ultra high frequency) 300 MHz to 3 GHz, L(long wave) 1-2 GHz, SHF (super high frequency) 3-30 GHz, S (short wave) 2-4 GHz, C (compromise between S and X bands) 4-8 GHz, X (cross) 8-12 GHz, Ku (Kurz under) 12-19 GHz, K (Kurz) 18-27 GHz, EHF (extremely high frequency) 30-300 GHz, Ka (Kurz above) 27-40 GHz, V 40-75 GHz, W 75-110 GHz, or mm 110-300 GHz radio bands. The transceiver of such a device generates its frequencies from a voltage controlled oscillator (VCO), or from an appropriate waveform generator that has a tuning range within the desired radio band. In some embodiments, the radar includes a transceiver that operates in any one or more of the ISM radio bands. ISM stands for Industrial, Scientific, and Medical radio bands typically reserved internationally for non-commercial use of RF fields for ISM purposes. The transceiver of such a device generates its frequencies from a voltage controlled oscillator (VCO), or from an appropriate waveform generator that has a tuning range within any ISM radio band. ISM bands may change by region, thus any region's ISM ranges are contemplated herein. For non-limiting example, within the HF band: 6.765-6.795 MHz, 13.553-13.567 MHz, or 26.957-27.283 MHz; within the VHF band: 40.660-40.700 MHz; within the UHF band: 433.050-434.790 MHz, or 902-928 MHz; within the SHF band: 2.4-2.4835 GHz (which also falls within the S band), 2.4-2.5 GHz (which also falls within the S band), 5.725-5.875 GHz (which also falls within the C band), or 24-24.25 GHz (which also falls within the K band); or within the EHF band: 61-61.5 GHz (which also falls within the V band), 122-123 GHz (which also falls within the mm band), or 244-246 GHz (which also falls within the mm band).

[00244] While preferred embodiments of the present invention have been shown and described herein, it will be obvious to those skilled in the art that such embodiments are provided by way of example only. Numerous variations, changes, and substitutions will now occur to those skilled in the art without departing from the invention. It should be understood that various alternatives to the embodiments of the invention described herein may be employed in practicing the invention. It is intended that the following claims define the scope of the invention and that methods and structures within the scope of these claims and their equivalents be covered thereby.

CLAIMS

WHAT IS CLAIMED IS:

1. A system for remote monitoring of a subject, said system comprising:
a device comprising a transceiver adapted for transmission of a stepped-frequency radar signal and receipt of reflections of the transmitted signal;
a signal processing unit configured to generate and analyze frequency and/or phase shifts between the transmitted signal and reflections of the transmitted signal data from the subject,
wherein the device is adapted to trigger the tag to send identification information about the subject to the device,
wherein the device is adapted to receive the identification from the tag, and
wherein the signal processing unit of the device comprises a digital signal processing- based computer that runs a target identification algorithm wherein the identification comprises a subject's location, movement, position, vital signs, or a combination thereof.

2. The system of claim 1, wherein the transceiver is a homodyne microwave transceiver.

3. The system of claim 1, wherein the device operates in an FCC-allocated radiolocation (radar) frequency band (3.1-3.4 GHz).

4. The system of claim 1, wherein the transceiver generates its frequencies from a voltage controlled oscillator (VCO) that has a tuning range of 3.1-3.6 GHz.

5. The system of claim 1, wherein the device operates in outside of an ISM band.

6. The system of claim 1, wherein the device operates in within an ISM band.

7. The system of claim 1, wherein the transceiver samples each of two receive antennas at each of 120 frequency steps that are utilized at a rate of at most 7 kHz.

8. The system of claim 1, wherein the transceiver has an overall sample rate of about 14 kHz.

9. The system of claim 1, wherein the transceiver samples each of two receive antennas at each of 50 frequency steps that are utilized at a rate of at most r 5 kHz.

10. The system of claim 1, wherein the transceiver samples each of two receive antennas at each of 50 frequency steps that are utilized at a rate of at most 20 kHz.

11. The system of claim 1, wherein the transceiver samples each of two receive antennas at each of 200 frequency steps that are utilized at a rate of just at most 20 kHz.

12. The system of claim 1, wherein the a receiver of the transceiver receives digital data at a rate of 500-9000, 6500-7500, 6000-8000, 6750 to 7250, 6900-7100 or 6950-7050 symbols per second.

13. The system of claim 1, wherein the device receives data at a sample rate of less than 27 kilobits per second.

14. The system of claim 1, wherein the device receives data at a sample rate of less than 128 kilobits per second.

15. The system of claim 1, wherein the tag emits at a data rate of no more than 7 kilobits per second.

16. The system of claim 1, wherein the tag comprises a battery.

17. The system of claim 1, wherein the tag is powered by the device.

18. The system of claim 1, wherein the tag uses a simple message system comprising on-off keying modulation.

19. The system of claim 18, wherein the on-off keying modulation comprises ones and zeros encoded as either the absence or presence of a level shift halfway through a symbol period.

20. The system of claim 1, wherein the tag can transmit the identification in a transmission period of six milliseconds.

21. The system of claim 1, wherein the tag can transmit the identification in a transmission period of at most 6 milliseconds, about 6 milliseconds, 4-8 milliseconds, 10 milliseconds, at most 10 milliseconds, at most 25 milliseconds, at most 30 milliseconds, at most 50 milliseconds, at most 100 milliseconds, or about 10 milliseconds.

22. The system of claim 1, wherein the tag provides at most four meters of detection range.

23. The system of claim 1, wherein the tag provides at least 1 meters of detection range, at least 2 meters of detection range, at least 3 meters of detection range, at least 4 meters of detection range, at least 5 meters of detection range, at least 6 meters of detection range, at least 7 meters of detection range, at least 8 meters of detection range, at least 9 meters of detection range, at least 10 meters of detection range, at least 12.5 meters of detection range, at least 15 meters of detection range, at least 17.5 meters of detection range, at least 20 meters of detection range, at least 25 meters of detection range, at least 30 meters of detection range, at least 40 meters of detection range, at least 50 meters of detection range, and/or at least 100 meters of detection range.

24. The system of claim 1, wherein the tag provides simple collision avoidance by waiting a random number of transmit periods before transmitting.

25. The system of claim 1, wherein the device comprises software that comprises a stepped-frequency continuous wave (SFCW) signal normally produced that is stopped and a single frequency tone is produced.

26. The system of claim 1, wherein the device emits a single frequency tone.

27. The system of claim 26, wherein on-off keying the single frequency tone triggers the tag if it is within range.

28. The system of claim 26, wherein on-off keying the single frequency tone triggers any other tag within range.

29. The system of claim 1, wherein the device waits for a preset period to receive all tag replies.

30. The system of claim 29, wherein once the preset period to receive replies ends, a normal radar signal is restored and target detection resumes.

31. The system of claim 1, wherein said system comprises multiple tags to enhance detection of a patient's location, movement, position, vital signs, or a combination thereof.

32. The system of claim 1, wherein said system further comprises at least one small integrated circuit for measuring biopotentials.

33. The system of claim 32, wherein said biopotentials are selected from the group consisting of ECG, EEG, EMG, oxygen saturation, temperature, blood pressure, glucose, action potentials and local field potentials.

