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(54) **LOCALIZATION AND HEALTH MONITORING**

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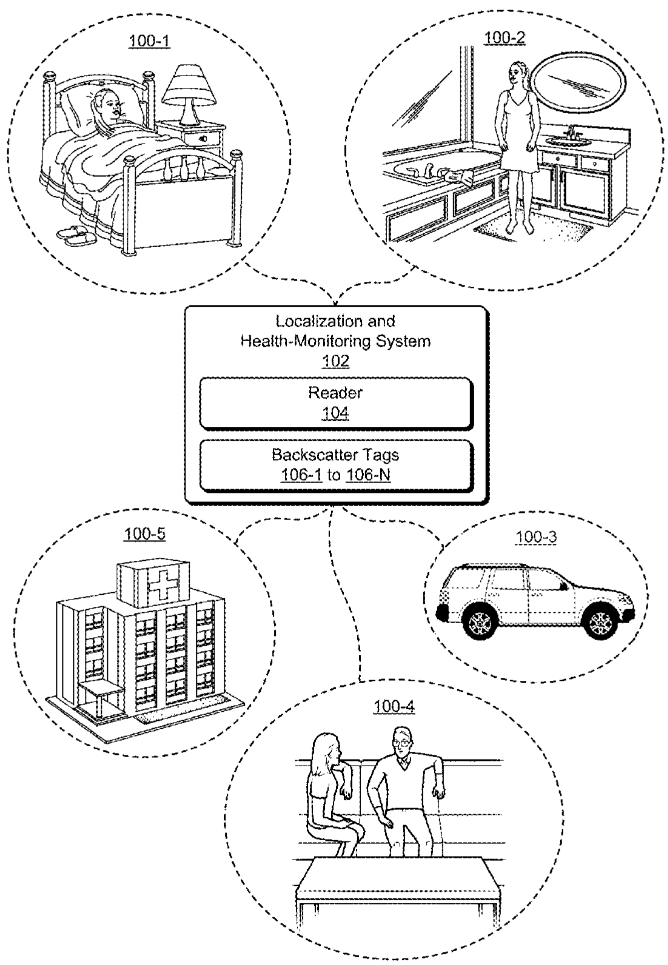
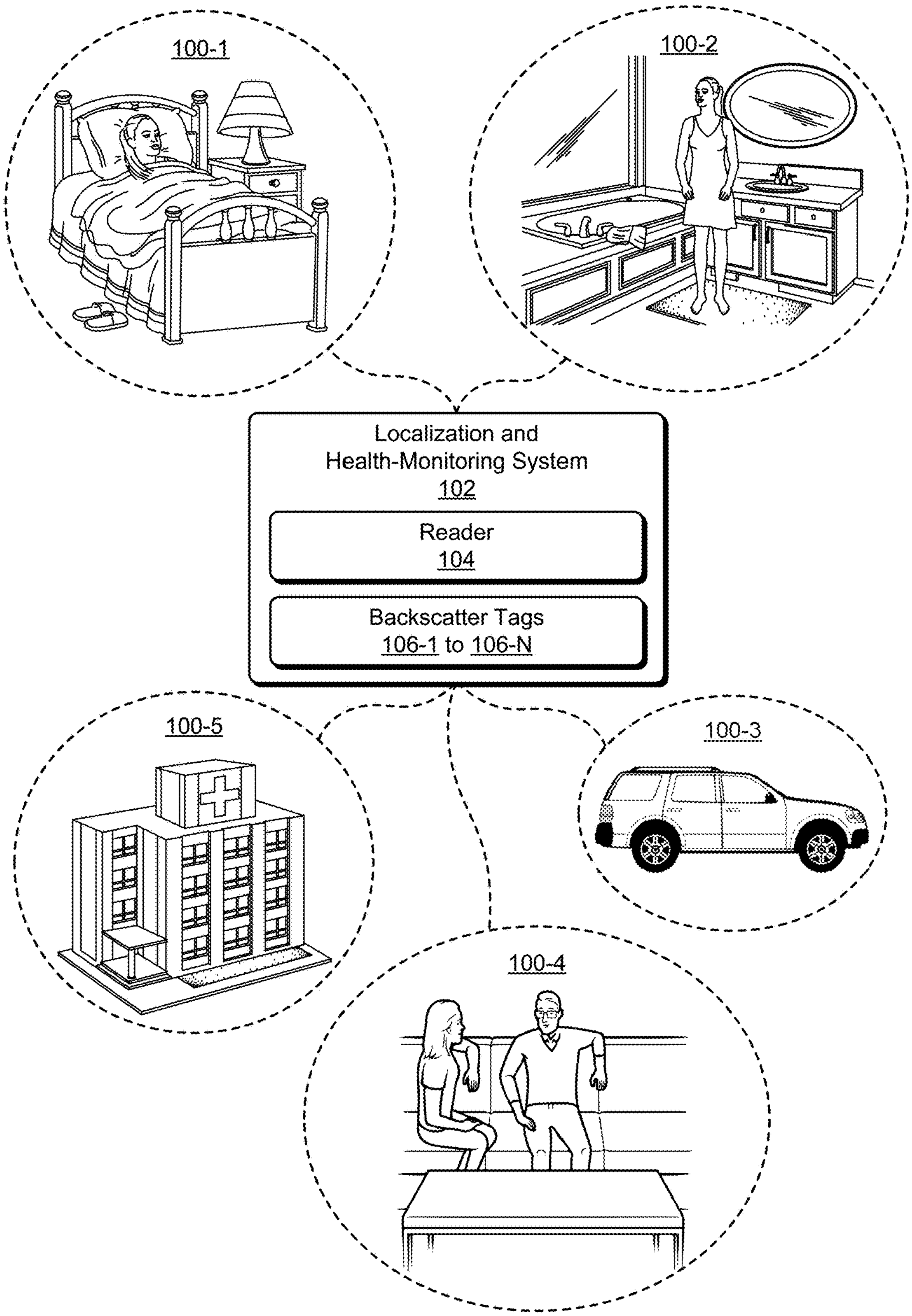
(57) **ABSTRACT**

Techniques and apparatuses are described that implement localization and health monitoring. With the use of multiple backscatter tags, a reader can be implemented with a single antenna and have a relatively small footprint compared to other systems that utilize antenna arrays or multiple readers. Also, the backscatter tags can be implemented as passive devices and located at fixed positions. In this way, a single power source can be provided at the reader, and target angular resolutions can be realized without the additional mechanical complexities associated with other moving systems. Additionally, the backscatter tags can be implemented using relatively low-cost commercial off-the-shelf hardware. As such, performance of the reader can be readily customized with the purchase of additional backscatter tags.





100-1
100-2
Localization and
Health-Monitoring System
102
Reader
104
Backscatter Tags
106-1 to 106-N
100-5
100-3
100-4

FIG. 1

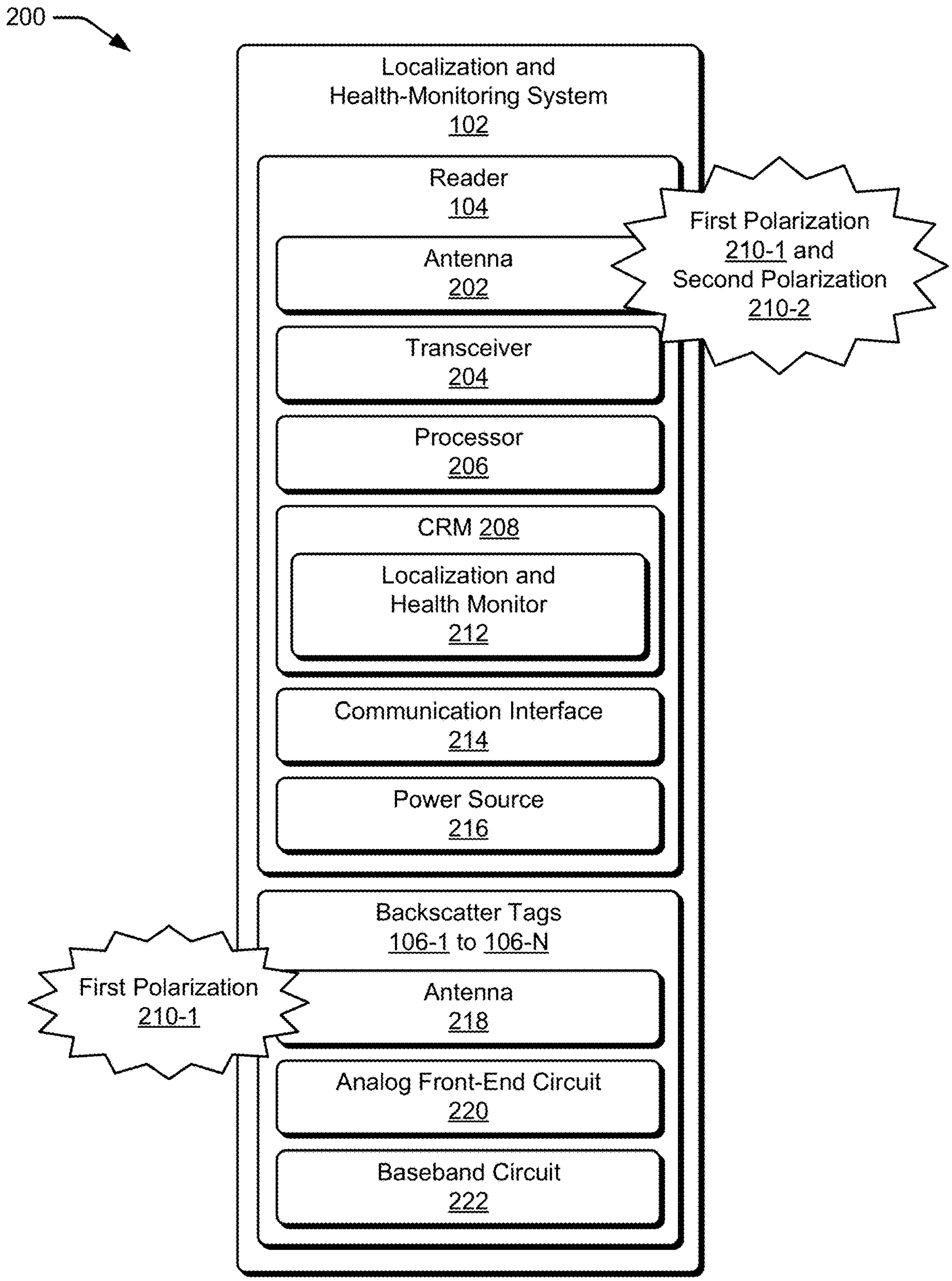

200
Localization and
Health-Monitoring System
102
Reader
104
Antenna
202
Transceiver
204
Processor
206
CRM 208
Localization and
Health Monitor
212
Communication Interface
214
Power Source
216
First Polarization
210-1 and
Second Polarization
210-2
Backscatter Tags
106-1 to 106-N
Antenna
218
Analog Front-End Circuit
220
Baseband Circuit
222
First Polarization
210-1

