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(54) **WIDE-FIELD RADAR-BASED GESTURE RECOGNITION**

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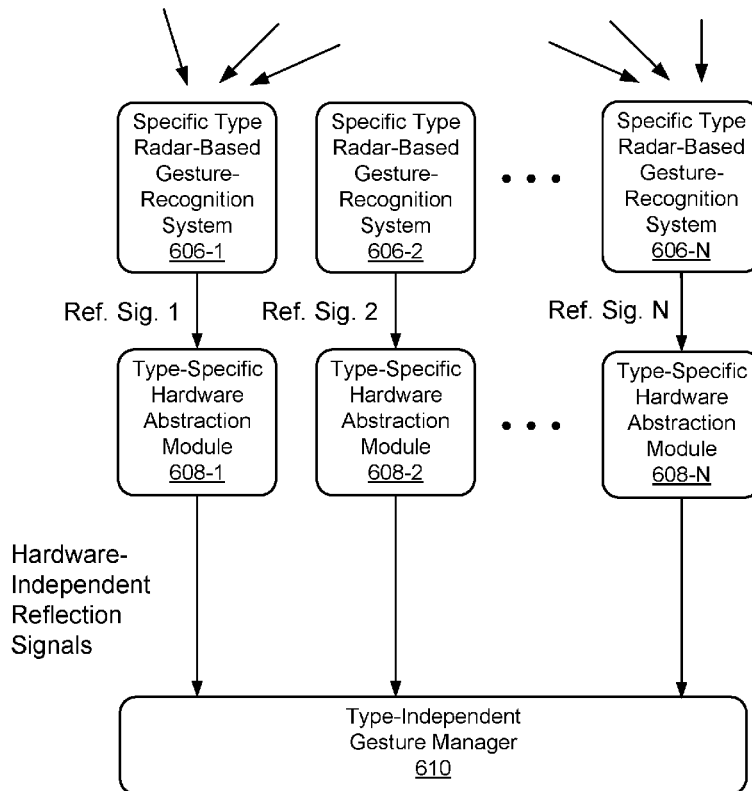
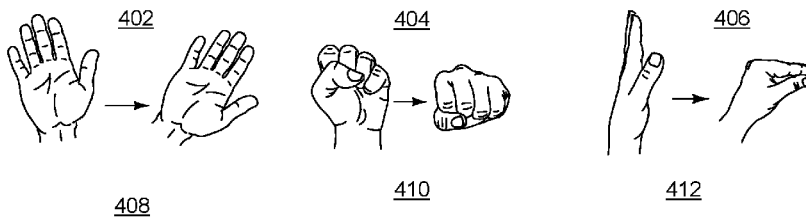
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CPC **G06F 3/017** (2013.01); **G06K 9/00355** (2013.01); **G06F 3/0325** (2013.01)

(57)

ABSTRACT

This document describes techniques using, and devices embodying, wide-field radar-based gesture recognition. These techniques and devices can enable a great breadth of gestures and uses for those gestures, such as gestures to use, control, and interact with computing and non-computing devices, from software applications to refrigerators.