34. A method for remotely monitoring a subject using a system comprising a device that is remote from the subject and a tag on the subject, said method comprising:

the device determining by emission and receipt of a reflection of a stepped-frequency continuous wave (SFCW) signal if:

a subject is within range of the device, or

whether a subject has new information to be monitored,

or a combination thereof;

the device transmitting a single frequency tone;

the device on-off keying the single frequency tone to trigger the tag on the subject;

the tag emitting a reply, wherein the reply relates the subject’s location, movement, position, vital signs, or a combination thereof;

the device receiving the reply from the tag;

the device analyzing reply to determine a subject's location, movement, position, vital signs, or a combination thereof; and

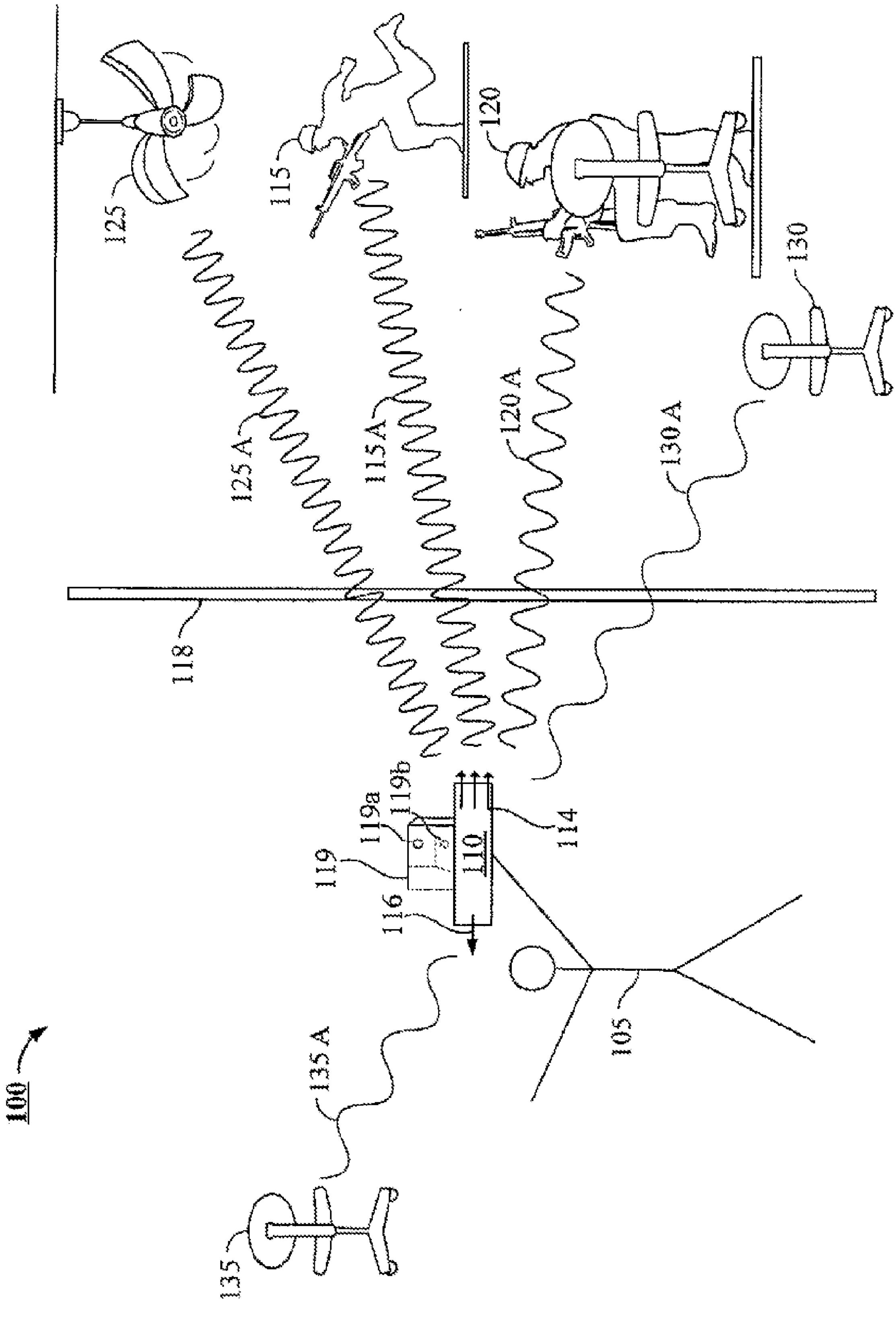
the device emitting a stepped-frequency continuous wave signal once the reply is received from the tag.

35. The method of claim 34, wherein the device waits a preset period for the reply from the tag.

36. The method of claim 34, wherein said vital signs comprise heart rate, heart rhythm, breathing rate, breathing rhythm or a combination thereof.

37. The method of claim 34, wherein said position comprises standing upright, sitting down, lying flat, or a combination thereof.

38. The method of claim 34, said method further comprising measuring a patient's biopotentials.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125
115
120
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115 A
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119a
119b
119
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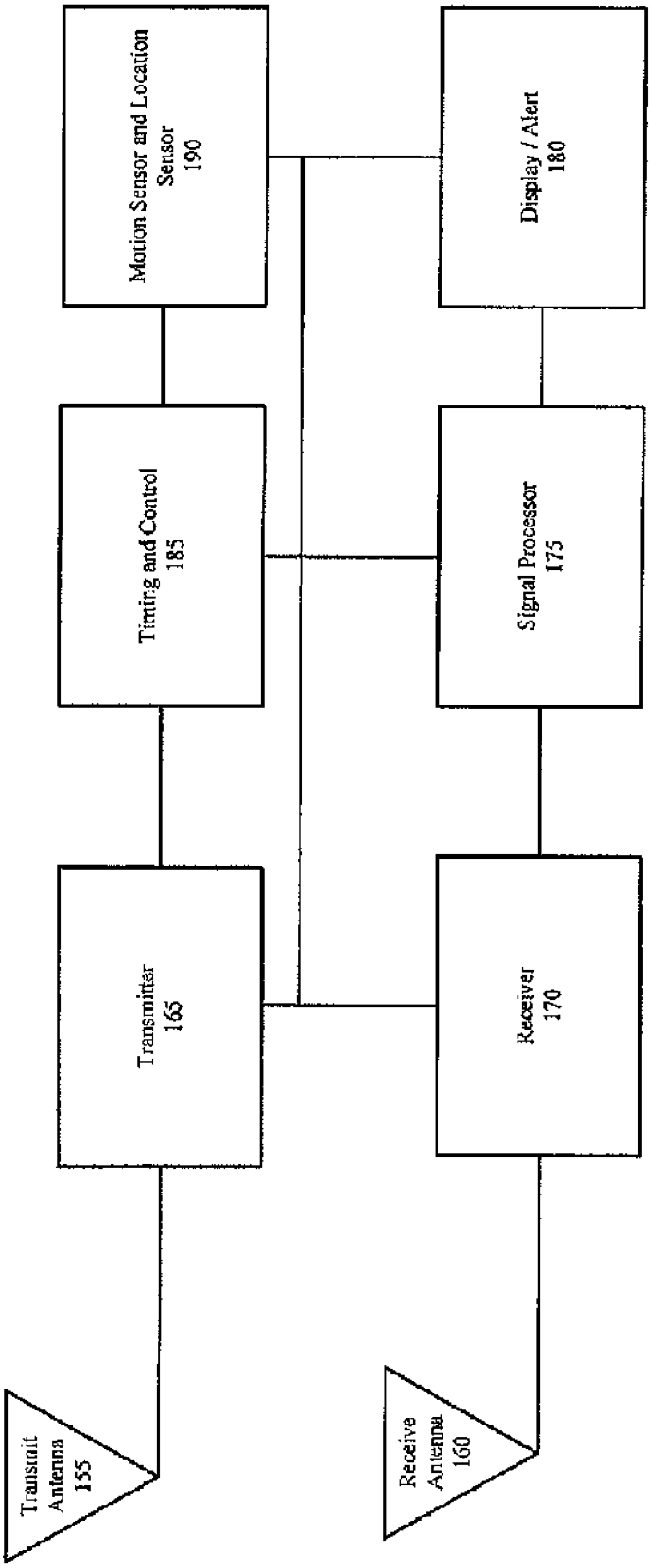
114
105
135 A
135