FIG. 2

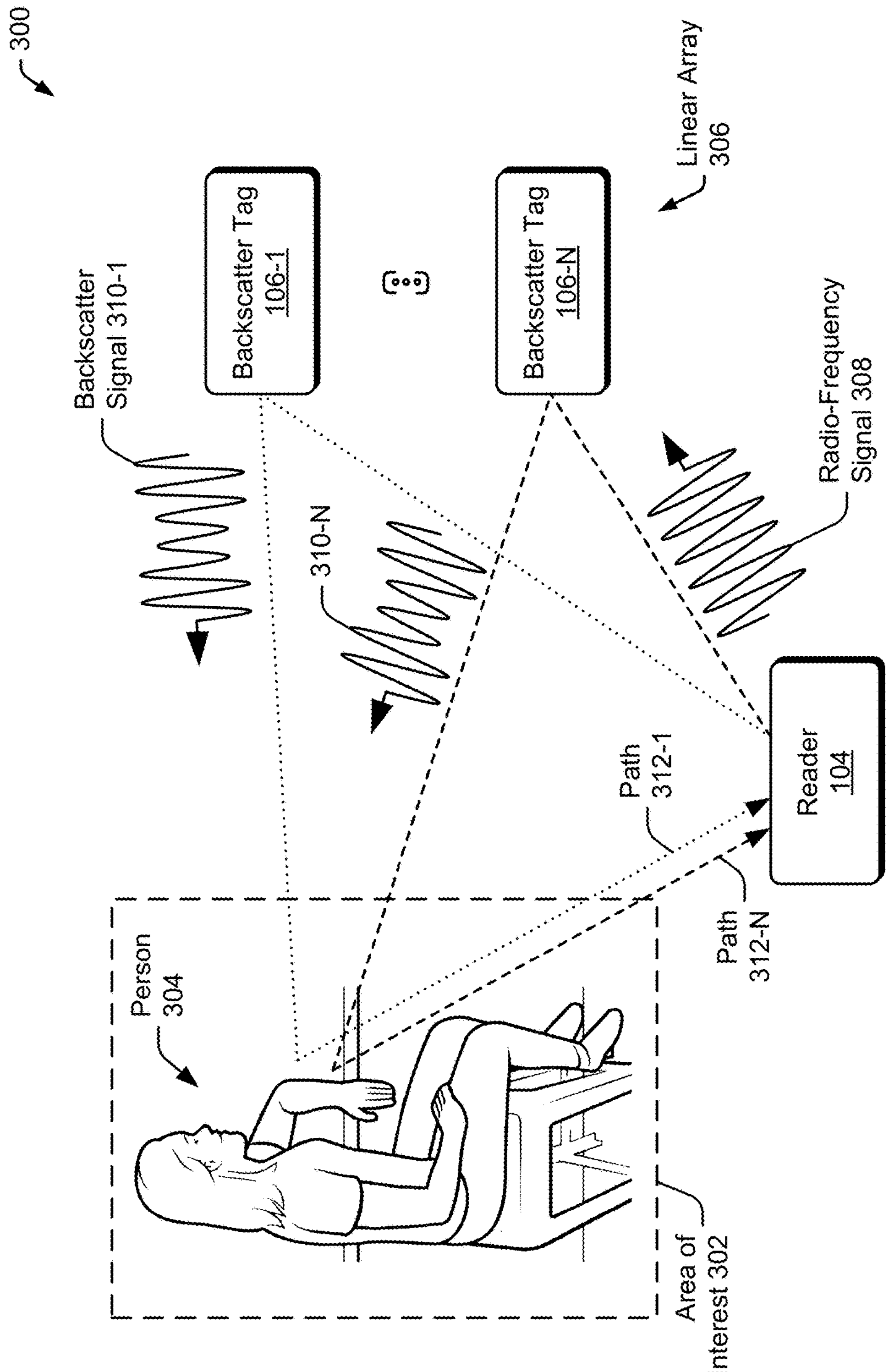
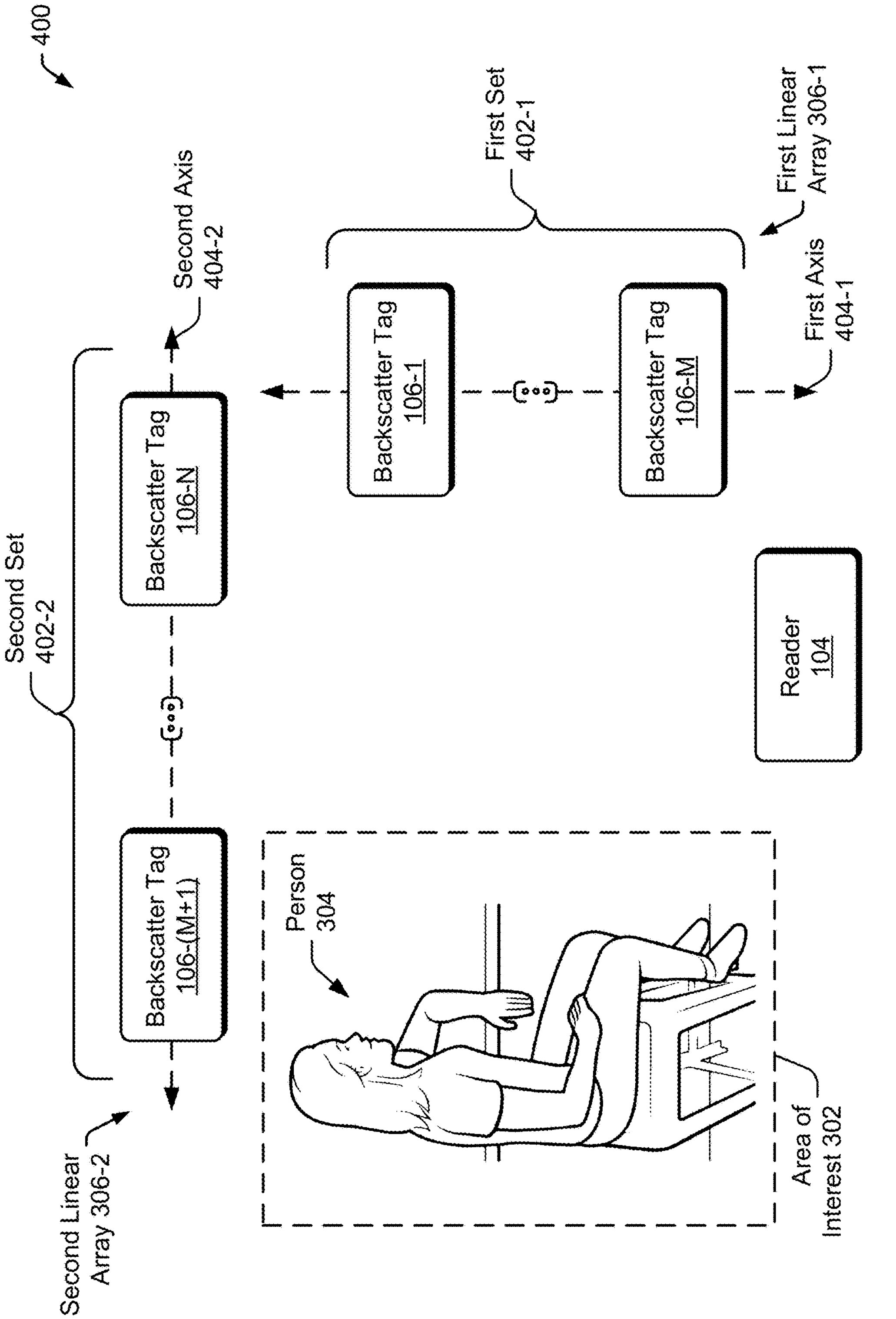

300
Backscatter Tag
106-1
Backscatter Tag
106-N
Linear Array
306
Backscatter
Signal 310-1
310-N
Radio-Frequency
Signal 308
Reader
104
Path
312-1
Path
312-N
Person
304
Area of
Interest 302

FIG. 3



400
Second Set
402-2
Second Axis
404-2
First Set
402-1
First Linear
Array 306-1
First Axis
404-1
Backscatter Tag
106-N
Backscatter Tag
106-1
Backscatter Tag
106-M
Backscatter Tag
106-(M+1)
Reader
104
Person
304
Second Linear
Array 306-2
Area of
Interest 302