FIG. 1A

150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Display / Alert 180
Timing and Control 185
Signal Processor 175
Transmitter 165
Receiver 170
Transmit Antenna 155
Receive Antenna 160

FIG. 1B

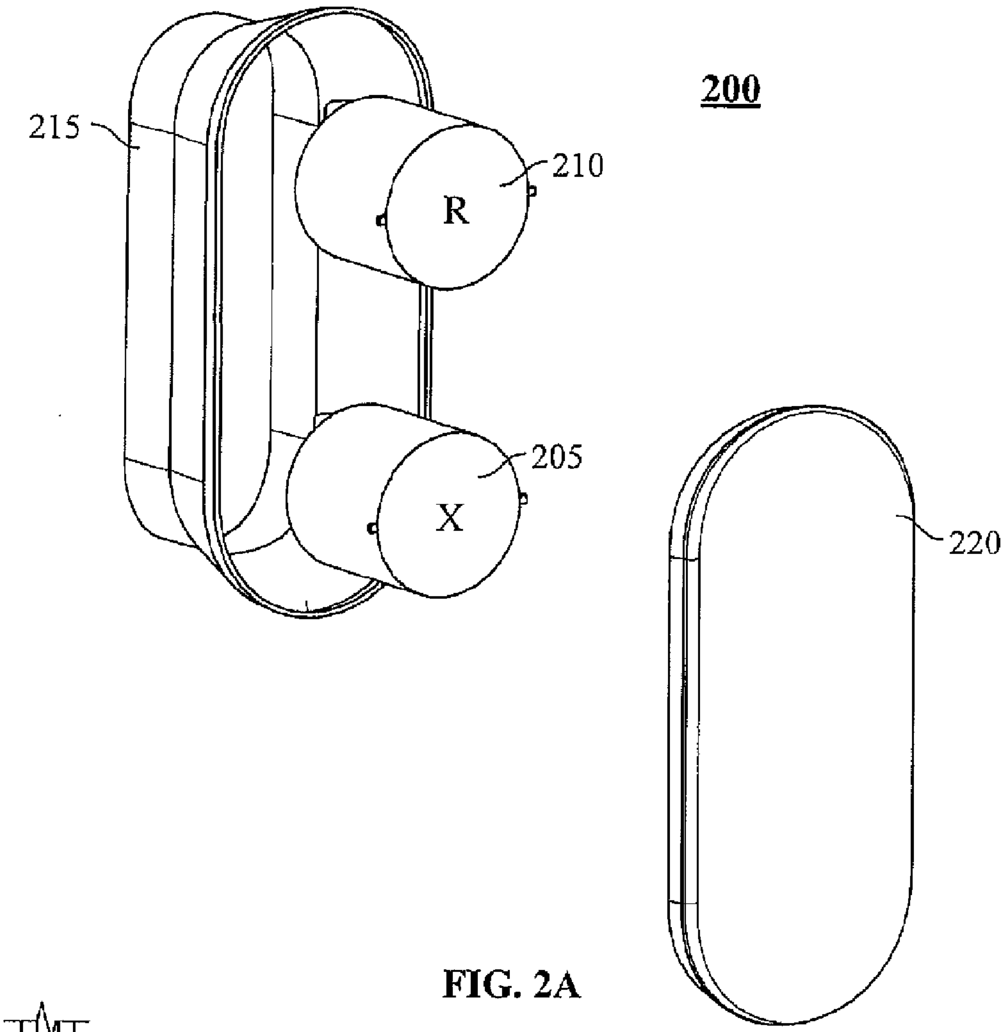


FIG. 2A

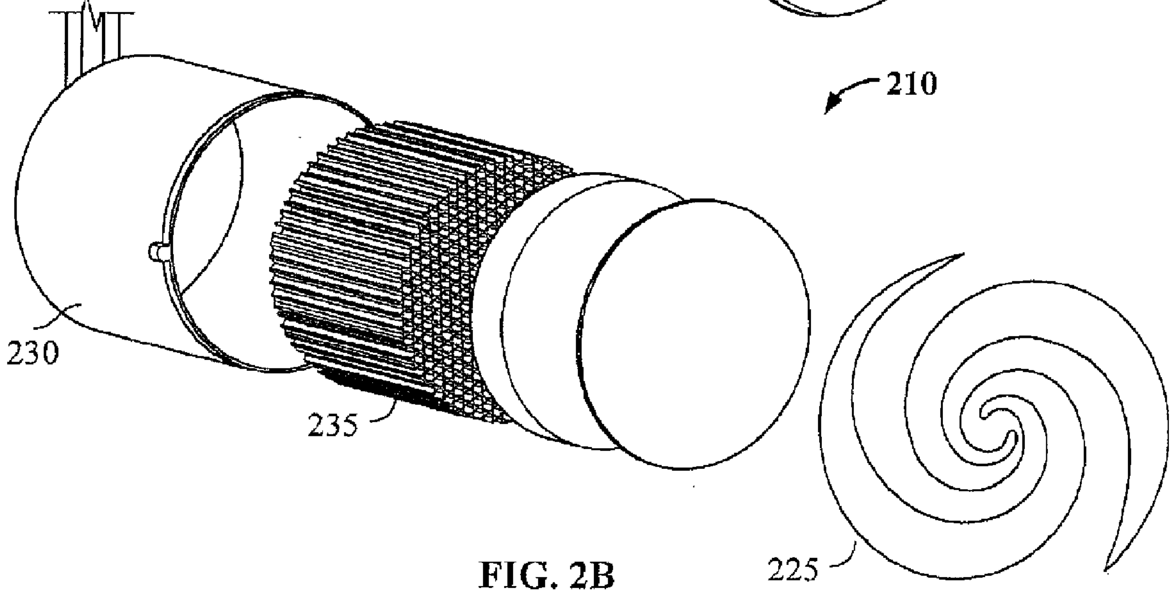


FIG. 2B

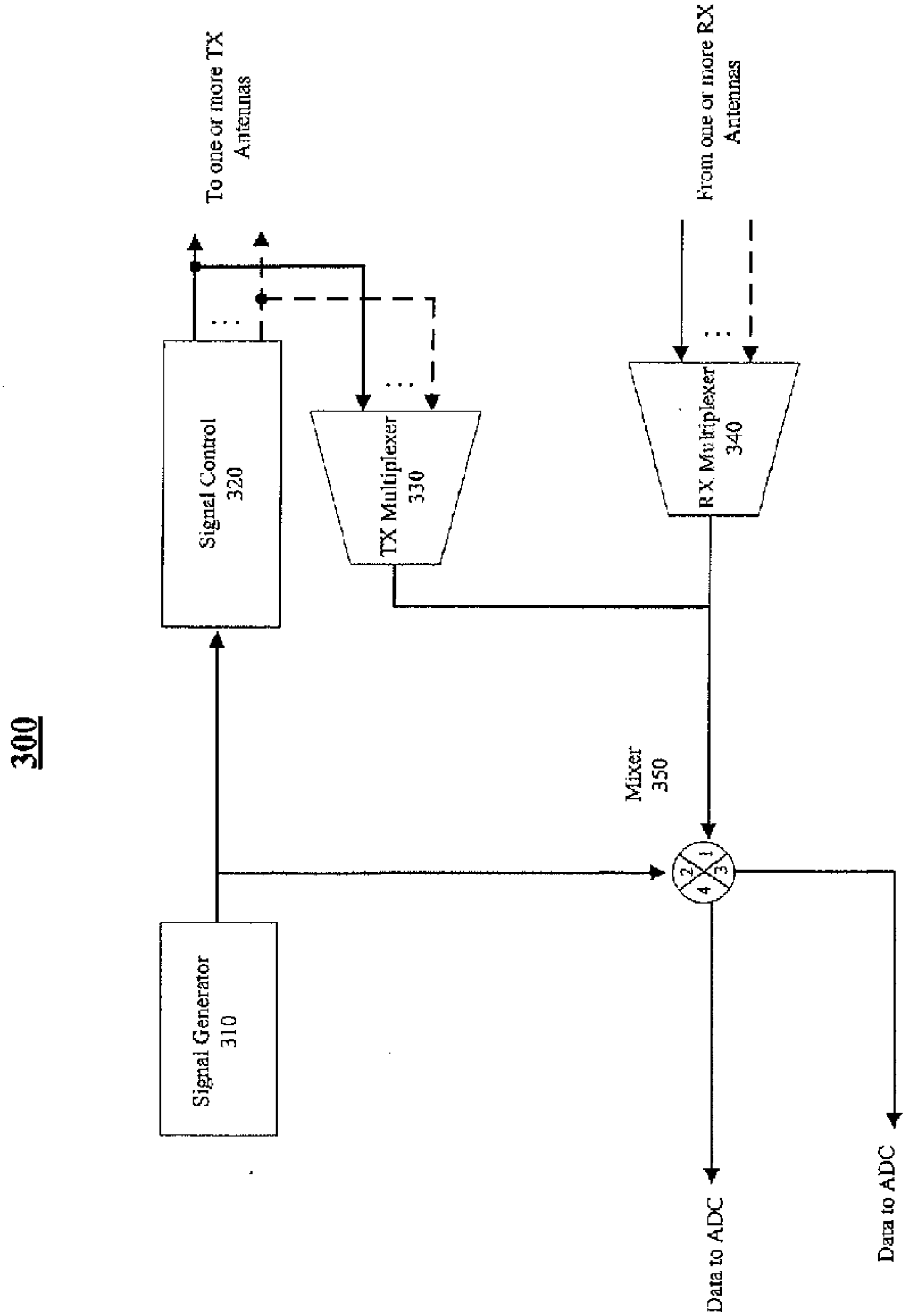

300
To one or more TX Antennas
From one or more RX Antennas
Signal Control 320
TX Multiplexer 330
RX Multiplexer 340
Mixer 350
Signal Generator 310
Data to ADC
Data to ADC