FIG. 4

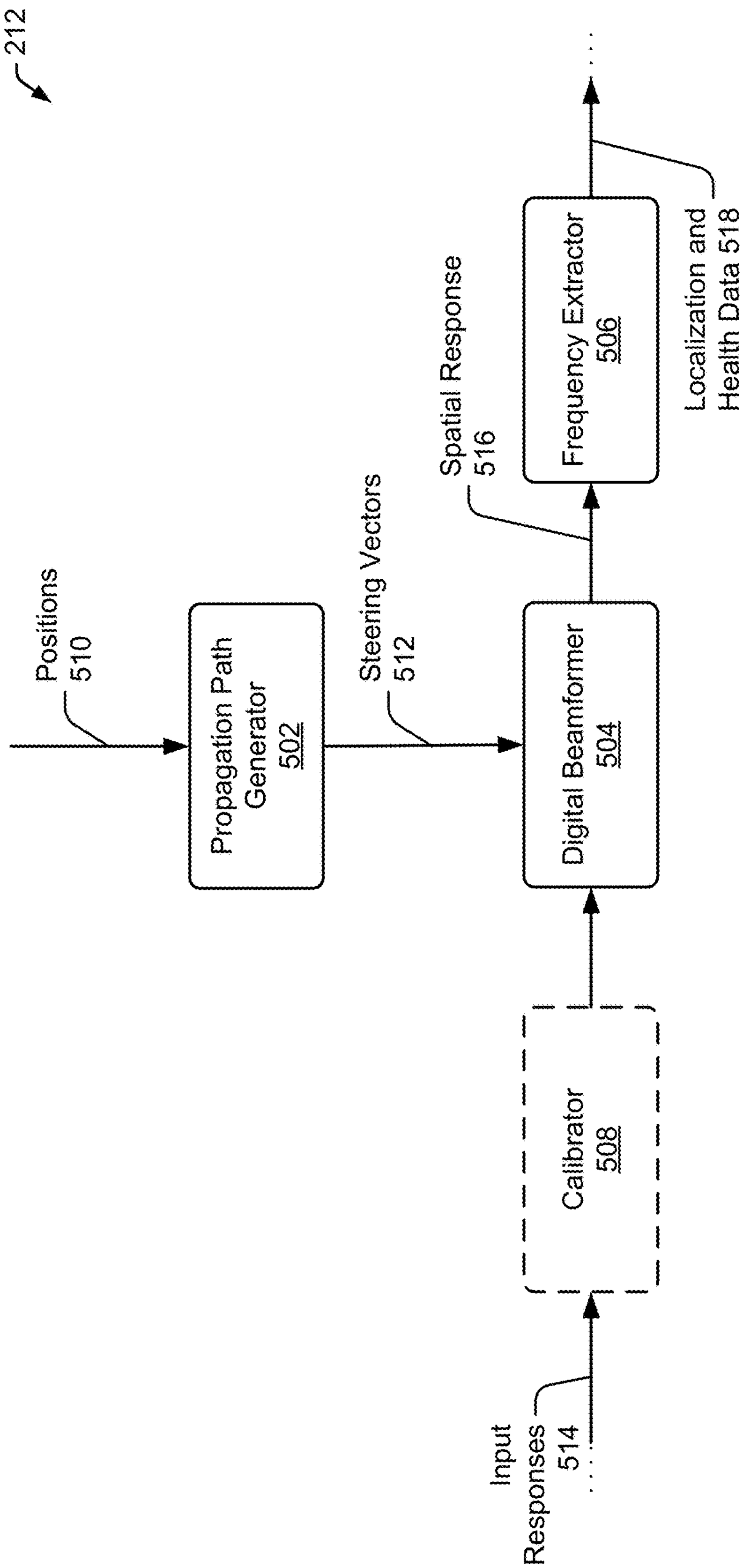

212
Positions 510
Propagation Path Generator 502
Steering Vectors 512
Digital Beamformer 504
Spatial Response 516
Frequency Extractor 506
Localization and Health Data 518
Calibrator 508
Input Responses 514

FIG. 5

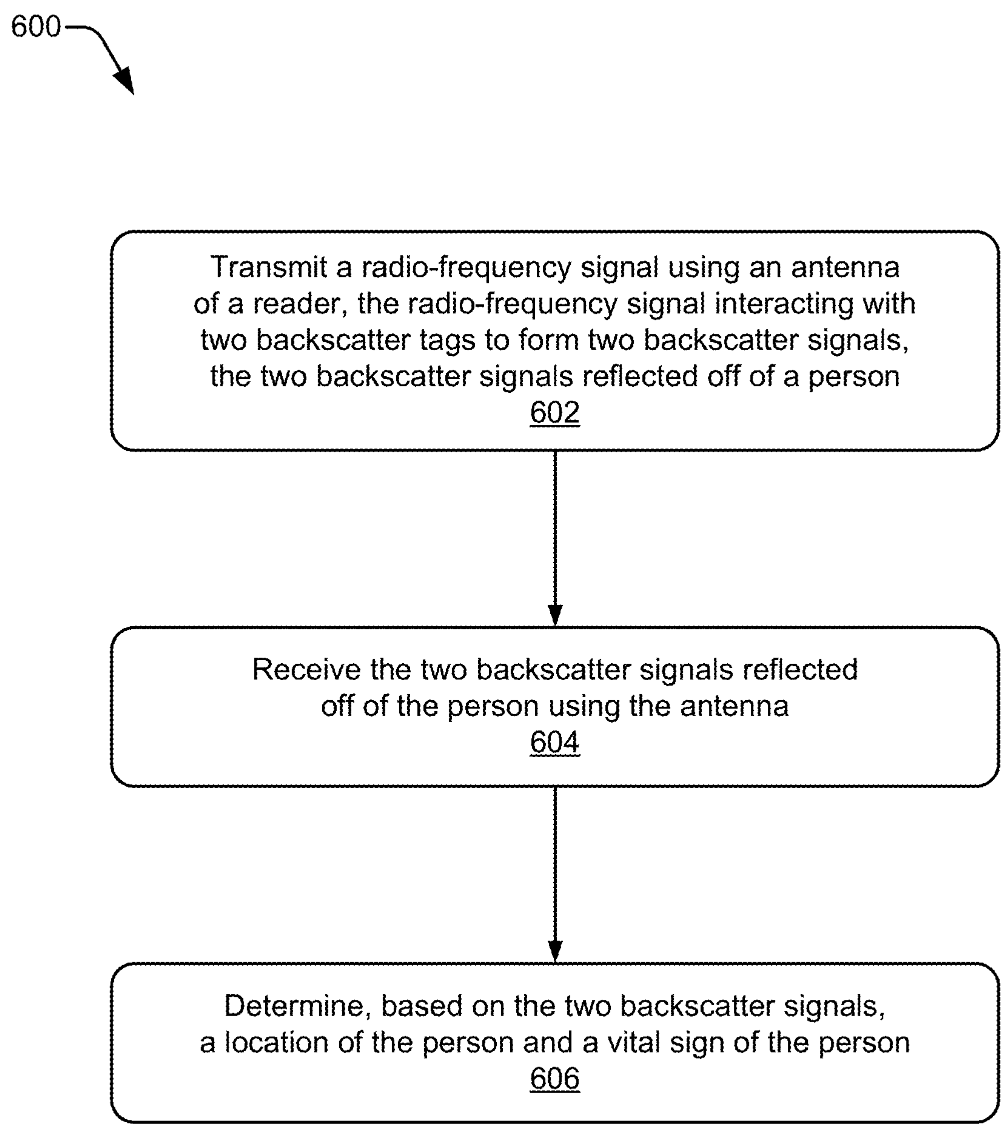

600
Transmit a radio-frequency signal using an antenna of a reader, the radio-frequency signal interacting with two backscatter tags to form two backscatter signals, the two backscatter signals reflected off of a person
602
Receive the two backscatter signals reflected off of the person using the antenna
604
Determine, based on the two backscatter signals, a location of the person and a vital sign of the person
606

FIG. 6

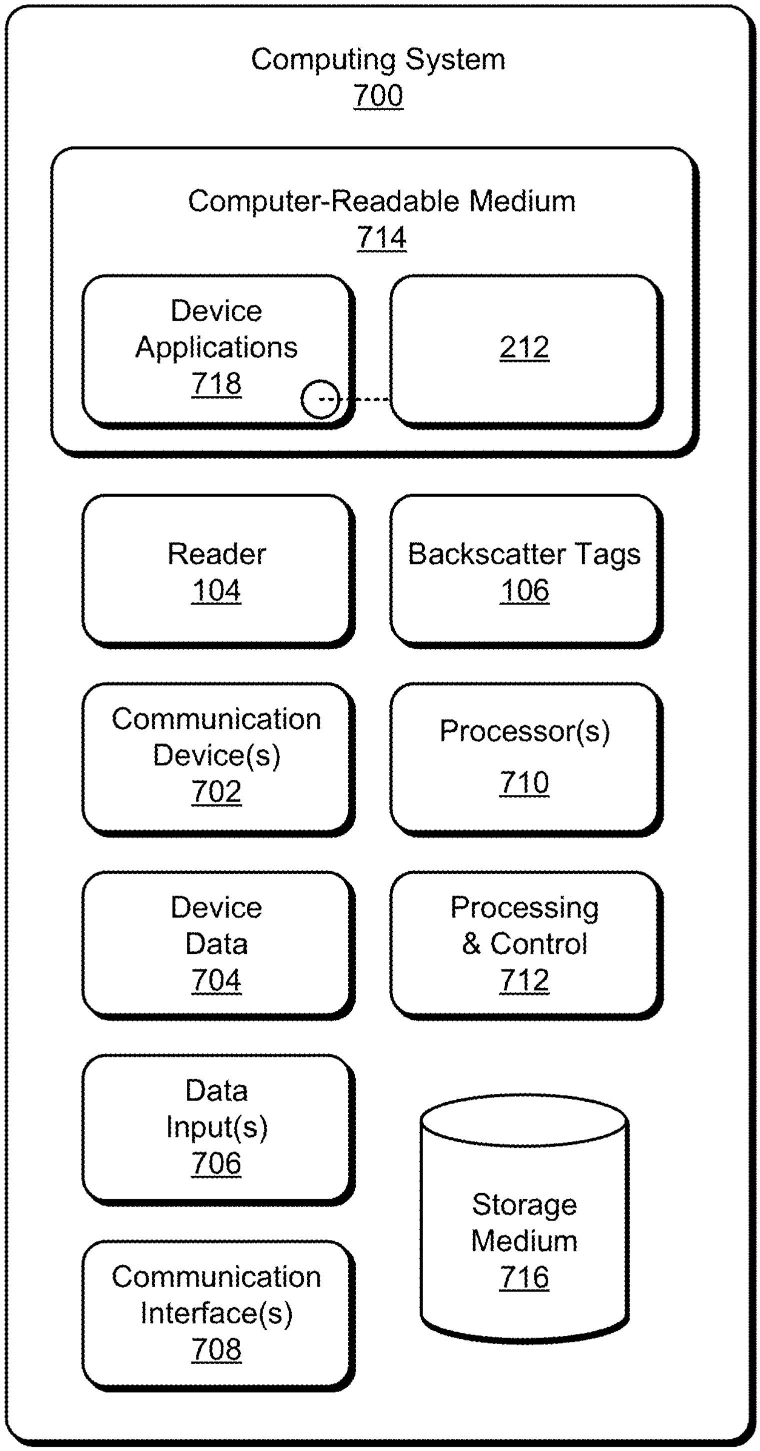

Computing System
700
Computer-Readable Medium
714
Device
Applications
718
212
Reader
104
Backscatter Tags
106
Communication
Device(s)
702
Processor(s)
710
Device
Data
704
Processing
& Control
712
Data
Input(s)
706
Storage
Medium
716
Communication
Interface(s)
708

FIG. 7

LOCALIZATION AND HEALTH MONITORING

BACKGROUND

[0001] A health-monitoring device can help a user improve or maintain their health by measuring and reporting the user's vital signs. With this information, the health-monitoring device can evaluate a user's progress towards a fitness goal or detect an anomaly for early disease diagnosis and prevention. Some health-monitoring devices, however, are obtrusive and require contact with the user's skin to accurately measure the user's vital signs. This may make it cumbersome for the user to use while performing other activities or impede actions of nurses or doctors that are tending to the user.

SUMMARY

[0002] Techniques and apparatuses are described that implement localization and health-monitoring using a reader and as few as two backscatter tags. With the use of multiple backscatter tags, a reader can be implemented with a single antenna and have a relatively small footprint compared to other systems that utilize antenna arrays. Also, the backscatter tags can be implemented as passive devices and located at fixed positions. In this way, a single power source can be provided at the reader, and target angular resolutions can be realized without the additional mechanical complexities associated with other moving systems. Additionally, the backscatter tags can be implemented using relatively low-cost commercial off-the-shelf hardware. As such, performance of the reader can be readily customized with the purchase of additional backscatter tags.

[0003] Aspects described below include a method performed by a reader for localization and health monitoring. The method includes transmitting a radio-frequency signal using an antenna of the reader. The radio-frequency signal interacts with two backscatter tags to form two backscatter signals. The two backscatter signals are reflected off of a person. The method also includes receiving the two backscatter signals reflected off of the person using the antenna. The method additionally includes determining, based on the two backscatter signals, a location of the person and a vital sign of the person.

[0004] Aspects described below also include a reader comprising at least one antenna. The reader is configured to perform any of the described methods.

[0005] Aspects described below include a system comprising at least two backscatter tags and a reader. The reader comprises at least one antenna and is configured to perform any of the described methods.

[0006] Aspects described below also include a system with means for performing localization and health monitoring.

BRIEF DESCRIPTION OF DRAWINGS

[0007] Apparatuses for and techniques implementing localization and health monitoring are described with reference to the following drawings. The same numbers are used throughout the drawings to reference like features and components:

[0008] FIG. **1** illustrates example environments in which localization and health monitoring can be performed;

[0009] FIG. **2** illustrates an example implementation of a localization and health-monitoring system;

[0010] FIG. **3** illustrates example operations of a reader and multiple backscatter tags for localization and health monitoring;

[0011] FIG. **4** illustrates an example configuration of multiple backscatter tags for localization and health monitoring;

[0012] FIG. **5** illustrates an example scheme implemented by a reader for localization and health monitoring;

[0013] FIG. **6** illustrates an example method for performing operations of a reader capable of performing localization and health monitoring using multiple backscatter tags; and

[0014] FIG. **7** illustrates an example computing system embodying, or in which techniques may be implemented that enable use of, a reader capable of performing localization and health monitoring using multiple backscatter tags.

DETAILED DESCRIPTION

Overview

[0015] A health-monitoring device can help a user improve or maintain their health by measuring and reporting the user's vital signs. With this information, the health-monitoring device can evaluate a user's progress towards a fitness goal or detect an anomaly for early disease diagnosis and prevention. Some health-monitoring devices, however, are obtrusive and require contact with the user's skin to accurately measure the user's vital signs. This may make it cumbersome for the user to use while performing other activities or impede actions of nurses or doctors that are tending to the user.

[0016] To address this problem, some radio-frequency technologies can provide contactless health monitoring. For example, some radar systems can measure vital signs of one or more people. However, a radar system is a dedicated, complex system, which can be expensive. Also, to achieve sufficient angular resolutions for distinguishing between multiple people, the radar system can utilize an antenna array, which can increase a footprint and cost of the radar system. Alternatively, the radar system can use techniques such as synthetic-aperture radar (SAR) to realize target angular resolutions. Synthetic-aperture radar, however, relies on motion, which can increase a mechanical complexity of the radar system.

[0017] Some radio-frequency identification (RFID) systems can provide contactless health monitoring. Without the ability to provide localization, however, it can be challenging for these radio-frequency identification systems to operate in a multi-user environment. Other radio-frequency identification systems can provide localization using multiple readers and a large quantity of radio-frequency identification tags (e.g., approximately 30 or more). However, these systems may not be designed to operate in non-ideal environments (e.g., environments with multipath and clutter) or provide contactless health monitoring. Furthermore, the large quantity of radio-frequency identification tags can increase the installation complexity of the radio-frequency identification system.

[0018] In contrast, this document describes techniques and systems that implement localization and health monitoring using a reader and as few as two backscatter tags. With the use of multiple backscatter tags, the reader can be implemented with a single antenna and have a relatively small footprint compared to other radar systems that utilize antenna arrays or other radio-frequency identification systems that utilize multiple readers. Also, the backscatter tags can be implemented as passive devices and can be located at fixed positions. In this way, a single power source can be provided at the reader, and target angular resolutions can be realized without the additional mechanical complexities associated with other moving systems. The single power source and stationary components can make it easier to install the reader and the backscatter tags compared to other systems that utilize multiple power sources and/or moving components. Additionally, the backscatter tags can be implemented using relatively low-cost commercial off-the-shelf hardware. As such, performance of the reader can be readily customized with the purchase of additional backscatter tags.

[0019] FIG. **1** illustrates example environments in which localization and health monitoring can be performed. In particular, a localization and health-monitoring system **102** provides contactless (non-contact) localization and health monitoring for one or more people. In some implementations, the localization and health-monitoring system **102** can provide the user information about a measured vital sign. Example vital signs can include a breathing rate or a heart rate. Additionally or alternatively, the localization and health-monitoring system **102** can alert the user or another entity (e.g., emergency services or a health professional) to an anomaly in the user's vital signs. In this way, the user can seek medical attention for early disease detection and prevention, or the other entity can provide emergency care, especially in situations in which the user becomes incapacitated.

[0020] The localization and health-monitoring system **102** can be installed in a variety of different environments, including those that may include multipath and clutter. Example environments can include glass, windows, concrete walls, metal separators, chairs, or screens (e.g., a monitor or a television).

[0021] In example environments **100-1** and **100-2**, the localization and health-monitoring system **102** is installed in a room of a building that is frequented by a user. Example rooms include a bedroom in environment **100-1** and a bathroom in environment **100-2**. The localization and health-monitoring system **102** can also be installed in other types of rooms, including an office or work room, or a cubicle within an office space.

[0022] In the environment **100-1**, the localization and health-monitoring system **102** can monitor a user's vital sign as the user sleeps. In some cases, a quality of the user's sleep can be measured based on the vital sign information provided by the localization and health-monitoring system **102**. Additionally or alternatively, the localization and health-monitoring system **102** can detect occurrences of sleep apnea that disrupt the user's breathing. With knowledge of the frequency and duration of the sleep apnea, the user may choose to seek medical treatment.

[0023] In the environment **100-2**, the localization and health-monitoring system **102** can evaluate the user's vital sign while they are present and using the facilities. In some implementations, the localization and health-monitoring system **102** can detect that a stroke or heart attack occurred and automatically notify a family member or emergency services to assist the user.

[0024] In some environments, the localization and health-monitoring system **102** is installed at a location that is frequented by multiple people. For example, the localization and health-monitoring system **102** can be installed within a vehicle, a living room, or a medical facility (e.g., within awaiting room or a patient's room), as illustrated in example environments **100-3**, **100-4**, and **100-5**, respectively. Other example environments can include a gym or a restaurant.

[0025] Within the medical facility of environment **100-5**, the localization and health-monitoring system **102** can detect that a particular patient within a waiting room is having trouble breathing or has an abnormal heart rate, and alert the staff to the patient's condition. As another example, the localization and health-monitoring system **102** can detect if a particular guest at a restaurant is experiencing an allergic reaction or choking, and send staff to that diner's table to assist the guest. In other situations, such as at the gym, the localization and health-monitoring system **102** can provide an individual with their vital sign measurements during an exercise routine.