FIG. 3

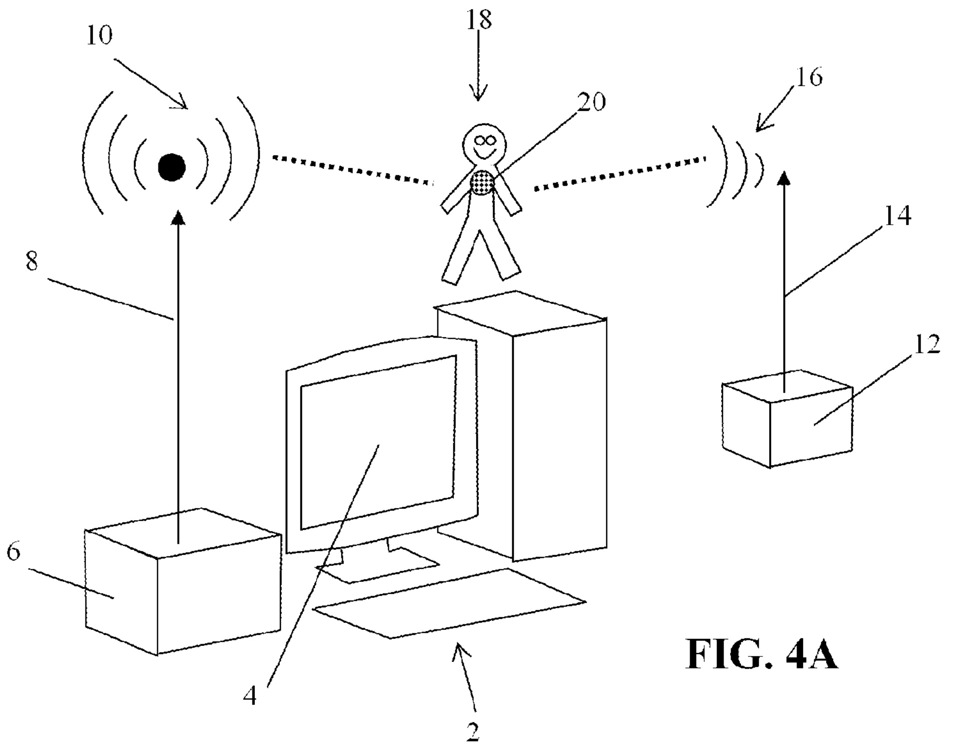


FIG. 4A

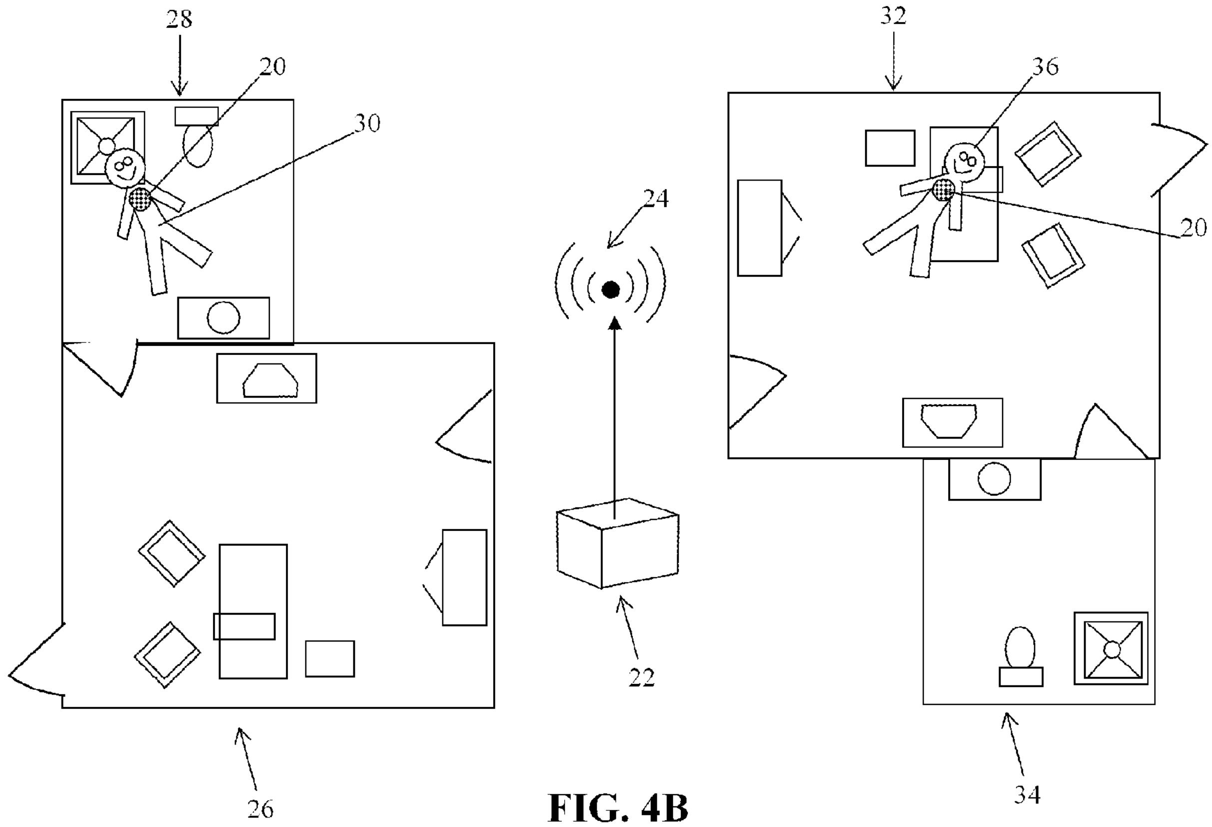


FIG. 4B

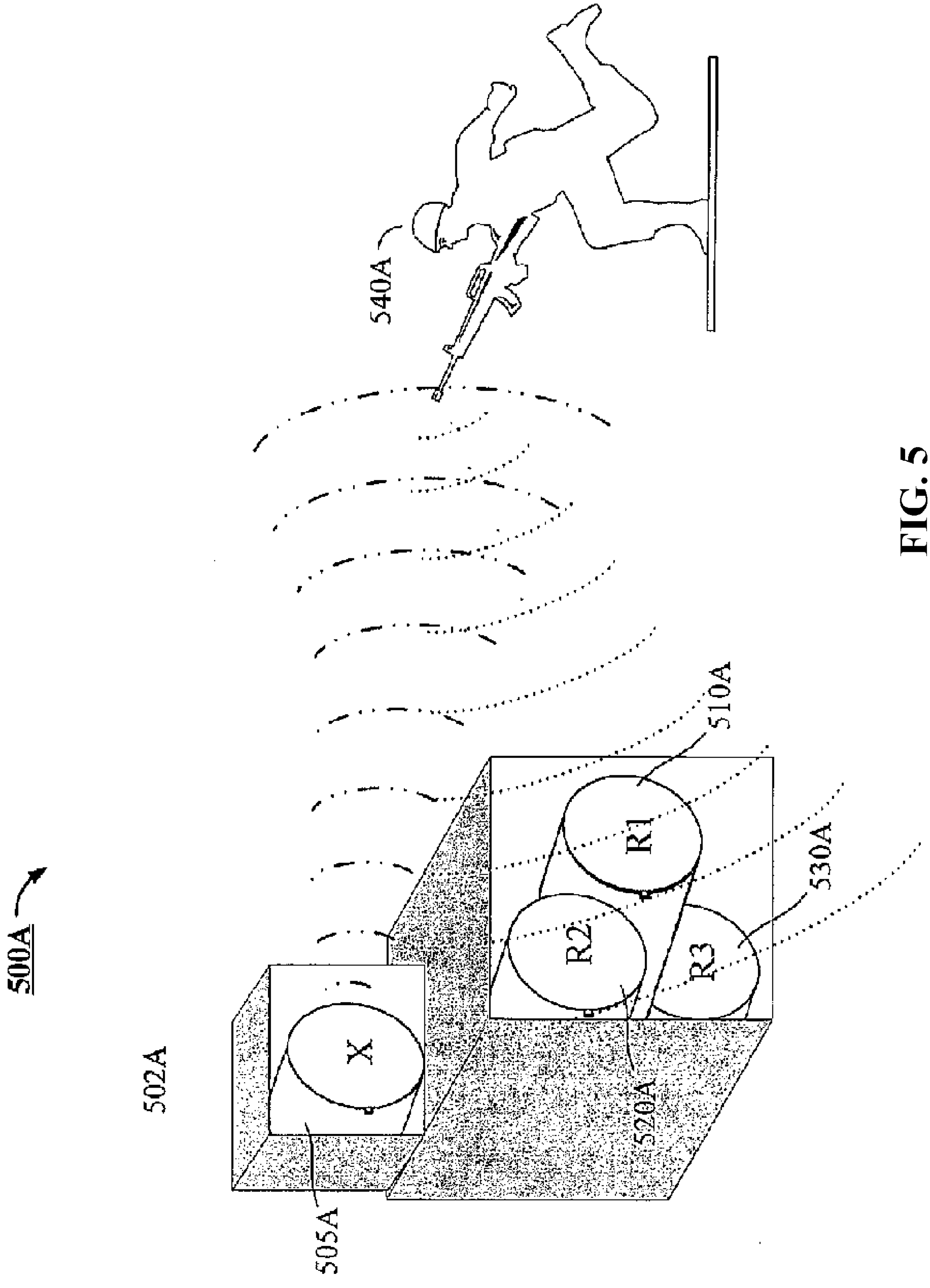


FIG. 5

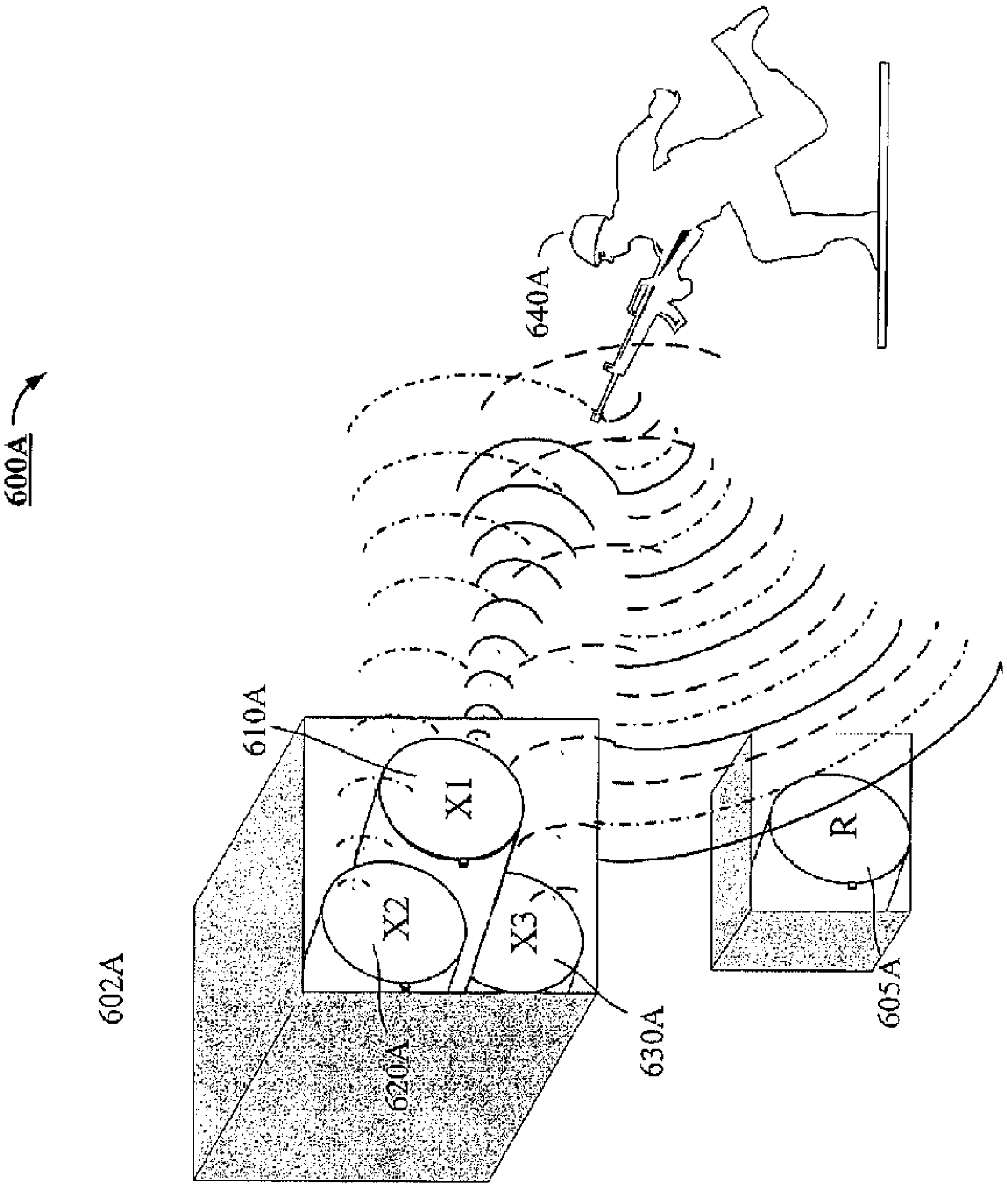


FIG. 6

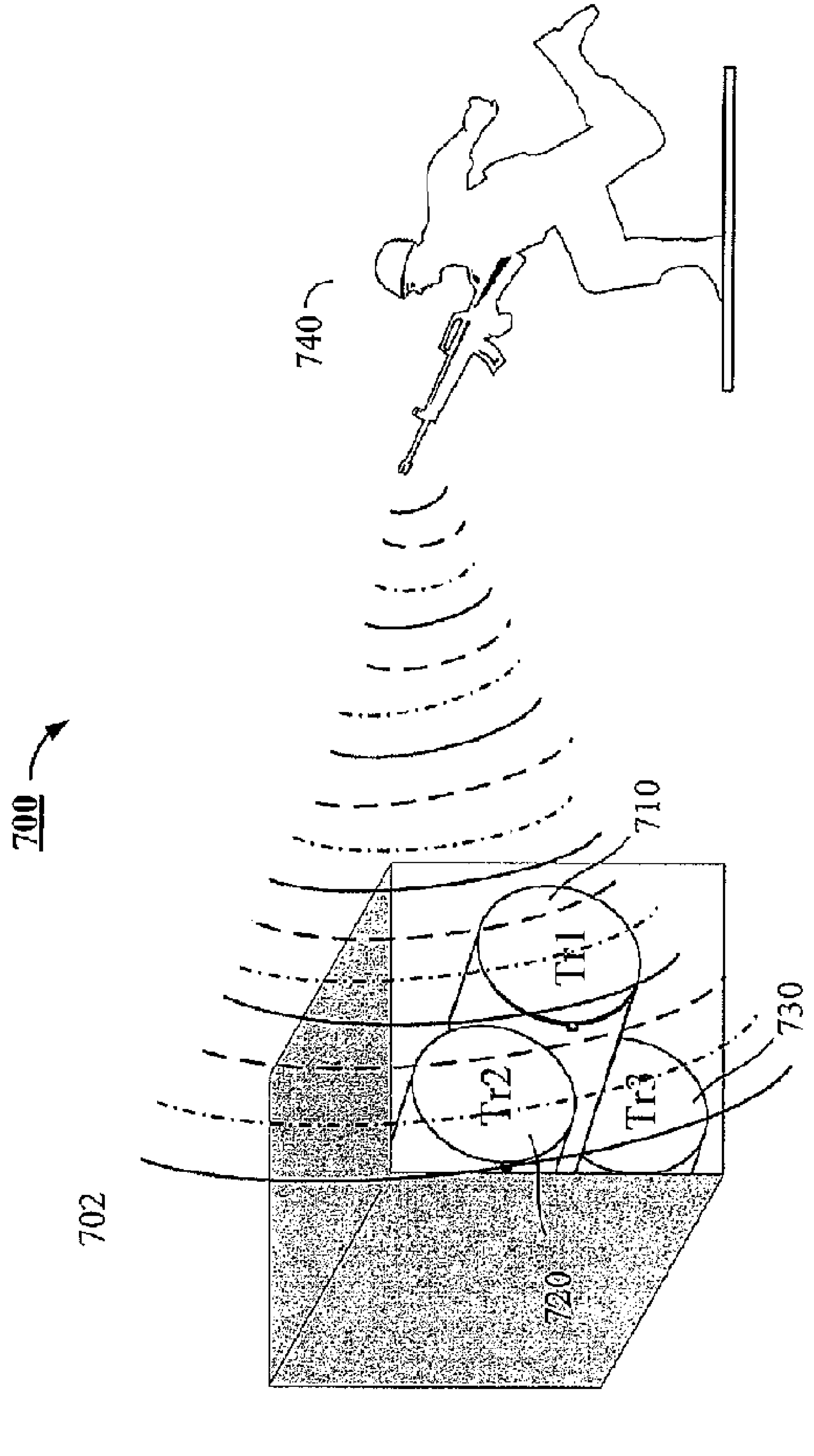


FIG. 7

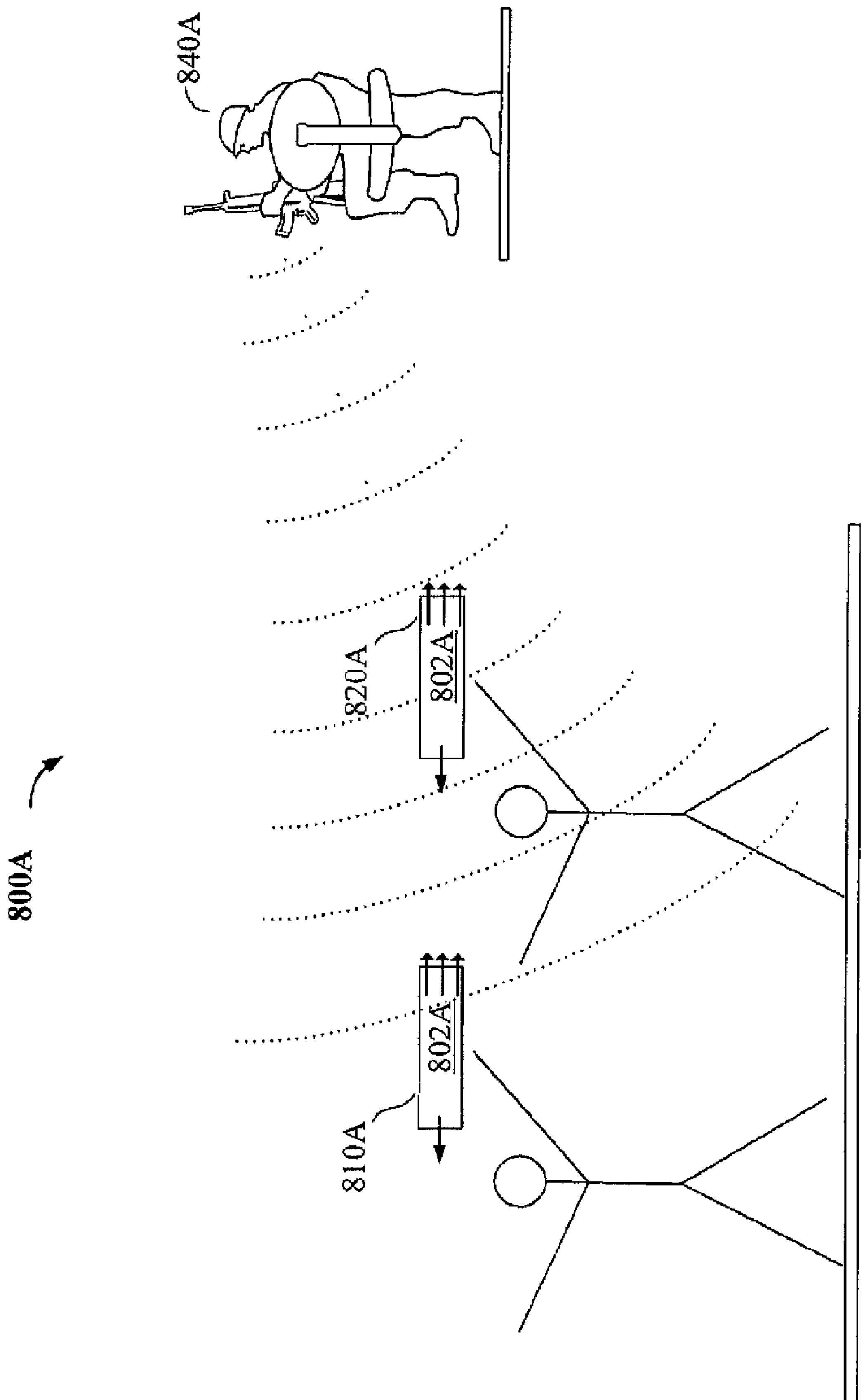


FIG. 8

900A

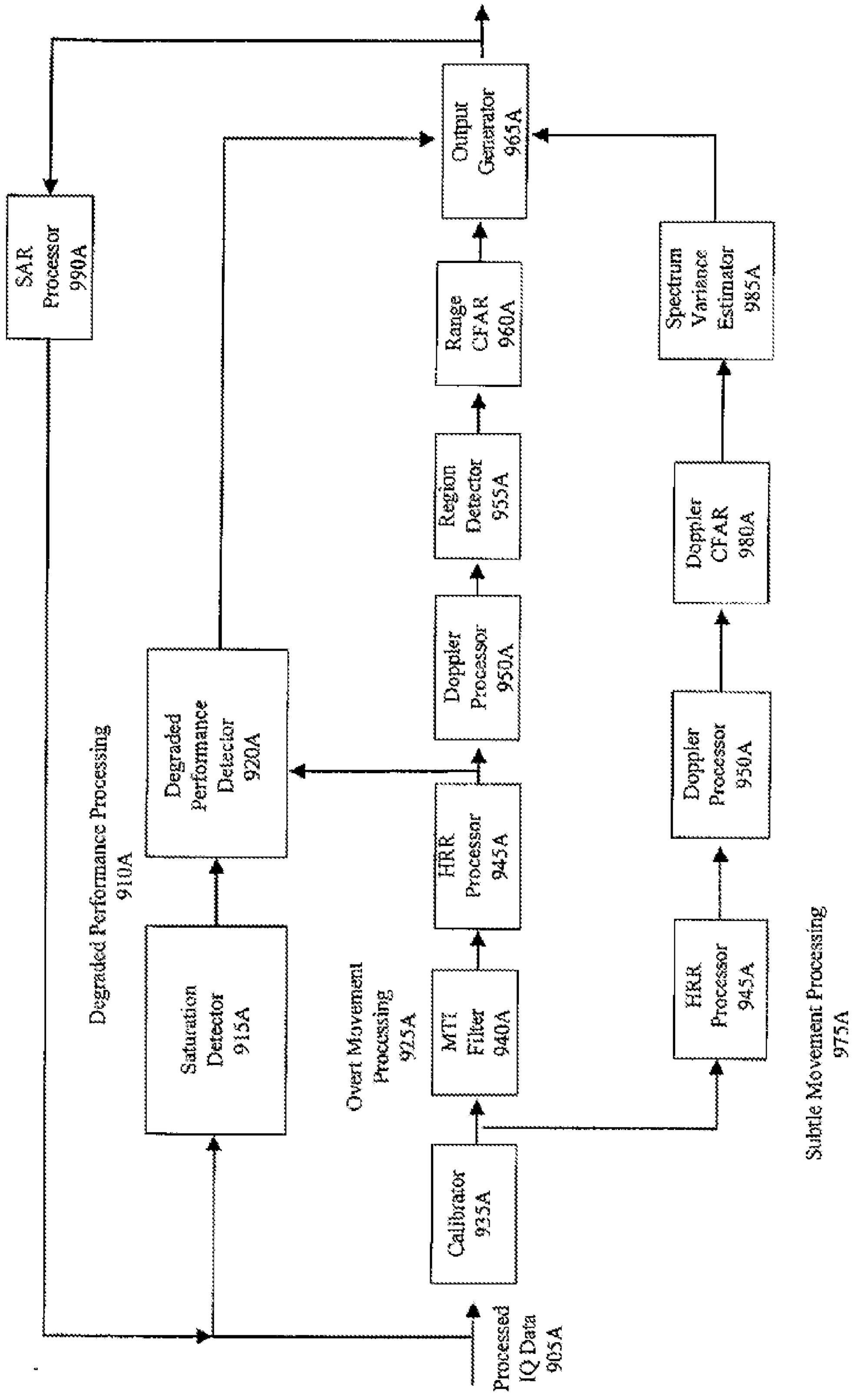

Processed IQ Data 905A
Degraded Performance Processing 910A
Saturation Detector 915A
Degraded Performance Detector 920A