[0026] To provide localization and health monitoring, the localization and health-monitoring system **102** includes at least one reader **104** (e.g., one reader **104**) and at least two backscatter tags **106-1** to **106**-N, where N represents a positive integer greater than or equal to two. The reader **104** can be implemented as a radio-frequency identification reader, and the backscatter tags **106-1** to **106**-N can be implemented as radio-frequency identification tags. In example implementations, the quantity of backscatter tags **106-1** to **106**-N can be equal to two, four, eight, or more. In general, increasing the quantity of backscatter tags (e.g., increasing N) increases an angular resolution and accuracy of the localization and health-monitoring system **102**. With two or more backscatter tags **106-1** to **106**-N, the localization and health-monitoring system **102** can distinguish between different people that are less than half a meter apart (e.g., less than approximately 50 centimeters apart or less than approximately 25 centimeters apart).

[0027] Some localization and health-monitoring systems **102** can be integrated as part of a smart home system. With the ability to operate with fewer components compared to other systems, the localization and health-monitoring system **102** can be relatively easy for a user to install along one or more walls of a residential room. In an example situation, the localization and health-monitoring system **102** can monitor a 10 foot by 10 foot room using four backscatter tags **106** installed across one wall of the room. In this case, the localization and health-monitoring system **102** can measure both a vital sign and location of the user while the user is present within the room. To improve the location measurement, the user can install four additional backscatter tags **106** on another wall that is orthogonal to the wall with the other backscatter tags **106**. Because the backscatter tags **106** can operate without a dedicated power source, the installation process can be less complicated compared to other systems and the user can have additional flexibility in positioning the backscatter tags **106**. At a later time, the user can improve the resolution and capability of the localization and health-monitoring system **102** by installing more than four backscatter tags **106** on a wall. With additional resolution, the localization and health-monitoring system **102** can support other operations, such as gesture recognition, fall detection, or collision avoidance. The localization and health-monitoring system **102** is further described with respect to FIG. **2**.

[0028] FIG. **2** illustrates an example localization and health-monitoring system **102**. In general, the localization and health-monitoring system **102** uses radio-frequency signals to evaluate signal path propagations within a backscatter environment. In the depicted configuration, the localization and health-monitoring system **102** includes the reader **104** and the backscatter tags **106-1** to **106**-N. The reader **104** generates the radio-frequency signals. The backscatter tags **106-1** to **106**-N interact with the radio-frequency signals to generate the backscatter environment. In general, the backscatter tags **106-1** to **106**-N operate as a quasi-virtual antenna array of the reader **104** to enable localization and health monitoring.

[0029] The reader **104** includes at least one antenna **202**, at least one transceiver **204**, at least one processor **206**, and at least one computer-readable storage medium **208** (CRM **208**). The antenna **202** can be implemented using a patch antenna (e.g., a microstrip antenna), a dipole antenna, or a helical antenna. In an example implementation, the antenna **202** can have a gain of approximately 9 dBi or more.

[0030] In some implementations, the antenna **202** transmits and receives using orthogonal polarizations. For example, the antenna **202** can transmit radio-frequency signals using a first polarization **210-1** and receive radio-frequency signals using a second polarization **210-2**, which is orthogonal to the first polarization **210-1**. The first polarization **210-1** and the second polarization **210-2** can be circular polarizations. For example, the first polarization **210-1** can be a left-hand circular polarization (LHCP), and the second polarization **210-2** can be a right-hand circular polarization (RHCP). In another example, the first polarization **210-1** can be the RHCP, and the second polarization **210-2** can be the LHCP.

[0031] The antenna **202** can be implemented using a single antenna. For example, the antenna **202** can include a dual linearly-polarized patch antenna. The patch antenna can have a square (e.g., rectangular) or circular shape. To generate the orthogonal circular polarizations, two feeds of the patch antenna can be coupled to two ports of a quadrature hybrid coupler, which have a 90 degree phase difference. The two feeds of the patch antenna can produce an electric field that varies in two orthogonal dimensions and results in the transmission and reception of circularly-polarized signals of opposite handedness.

[0032] Alternatively, the antenna **202** can be implemented using at least two antennas. For example, a first antenna can transmit the radio-frequency signals with the first polarization **210-1**, and a second antenna can receive the radio-frequency signals with the second polarization **210-2**.

[0033] The transceiver **204** is coupled to the antenna **202** and includes circuitry and logic for transmitting and receiving the radio-frequency signals via the antenna **202**. Components of the transceiver **204** can include amplifiers, oscillators, and so forth. The transceiver **204** can also include logic to perform in-phase/quadrature (I/Q) operations, such as modulation or demodulation. In an example implementation, the transceiver **204** can have a transmit power of approximately 30 dBm or more and a sensitivity of at least −84 dBm.

[0034] The processor **206** executes instructions that are stored within the CRM **208**. The CRM **208** enables persistent and/or non-transitory data storage (i.e., in contrast to mere signal transmission). The processor **206** can be integrated within the transceiver **204** or implemented on a separate integrated circuit. The CRM **208** includes a localization and health monitor **212**. The localization and health monitor **212** uses holography and beamforming to measure locations and vital signs of one or more people.

[0035] The reader **104** can optionally include a communication interface **214** and a power source **216**. The communication interface **214** can communicate data over wired, wireless, or optical networks. The power source **216** can be an internal power source, such as a battery. In other implementations, the reader **104** can include a connection to an external power source, such as a solar panel, an external battery, or a power outlet.

[0036] The backscatter tags **106-1** to **106**-N can each include at least one antenna **218**, at least one analog front-end circuit **220**, and at least one baseband circuit **222**. The backscatter tags **106-1** to **106**-N can be implemented as passive devices, which are powered by incoming radio-frequency signals. In this way, the backscatter tags **106-1** to **106**-N can be powered wirelessly and can operate without a dedicated power source.

[0037] The antenna **218** can have the first polarization **210-1**. In this way, the antenna **218** is co-polarized with the transmission of the antenna **202** and cross-polarized with the reception of the antenna **202**. This enables the reader **104** to attenuate radio-frequency signals that propagate from the backscatter tags **106-1** to **106**-N along a line-of-sight propagation path, as further described with respect to FIG. **3**.

[0038] The analog front-end circuit **220** includes circuitry and logic for transmitting and receiving radio-frequency signals via the antenna **218**. The analog front-end circuit **220** can include logic to perform in-phase/quadrature (I/Q) operations, such as modulation or demodulation. Additionally, the analog front-end circuit **220** can harvest energy from an incoming radio-frequency signal for power.

[0039] The baseband circuit **222** can process data that is demodulated by the analog front-end circuit **220** or provide data to the analog front-end circuit **220** for modulation. As an example, the baseband circuit **222** can store an identification number of the corresponding backscatter tag **106-1** to **106**-N and provide the identification number to the analog front-end circuit **220**. The analog front-end circuit **220** can modulate a radio-frequency signal based on the identification number to enable the reader **104** to associate the radio-frequency signal as being generated by the corresponding backscatter tag **106-1** to **106**-N. Example modulations can include amplitude modulation, phase modulation, and/or frequency modulation.

[0040] A frequency spectrum (e.g., range of frequencies) that the reader **104** and the backscatter tags **106-1** to **106**-N use can include radio frequencies (e.g., frequencies between approximately 30 hertz (Hz) and 300 gigahertz (GHz)). In some implementations, the frequency spectrum includes ultra-high frequencies (UHF) (e.g., frequencies between approximately 300 and 3000 megahertz (MHz)). In this case, the reader **104** can be implemented as an ultra-high-frequency (UHF) radio-frequency identification (RFID) reader, and the backscatter tags **106-1** to **106**-N can be implemented as UHF RFID tags. As an example, the UHF RFID reader and UHF RFID tags can operate with frequencies that are between approximately 902 and 928 MHz. To support the UHF frequencies, dimensions of the antenna **202** of the reader **104** and the antennas **218** of the backscatter tags **106-1** to **106**-N can be at least 10 millimeters (mm) by 10 mm. Some example implementations have dimensions are approximately 2 centimeters (cm) by 2 cm.

[0041] Additionally or alternatively, the frequency spectrum of the reader **104** and backscatter tags **106-1** to **106**-N can include extremely-high frequencies (EHF) associated with millimeter wavelengths. Example frequencies can include those between approximately 30 and 300 GHz (e.g., approximately 60 GHz). To support the EHF frequencies, dimensions of the antenna **202** of the reader **104** and the antennas **218** of the backscatter tags **106-1** to **106**-N can be at least 0.2 mm by 0.2 mm. Some example implementations are approximately 2 mm by 2 mm.

[0042] To provide localization and health monitoring for a 10 foot by 10 foot room, the localization and health-monitoring system **102** can include UHF or EHF backscatter tags **106-1** to **106**-N that are installed along at least one wall of the room. As an example, the backscatter tags **106-1** to **106**-N can be separated by approximately half a wavelength or more. For example, four backscatter tags **106-1** to **106**-N that operate at approximately 60 GHz can be spaced approximately 0.25 cm apart or more across the wall. Operations of the reader **104** and the backscatter tags **106-1** to **106**-N are further described with respect to FIG. **3**.

[0043] FIG. **3** illustrates example operation of the reader **104** and the backscatter tags **106-1** to **106**-N. In an environment **300**, the reader **104** and the backscatter tags **106-1** to **106**-N are positioned proximate to an area of interest **302**. The area of interest **302** represents a region in which one or more people, including person **304**, are likely to be located. The localization and health-monitoring system **102** measures the location and vital signs of people within the area of interest **302**. In some implementations, the area of interest **302** can include a region in which angular ambiguities associated with the localization and health-monitoring system **102** are reduced in quantity relative to other regions outside of the area of interest **302**.

[0044] In the environment **100-1**, the area of interest **302** can include the bed. In the environment **100-2**, the area of interest **302** can include a region next to a sink. As another example, the area of interest **302** can include various positions at a desk. In some case, a size of the area of interest **302** can be on the order of ten square meters, such as approximately 12 square meters. In other cases, the size of the area of interest **302** can be twenty square meters or more to encompass a significant portion of a room, such as a waiting room of the medical institution in environment **100-5** or an exercise room of a gym.