SAR Processor 990A
Overt Movement Processing 925A
Calibrator 935A
MTI Filter 940A
HRR Processor 945A
Doppler Processor 950A
Region Detector 955A
Range CFAR 960A
Output Generator 965A
Subtle Movement Processing 975A
HRR Processor 945A
Doppler Processor 950A
Doppler CFAR 980A
Spectrum Variance Estimator 985A

FIG. 9

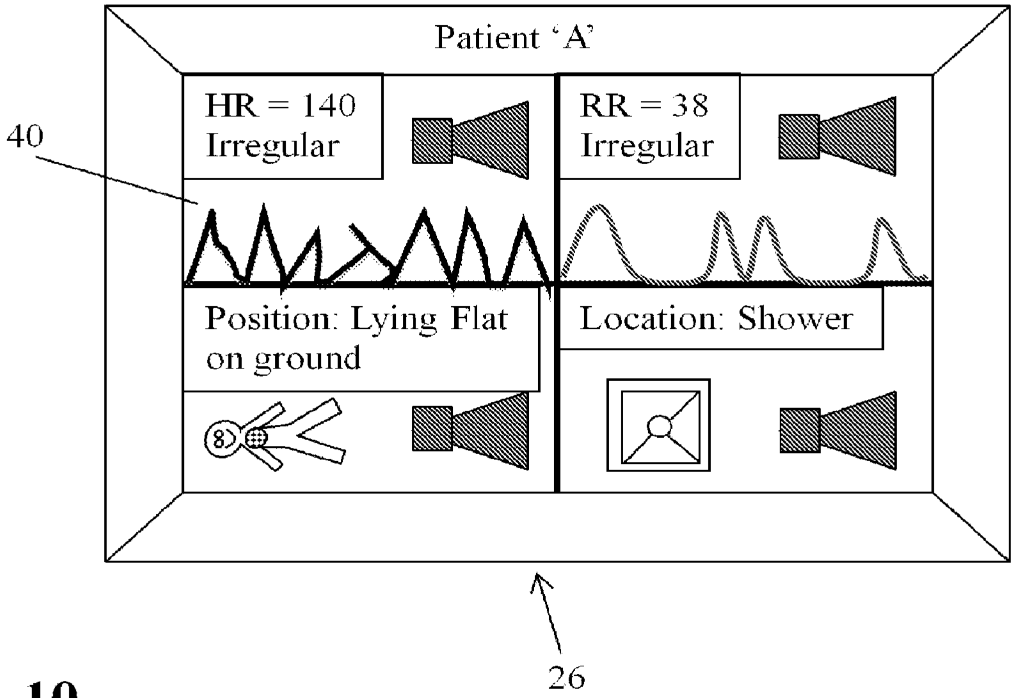

Patient 'A'
HR = 140
Irregular
RR = 38
Irregular
Position: Lying Flat on ground
Location: Shower
40
26

FIG. 10

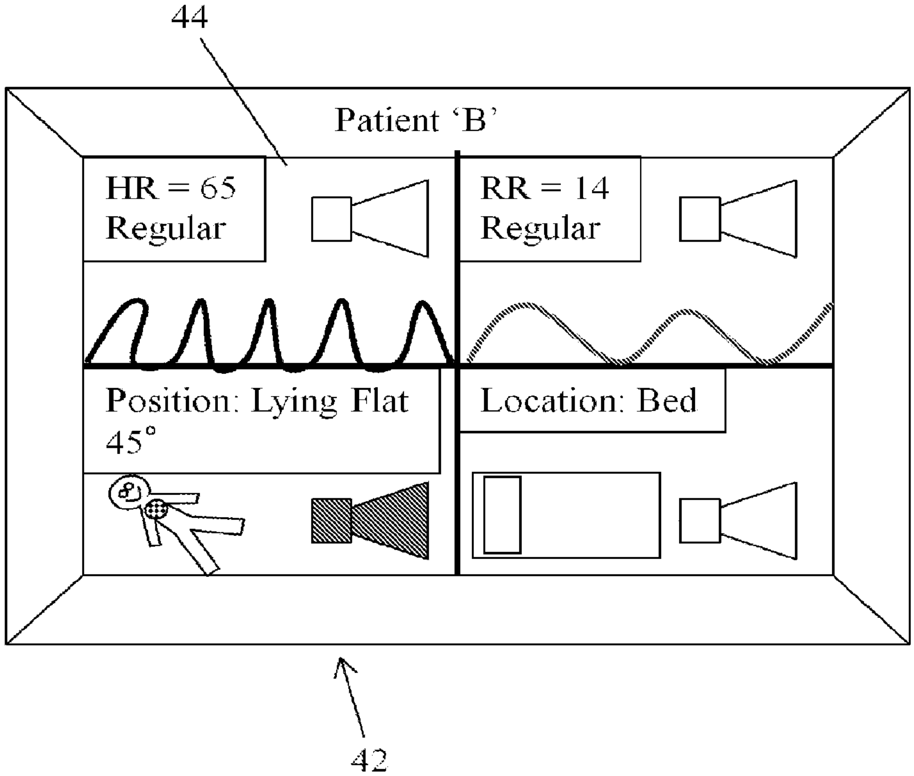
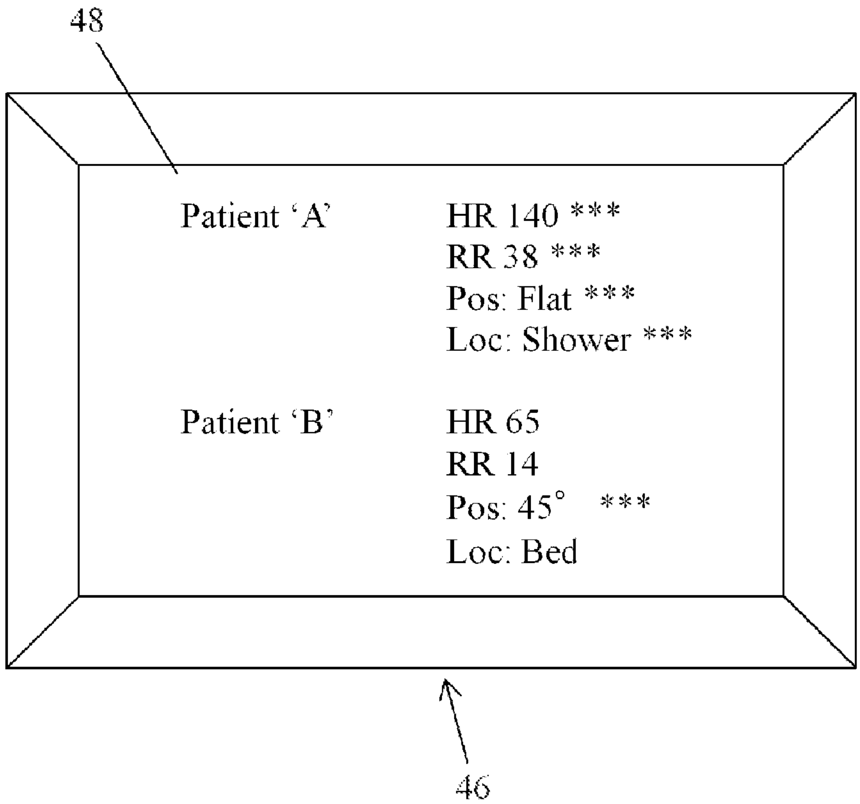

44
Patient 'B'
HR = 65
Regular
RR = 14
Regular
Position: Lying Flat 45°
Location: Bed
42

FIG. 11


48
Patient 'A'
HR 140 ***
RR 38 ***
Pos: Flat ***
Loc: Shower ***
Patient 'B'
HR 65
RR 14
Pos: 45° ***
Loc: Bed
46

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 12/38208

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - G08B 1/08 (2012.01)
USPC - 340/539.12
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(8) - G08B 1/08 (2012.01)
USPC - 340/539.12

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
IPC(8) - G08B 1/08 (2012.01) (Keyword limited - see terms below)
USPC - 340/539.1; 340/573.1; 340/572.1; 340/286.1 (Keyword limited - see terms below)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PubWEST (PGPB, USPT, EPAB, JPAB), Google Scholar, Google Patents, Search Terms Used: Surveillance, monitor$4, band, tag, fob, jewelry, key, patch, blood pressure, nurse, real time, Lifeflow technologies, medtronic, predetermined range, breathing, homodyne, radar, radiolocation, batter$4, ISM, FCC, power, key$4, modulat$4, location, patient, time

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X -- Y	US 2010/0240999 A1 (Droitcour et al.) 23 September 2010 (23.09.2010), para. [0007], [0053], [0196], [0201], [0209], [0210], [0223], [0247], [0289], [0480], [0532], [0580], [0586], [0593], [0594], [0607], [0632], [0638], [0646], [0674], [0688] and Fig. 38L	1-11, 16-19, 22-38 -------------------- 12-15, 20, 21
Y	US 6,064,663 A (Honkasalo et al.) 16 May 2000 (16.05.2000), col. 6 ln. 30-40 and col. 22 ln. 20-45	12, 20, 21
Y	US 2009/0061880 A1 (Roberts et al.) 05 March 2009 (05.03.2009), para. [0039]	13-15
A	US 2008/0094228 A1 (Welch et al.) 24 April 2008 (24.04.2008), para. [0001] - [0043] and abstract	1-38

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
03 August 2012 (03.08.2012)	17 AUG 2012

Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774