[0045] In the depicted configuration, the backscatter tags **106-1** to **106**-N and the reader **104** are arranged on adjacent sides of the area of interest **302**. For example, the backscatter tags **106-1** to **106**-N are positioned on a right side of the area of interest **302** and the reader **104** is positioned on a bottom side of the area of interest **302**. If the quantity of backscatter tags (N) is greater than two, the backscatter tags **106-1** to **106**-N can be arranged in a line to form a linear array **306**. A spacing between the backscatter tags **106-1** to **106**-N can be larger than half a wavelength to reduce coupling between the backscatter tags **106-1** to **106**-N. The wavelength can refer to a wavelength associated with a frequency spectrum of the localization and health-monitoring system **102**. As an example, the spacing between the backscatter tags **106-1** to **106**-N can be approximately three-quarters of a wavelength. In general, the spacing can be chosen to reduce the quantity of sidelobes within the area of interest **302**.

[0046] During operation, the reader **104** transmits a radio-frequency signal **308**. The radio-frequency signal **308** can be a continuous-wave signal and can have the first polarization **210-1**. In some implementations, the reader **104** uses a frequency-hopping spread-spectrum (FHSS) technique to transmit the radio-frequency signal **308**. As a result, the radio-frequency signal **308** can have a frequency that changes between consecutive time periods. For example, the radio-frequency signal **308** can have a frequency that hops approximately every ten seconds and cycles between frequencies associated with ten different frequency channels or more.

[0047] At separate times, the backscatter tags **106-1** to **106**-N receive the radio-frequency signal **308** and generate respective backscatter signals **310-1** to **310**-N based on the radio-frequency signal **308**. In this way, the backscatter tags **106-1** to **106**-N interact with the radio-frequency signal **308** to create a backscatter environment for localization and health monitoring. In some implementations, the backscatter signals **310-1** to **310**-N represent modified versions of the radio-frequency signal **308**. For example, the backscatter tags **106-1** to **106**-N can modulate data, such as a corresponding identification number, onto the backscatter signals **310-1** to **310**-N. The backscatter tags **106-1** to **106**-N can generate the backscatter signals **310-1** to **310**-N with the first polarization **210-1**.

[0048] The backscatter signals **310-1** to **310**-N impinge on the person **304** within the area of interest **302** (e.g., reflect off of the person **304**) and propagate back towards the reader **104**. Due to the reflection, a handedness of the reflected backscatter signals **310-1** to **310**-N is reversely polarized. For example, a backscatter signal **310** with the first polarization **210-1** is reflected with the second polarization **210-2**.

[0049] The reflected backscatter signals **310-1** to **310**-N can also have frequencies that differ from the transmitted backscatter signals **310-1** to **310**-N due to the Doppler effect. More specifically, the reflected backscatter signals **310-1** to **310**-N can include a frequency component associated with the person's **304** vital sign, such as the person **304**'s breathing rate or heart rate.

[0050] The reader **104** receives the reflected backscatter signals **310-1** to **310**-N. In some implementations, the reader **104** receives the reflected backscatter signals **310-1** to **310**-N using a same polarization as the reflected backscatter signals **310-1** to **310**-N. By transmitting and receiving with opposite handedness, the reflected backscatter signals **310-1** to **310**-N can have a higher signal strength at the reader **104** compared to other signals within the environment **300**, including the radio-frequency signal **308** or non-reflected versions of the backscatter signals **310-1** to **310**-N. The non-reflected versions of the backscatter signals **310-1** to **310**-N can propagate along a line-of-sight between the reader **104** and the corresponding backscatter tags **106-1** to **106**-N. This polarization mismatch enables the reader **104** to operate at farther distances from the backscatter tags **106-1** to **106**-N and the area of interest **302**.

[0051] Propagation paths **312-1** to **312**-N (paths **312-1** to **312**-N) characterize the propagation of the radio-frequency signal **308** from the reader **104** to the individual backscatter tags **106-1** to **106**-N, the propagation of the backscatter signals **310-1** to **310**-N from the corresponding backscatter tags **106-1** to **106**-N to the area of interest **302**, and the propagation of reflected versions of the backscatter signals **310-1** to **310**-N from the area of interest **302** to the reader **104**. Phases of the reflected backscatter signals **310-1** to **310**-N received at the reader **104** can vary based on the lengths (e.g., distances) of the propagation paths **312-1** to **312**-N. These phases can provide information about the location of the person **304** within the area of interest **302**, as further described with respect to FIG. **5**.

[0052] A proximity of the reader **104** and backscatter tags **106-1** to **106**-N to the area of interest **302** can be based on the transmit power and sensitivity of the reader **104**. In general, the positions and orientations of the reader **104** and backscatter tags **106-1** to **106**-N is sufficient for the radio-frequency signal **308** to propagate to the backscatter tags **106-1** to **106**-N and is sufficient for the reflected versions of the backscatter signals **310-1** to **310**-N to be received at the reader **104**.

[0053] If an antenna pattern of the antenna **202** of the reader **104** has a main lobe, the main lobe can be oriented towards the backscatter tags **106-1** to **106**-N and the area of interest **302**. If the antenna **202** includes a separate transmit antenna and a separate receive antenna, a main lobe of the transmit antenna can be directed towards the backscatter tags **106-1** to **106**-N and a main lobe of the receive antenna can be directed towards the area of interest **302**. Likewise, main lobes of the backscatter tags **106-1** to **106**-N can be directed towards the reader **104** and the area of interest **302**.

[0054] Using the linear array **306** of backscatter tags **106-1** to **106**-N, the reader **104** can measure a direction-of-arrival (DOA) (or an angle-of-arrival (AOA)) of the reflected backscatter signals **310-1** to **310**-N to determine a location of the person **304**. Alternatively, another arrangement of the backscatter tags **106-1** to **106**-N can enable the reader **104** to measure a multi-dimensional location of the person **304**, as further described with respect to FIG. **4**.

[0055] FIG. **4** illustrates another example configuration of the backscatter tags **106-1** to **106**-N for localization and health monitoring. In the environment **400**, the backscatter tags **106-1** to **106**-N are divided into two sets. A first set **402-1** includes backscatter tags **106-1** to **106**-M, where M represents a positive integer that is less than N. A second set **402-2** includes backscatter tags **106**-(M+1) to **106**-N. The first set **402-1** of backscatter tags are positioned along a first axis **404-1** to form a first linear array **306-1**. The second set **402-2** of backscatter tags are positioned along a second axis **404-2** to form a second linear array **306-2**. The second axis **404-2** is approximately perpendicular to the first axis **404-1**.

[0056] The quantity of backscatter tags within the first set **402-1** (M) can be equal to, greater than, or less than the quantity of backscatter tags within the second set **402-2** (N-M). In an example implementation, N can be equal to four, and M can be equal to two. In another example implementation, N can be equal to eight, and M can be equal to four.

[0057] In the depicted configuration, the first set **402-1** of backscatter tags, the second set **402-2** of backscatter tags, and the reader **104** are arranged on adjacent sides of the area of interest **302**. For example, the reader **104** is positioned on a bottom side of the area of interest **302**. The first set **402-1** of backscatter tags are positioned on a right side of the area of interest **302**, which is adjacent to the bottom side. The second set **402-2** of backscatter tags are positioned on atop side of the area of interest **302**, which is adjacent to the right side. A spacing between the backscatter tags within the first set **402-1** and second set **402-2** can be larger than half a wavelength to reduce coupling. As an example, the spacing between the backscatter tags **106-1** to **106**-M within the first set **402-1** and the spacing between the backscatter tags **106**-(M+1) to **106**-N within the second set **402-2** can be approximately three-quarters of a wavelength.

[0058] Together, the first set **402-1** and second set **402-2** of backscatter tags form a two-dimensional array, which enables the reader **104** to measure a location of the person **304** across two dimensions associated with the first axis **404-1** and the second axis **404-2**. With the backscatter tags **106-1** to **106**-N forming a one-dimensional array, as shown in FIG. **3**, or a multi-dimensional array, as shown in FIG. **4**, the reader **104** can measure the vital sign and location of the person **304**, as further described with respect to FIG. **5**.

[0059] Although not explicitly shown, other implementations of the localization and health-monitoring system **102** can position the backscatter tags **106-1** to **106**-N in other arrangements. For example, the backscatter tags **106-1** to **106**-N can be positioned to form a three-dimensional array. As such, the reader **104** can measure a three-dimensional location of the person **304**. Alternatively, the backscatter tags **106-1** to **106**-N can be positioned in a distributed (non-linear) arrangement.

[0060] FIG. **5** illustrates an example scheme implemented by the reader **104** for localization and health monitoring. In the depicted configuration, the reader **104** implements the localization and health monitor **212**, which includes a propagation path generator **502**, a digital beamformer **504**, and a frequency extractor **506**. The localization and health monitor **212** can also optionally include a calibrator **508** if the reader **104** uses a FHSS technique to transmit the radio-frequency signal **308**.

[0061] During initialization, the localization and health monitor **212** stores information about positions **510** of the antenna **202** of the reader **104** and the antennas **218** of the backscatter tags **106-1** to **106**-N. The positions **510** can be relative positions based on a reference point, such as a center of the linear array **306** or the antenna **202** of the reader **104**. This information can be provided by a user or automatically determined by the localization and health-monitoring system **102** using ranging techniques.

[0062] During operation, the propagation path generator **502** uses a propagation model to generate steering vectors **512** based on the positions **510**. The steering vectors **512** can be determined based on resulting propagation phases, which are dependent upon the distances of modeled propagation paths and the wavelength of the radio-frequency signals. In other words, the steering vectors **512** represent a delay encountered due to propagation path differences.

[0063] The localization and health monitor **212** accepts, from the transceiver **204**, input responses **514** associated with the received backscatter signals **310-1** to **310**-N. The input responses **514** can be in a time domain or a frequency domain. In general, the input responses **514** include digital samples having amplitude information (e.g., received signal strength indicator (RSSI) information) and phase information.

[0064] Due to the operations of the backscatter tags **106-1** to **106**-N occurring at different time intervals, the input responses **514** are generated in series for each of the backscatter signals **310-1** to **310**-N. The localization and health monitor **212** can store the input responses **514** and proceed to the next operation once an input response **514** for each backscatter signal **310-1** to **310**-N is available. The localization and health monitor **212** can detect this event by identifying the identification numbers provided by the backscatter signals **310-1** to **310**-N. The input responses **514** can be provided to the calibrator **508** or the digital beamformer **504**, depending on the implementation.

[0065] If the reader **104** uses an FHSS technique to transmit the radio-frequency signal **308**, the calibrator **508** can calibrate the input responses **514** to reduce variations caused by the FHSS technique. In particular, the calibrator **508** can remove a medium value of the amplitude and phase associated with each input response **514**. The calibrator **508** can also unwrap the phase within the input responses **514** to remove ambiguities associated with the phase being greater than or equal to 180 degrees.

[0066] The digital beamformer **504** accepts the steering vectors **512** and input responses **514** (or calibrated input responses **514** provided by the calibrator **508**). Using conventional beamforming techniques or adaptive beamforming techniques, the digital beamformer **504** generates a spatial response **516** based on the steering vectors **512** and the input responses **514**.

[0067] In an example implementation, the digital beamformer **504** implements a delay-and-sum beamformer. The delay-and-sum beamformer determines weights based on the steering vectors **512** (e.g., based on complex conjugates of the steering vectors **512**). In this case, the weights are not derived based on the input responses **514**. As such, the weights can be considered data-independent weights. The delay-and-sum beamformer applies the weights to the input responses **514** and performs a summation across the weighted input responses **514**. The summation of the weighted input responses **514** produces a spatial response **516**, which includes amplitude and phase information.

[0068] In another example implementation, the digital beamformer **504** implements a Capon beamformer (e.g., a minimum-variance distortionless-response (MVDR) beamformer). The Capon beamformer determines weights based on the steering vectors **512** and the input responses **514**. In particular, the Capon beamformer calculates the weights based on covariance matrices of the input responses **514** and the steering vectors **512**. The Capon beamformer applies the weights to the input responses **514** to generate the spatial response **516**.

[0069] The spatial response **516** can include direction-of-arrival information for a one-dimensional array of backscatter tags **106-1** to **106**-N or multi-dimensional information for a multi-dimensional array of backscatter tags **106-1** to **106**-N. By analyzing the spatial response **516**, the localization and health monitor **212** can determine a location of the person **304**.

[0070] The frequency extractor **506** can extract the frequencies associated with different spatial locations within the spatial response **516**. By analyzing the frequencies at a location corresponding to the person **304**, the frequency extractor **506** can determine a vital sign of the person **304**, including a breathing rate and/or a heart rate. In some situations, the frequency extractor **506** can measure the vital sign of the person **304** based on the frequency with a highest amplitude. The frequency extractor **506** generates localization and health data **518**, which includes the measured location and measured vital sign of the person **304**. If multiple people are present within the area of interest **302**, the localization and health data **518** can include locations and vital signs for each person.

[0071] In general, the localization and health monitor **212** combines holography and beamforming techniques to localize and evaluate the health of the person **304**. The techniques of holography enable the reader **104** to generate a representative digital signature of the person **304** based on the positions **510** of the reader **104** and the backscatter tags **106-1** to **106**-N. In particular, the propagation path generator **502** and the digital beamformer **504** enable the localization and health monitor **212** to correlate the input responses **514** with the reference steering vectors **512** to localize and monitor the health of the person **304**.

[0072] The localization and health monitor **212** can provide the localization and health data **518** to the communication interface **214**, which can perform an action to convey this information to the person **304** or another entity. For example, the communication interface **214** can display this information or communicate this information to another device.

[0073] In example implementations, the localization and health-monitoring system **102** can measure breathing rates between approximately 4.5 and 60 beats-per-minute (bmp) with errors of approximately 2 bmp or less (e.g., less than 1 bmp). Depending on the quantity of backscatter tags (N) and the arrangement of the backscatter tags **106-1** to **106**-N, the localization and health-monitoring system **102** can achieve various location accuracies. In an example implementation in which the localization and health-monitoring system **102** includes four backscatter tags **106** arranged to form the linear array **306** of FIG. **3**, the localization and health-monitoring system **102** can have a direction-of-arrival error less than approximately ten degrees for detecting one person **304**. In another example implementation in which the localization and health-monitoring system **102** includes eight backscatter tags **106** arranged to form the linear arrays **306-1** and **306-2** of FIG. **4**, the localization and health-monitoring system **102** can have a location error of less than approximately twenty centimeters along the first axis **404-1** or the second axis **404-2**.

Example Method

[0074] FIG. **6** depicts an example method **600** for performing operations of localization and health monitoring. Method **600** is shown as sets of operations (or acts) performed but not necessarily limited to the order or combinations in which the operations are shown herein. Further, any of one or more of the operations may be repeated, combined, reorganized, or linked to provide a wide array of additional and/or alternate methods. In portions of the following discussion, reference may be made to the environment **100-1** to **100-5** of FIG. **1**, and entities detailed in FIG. **2** or **3**, reference to which is made for example only. The techniques are not limited to performance by one entity or multiple entities operating on one device.

[0075] At **602**, a radio-frequency signal is transmitted using an antenna of a reader. The radio-frequency signal interacts with two backscatter tags to form two backscatter signals. The two backscatter signals are reflected off of a person. For example, the reader **104** transmits the radio-frequency signal **308** using the antenna **202**, as shown in FIG. **3**. In some implementations, the reader **104** transmits the radio-frequency signal **308** with the first polarization **210-1**, such as a first circular polarization. The reader **104** can also transmit the radio-frequency signal **308** using a frequency-hopping spread-spectrum technique, which changes the frequency of the radio-frequency signal **308** between consecutive time intervals.

[0076] The radio-frequency signal **308** interacts with the two backscatter tags **106-1** to **106**-N to form the backscatter signals **310-1** to **310**-N, as shown in FIG. **3**. The backscatter signals **310-1** to **310**-N can have a same polarization as the radio-frequency signal **308**. The backscatter signals **310-1** to **310**-N can be formed at different times.

[0077] The backscatter signals **310-1** to **310**-N are reflected off of the person **304**, as shown in FIG. **3**. Due to the reflection, the reflected backscatter signals **310-1** to **310**-N can have an orthogonal polarization relative to the radio-frequency signal **308**. For example, the reflected backscatter signals **310-1** to **310**-N can have the second polarization **210-2**. The reflected backscatter signals **310-1** to **310**-N can include frequency components based on a vital sign of the person **304**. Also, the reflected backscatter signals **310-1** to **310**-N can include phases that are based on a location of the person **304**, a position of the reader **104**, and positions of the corresponding backscatter tags **106-1** to **106**-N.

[0078] At **604**, the two backscatter signals reflected by the at least one person are received using the antenna. For example, the reader **104** receives the reflected backscatter signals **310-1** to **310**-N using the antenna **202**. The reader **104** can receive the reflected backscatter signals **310-1** to **310**-N using the second polarization **210-2**, which is orthogonal to the first polarization **210-1**.

[0079] At **606**, a location of the person and a vital sign of the person are determined based on the two backscatter signals. For example, the reader **104** determines the location of the person **304** and the vital sign of the person **304** based on the backscatter signals **310-1** to **310**-N. The location can include a direction-of-arrival or a multi-dimensional location (e.g., X and Y coordinates, or X, Y, and Z coordinates) of the person **304**. The vital sign can include a breathing rate and/or a heart rate of the person **304**. The reader **104** can use holography and beamforming techniques to measure the position of the person **304** and the vital sign of the person **304**, as further described with respect to FIG. **5**.

Example Computing System

[0080] FIG. **7** illustrates various components of an example computing system **700** that can be implemented as any type of computing system to perform localization and health monitoring. The computing system **700** includes the reader **104** and the backscatter tags **106-1** to **106**-N of FIG. **2**. The computing system **700** also includes communication devices **702** that enable wired and/or wireless communication of device data **704**. The device data **704** or other device content can include localization and health data **518** generated by the reader **104**. The computing system **700** includes one or more data inputs **706** via which any type of data and/or inputs can be received, including the positions **510** of the reader **104** and the backscatter tags **106-1** to **106**-N.

[0081] The computing system **700** also includes communication interfaces **708**, which can be implemented as any one or more of a serial and/or parallel interface, a wireless interface, any type of network interface, a modem, and as any other type of communication interface. The communication interfaces **708** provide a connection and/or communication links between the computing system **700** and a communication network by which other electronic, computing, and communication devices communicate data with the computing system **700**.

[0082] The computing system **700** includes one or more processors **710** (e.g., any of microprocessors, controllers, and the like), which process various computer-executable instructions to control the operation of the computing system **700** and to enable techniques for, or in which can be embodied, localization and health monitoring. Alternatively or in addition, the computing system **700** can be implemented with any one or combination of hardware, firmware, or fixed logic circuitry that is implemented in connection with processing and control circuits which are generally identified at **712**. Although not shown, the computing system **700** can include a system bus or data transfer system that couples the various components within the system. A system bus can include any one or combination of different bus structures, such as a memory bus or memory controller, a peripheral bus, a universal serial bus, and/or a processor or local bus that utilizes any of a variety of bus architectures.

[0083] The computing system **700** also includes a computer-readable medium **714**, such as one or more memory devices that enable persistent and/or non-transitory data storage (i.e., in contrast to mere signal transmission), examples of which include random access memory (RAM), non-volatile memory (e.g., any one or more of a read-only memory (ROM), flash memory, EPROM, EEPROM, etc.), and a disk storage device. The disk storage device may be implemented as any type of magnetic or optical storage device, such as a hard disk drive, a recordable and/or rewriteable compact disc (CD), any type of a digital versatile disc (DVD), and the like. The computing system **700** can also include a mass storage media device (storage media) **716**.

[0084] The computer-readable medium **714** provides data storage mechanisms to store the device data **704**, as well as various device applications **718** and any other types of information and/or data related to operational aspects of the computing system **700**. For example, an operating system can be maintained as a computer application with the computer-readable medium **714** and executed on the processors **710**. The device applications **718** may include a device manager, such as any form of a control application, software application, signal-processing and control module, code that is native to a particular device, a hardware abstraction layer for a particular device, and so on.

[0085] The device applications **718** also include any system components, engines, or managers to implement localization and health monitoring. In this example, the device applications **718** includes the localization and health monitor **212** of FIG. **2**.

[0086] Although described with respect to health monitoring, the localization and health-monitoring system **102** can be designed to perform other operations in addition to or instead of health monitoring. In some implementations, the localization and health-monitoring system **102** can support other applications, including gesture recognition, fall detection, or collision avoidance.

CONCLUSION

[0087] Although techniques using, and apparatuses including, localization and health monitoring have been described in language specific to features and/or methods, it is to be understood that the subject of the appended claims is not necessarily limited to the specific features or methods described. Rather, the specific features and methods are disclosed as example implementations of localization and health monitoring.

[0088] Some examples are described below.

[0089] Example 1: A method performed by a reader, the method comprising:

[0090] transmitting a radio-frequency signal using an antenna of the reader, the radio-frequency signal interacting with two backscatter tags to form two backscatter signals, the two backscatter signals reflected off of a person;

[0091] receiving the two backscatter signals reflected off of the person using the antenna; and

[0092] determining, based on the two backscatter signals, a location of the person and a vital sign of the person.

[0093] Example 2: The method of example 1, wherein:

[0094] the two backscatter signals are reflected off of another person; and

[0095] the determining comprises determining a location of the other person and a vital sign of the other person.

[0096] Example 3: The method of example 1 or 2, wherein,

[0097] the transmitting of the radio-frequency signal comprises transmitting the radio-frequency signal in a direction towards the two backscatter tags; and

[0098] the receiving of the two backscatter signals comprises receiving the two backscatter signals from a direction associated with an area of interest in which the person is located.

[0099] Example 4: The method of example 3, wherein the area of interest comprises:

[0100] a room in a building;

[0101] a bed;

[0102] a desk; or

[0103] a vehicle.

[0104] Example 5: The method of any preceding example, wherein:

[0105] the transmitting of the radio-frequency signal comprises transmitting the radio-frequency signal with a first polarization that is co-polarized with antennas of the backscatter tags; and

[0106] the receiving of the radio-frequency signal comprises receiving the radio-frequency signal with a second polarization that is cross-polarized with the antennas of the backscatter tags.

[0107] Example 6: The method of example 5, wherein:

[0108] the first polarization comprises a first circular polarization; and

[0109] the second polarization comprises a second circular polarization that is orthogonal to the first circular polarization.

[0110] Example 7: The method of example 6, wherein:

[0111] the first circular polarization comprises a left-hand circular polarization; and

[0112] the second circular polarization comprises a right-hand circular polarization.

[0113] Example 8: The method of any preceding example, wherein the vital sign comprises at least one of a breathing rate or a heart rate.

[0114] Example 9: The method of any preceding example, wherein:

[0115] the transmitting of the radio-frequency signal comprises transmitting the radio-frequency signal using a frequency-hopping spread-spectrum technique; and

[0116] the determining comprises calibrating input responses associated with the two backscatter signals to reduce variations caused by the frequency-hopping spread-spectrum technique.

[0117] Example 10: A reader comprising at least one antenna, the reader configured to perform any of the methods of claims **1** to **9**.

[0118] Example 11: The reader of example 10, wherein the at least one antenna comprises:

[0119] a transmit antenna; and

[0120] a receive antenna.

[0121] Example 12: The reader of example 10, wherein the at least one antenna is configured to transmit and receive radio-frequency signals with orthogonal circular polarizations.

[0122] Example 13: A system comprising:

[0123] at least two backscatter tags; and

[0124] a reader comprising at least one antenna, the reader configured to perform any of the methods of claims **1** to **9**.

[0125] Example 14: The system of example 13, wherein the at least two backscatter tags comprise at least four backscatter tags.

[0126] Example 15: The system of example 14, wherein an arrangement of the at least four backscatter tags forms a linear array.

[0127] Example 16: The system of example 14, wherein:

[0128] the at least four backscatter tags comprise:

[0129] a first set of backscatter tags; and

[0130] a second set of backscatter tags;

[0131] an arrangement of the first set of backscatter tags forms a first linear array along a first axis; and

[0132] an arrangement of the second set of backscatter tags forms a second linear array along a second axis that is approximately perpendicular to the first axis.

[0133] Example 17: The system of any one of examples 13-15, wherein a spacing between the at least two backscatter tags is greater than half a wavelength.

[0134] Example 18: The system of claim **17**, wherein the spacing between the at least two backscatter tags is approximately equal to three-quarters of a wavelength.

[0135] Example 19: The system of any one of examples 13-18, wherein:

[0136] the reader comprises a radio-frequency identification reader; and

[0137] the at least two backscatter tags comprise at least two radio-frequency identification tags.

[0138] Example 20: The system of example 19, wherein the radio-frequency identification tags and the radio-frequency identification reader are configured according to an ultra-high frequency band or an extremely-high frequency band.

1. A method performed by a reader, the method comprising:

transmitting a radio-frequency signal using an antenna of the reader, the radio-frequency signal interacting with two backscatter tags to form two backscatter signals, the two backscatter signals reflected off of a person;

receiving the two backscatter signals reflected off of the person using the antenna; and determining, based on the two backscatter signals, a location of the person and a vital sign of the person.

2. The method of claim **1**, wherein:

the two backscatter signals are reflected off of another person; and

the determining comprises determining a location of the other person and a vital sign of the other person.

3. The method of claim **1**, wherein,

the transmitting of the radio-frequency signal comprises transmitting the radio-frequency signal in a direction towards the two backscatter tags; and

the receiving of the two backscatter signals comprises receiving the two backscatter signals from a direction associated with an area of interest in which the person is located.

4. The method of claim **3**, wherein the area of interest comprises:

a room in a building;

a bed;

a desk; or

a vehicle.

5. The method of claim **1**, wherein:

the transmitting of the radio-frequency signal comprises transmitting the radio-frequency signal with a first polarization that is co-polarized with antennas of the backscatter tags; and

the receiving of the radio-frequency signal comprises receiving the radio-frequency signal with a second polarization that is cross-polarized with the antennas of the backscatter tags.

6. The method of claim **5**, wherein:

the first polarization comprises a first circular polarization; and

the second polarization comprises a second circular polarization that is orthogonal to the first circular polarization.

7. The method of claim **6**, wherein:

the first circular polarization comprises a left-hand circular polarization; and

the second circular polarization comprises a right-hand circular polarization.

8. The method of claim **1**, wherein the vital sign comprises at least one of a breathing rate or a heart rate.

9. The method of claim **1**, wherein:

the transmitting of the radio-frequency signal comprises transmitting the radio-frequency signal using a frequency-hopping spread-spectrum technique; and

the determining comprises calibrating input responses associated with the two backscatter signals to reduce variations caused by the frequency-hopping spread-spectrum technique.

10. A reader comprising at least one antenna, the reader configured to:

transmit a radio-frequency signal using the at least one antenna, the radio-frequency signal interacting with two backscatter tags to form two backscatter signals, the two backscatter signals reflected off of a person;

receive the two backscatter signals reflected off of the person using the at least one antenna; and

determine, based on the two backscatter signals, a location of the person and a vital sign of the person.

11. The reader of claim **10**, wherein the at least one antenna comprises:

a transmit antenna; and

a receive antenna.

12. The reader of claim **10**, wherein the at least one antenna is configured to transmit and receive radio-frequency signals with orthogonal circular polarizations.

13. A system comprising:

at least two backscatter tags; and

a reader comprising at least one antenna, the reader configured to:

transmit a radio-frequency signal using the at least one antenna, the radio-frequency signal interacting with the at least two backscatter tags to form at least two backscatter signals, the at least two backscatter signals reflected off of a person;

receive the at least two backscatter signals reflected off of the person using the at least one antenna; and

determine, based on the at least two backscatter signals, a location of the person and a vital sign of the person.

14. The system of claim **13**, wherein the at least two backscatter tags comprise at least four backscatter tags.

15. The system of claim **14**, wherein an arrangement of the at least four backscatter tags forms a linear array.

16. The system of claim **14**, wherein:

the at least four backscatter tags comprise:

a first set of backscatter tags; and

a second set of backscatter tags;

an arrangement of the first set of backscatter tags forms a first linear array along a first axis; and

an arrangement of the second set of backscatter tags forms a second linear array along a second axis that is approximately perpendicular to the first axis.

17. The system of claim **13**, wherein a spacing between the at least two backscatter tags is greater than half a wavelength.

18. The system of claim **17**, wherein the spacing between the at least two backscatter tags is approximately equal to three-quarters of a wavelength.

19. The system of claim **13**, wherein:

the reader comprises a radio-frequency identification reader; and

the at least two backscatter tags comprise at least two radio-frequency identification tags.

20. The system of claim **19**, wherein the radio-frequency identification tags and the radio-frequency identification reader are configured according to an ultra-high frequency band or an extremely-high frequency band.

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