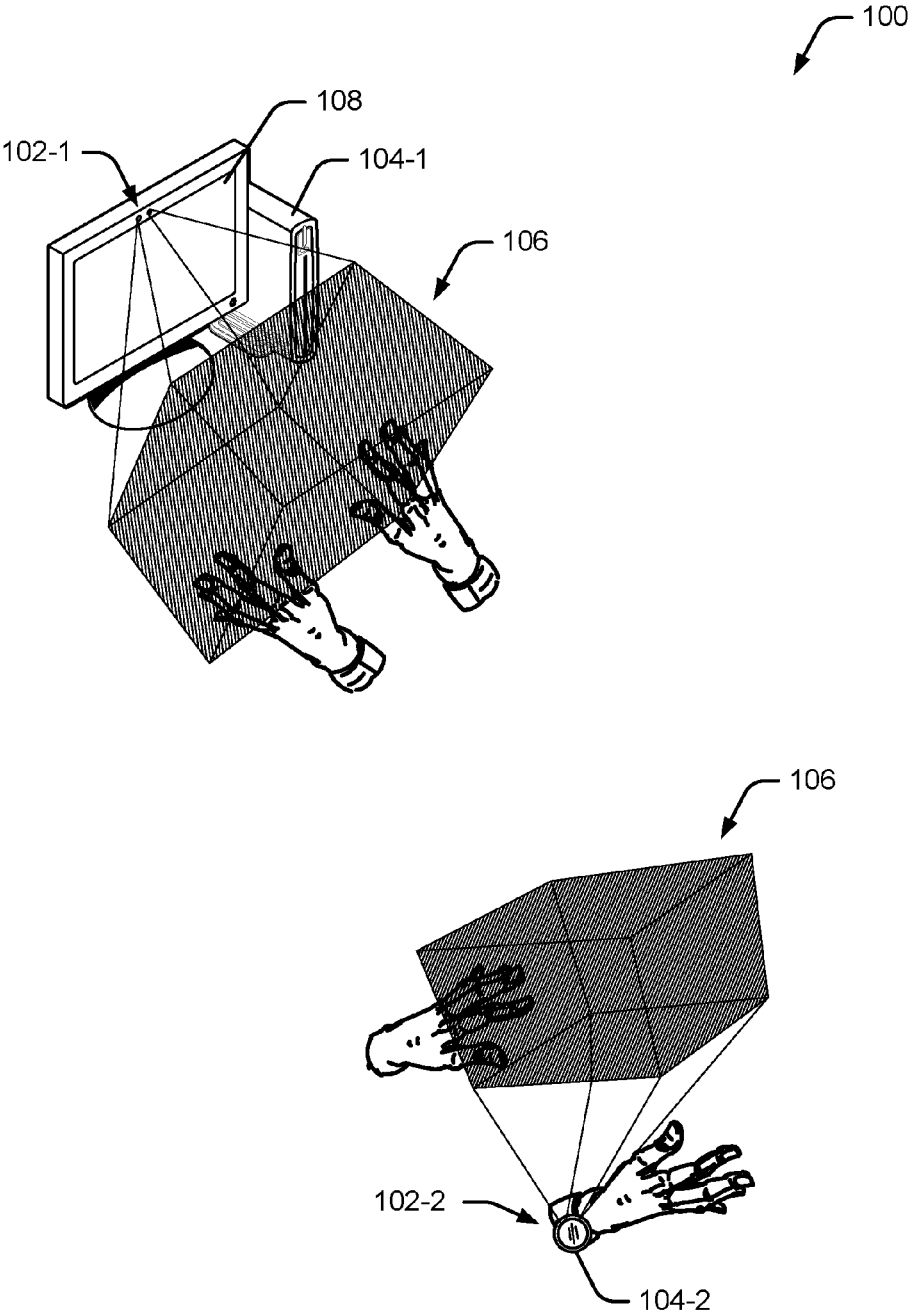


Fig. 1

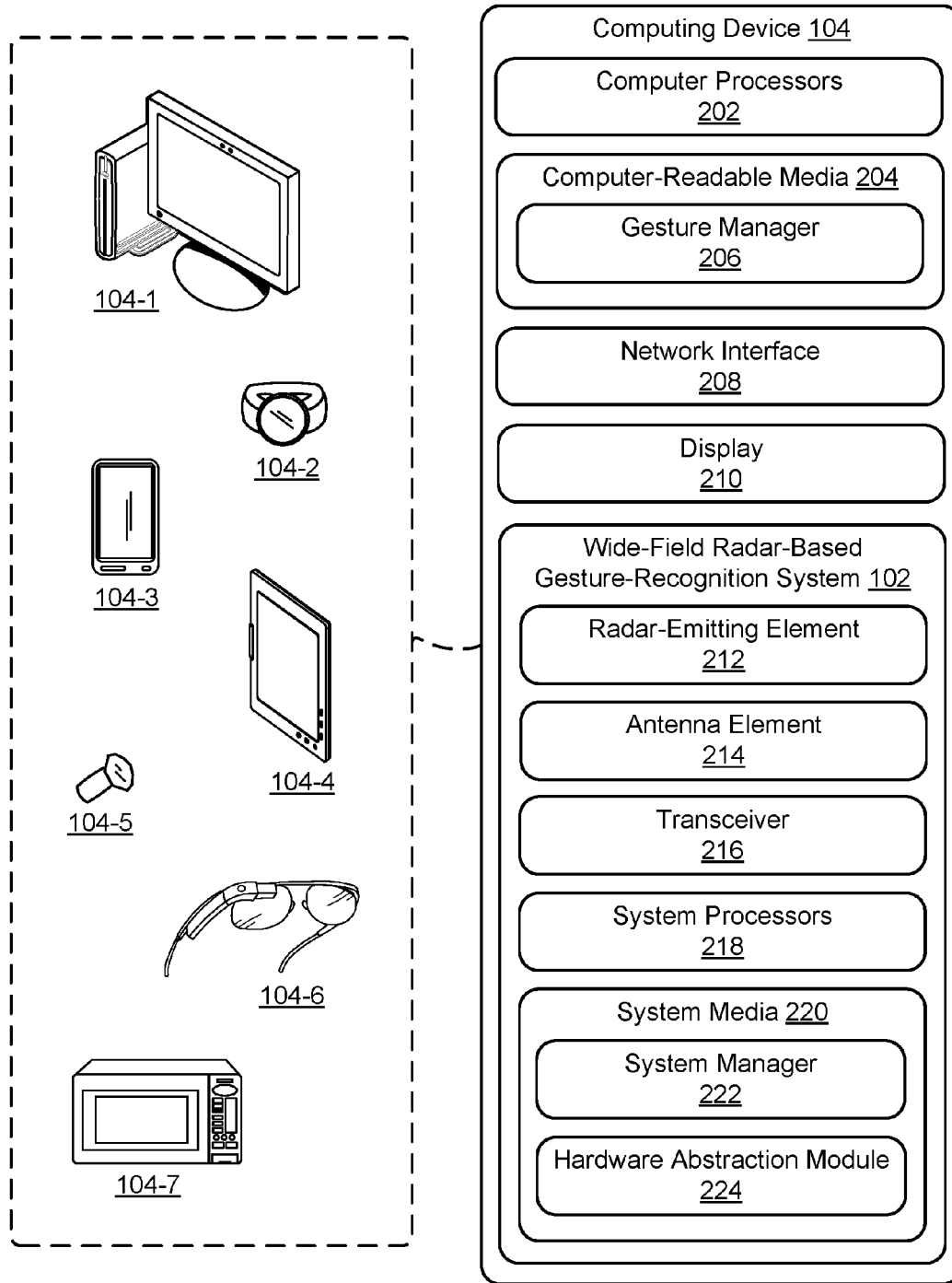


Fig. 2

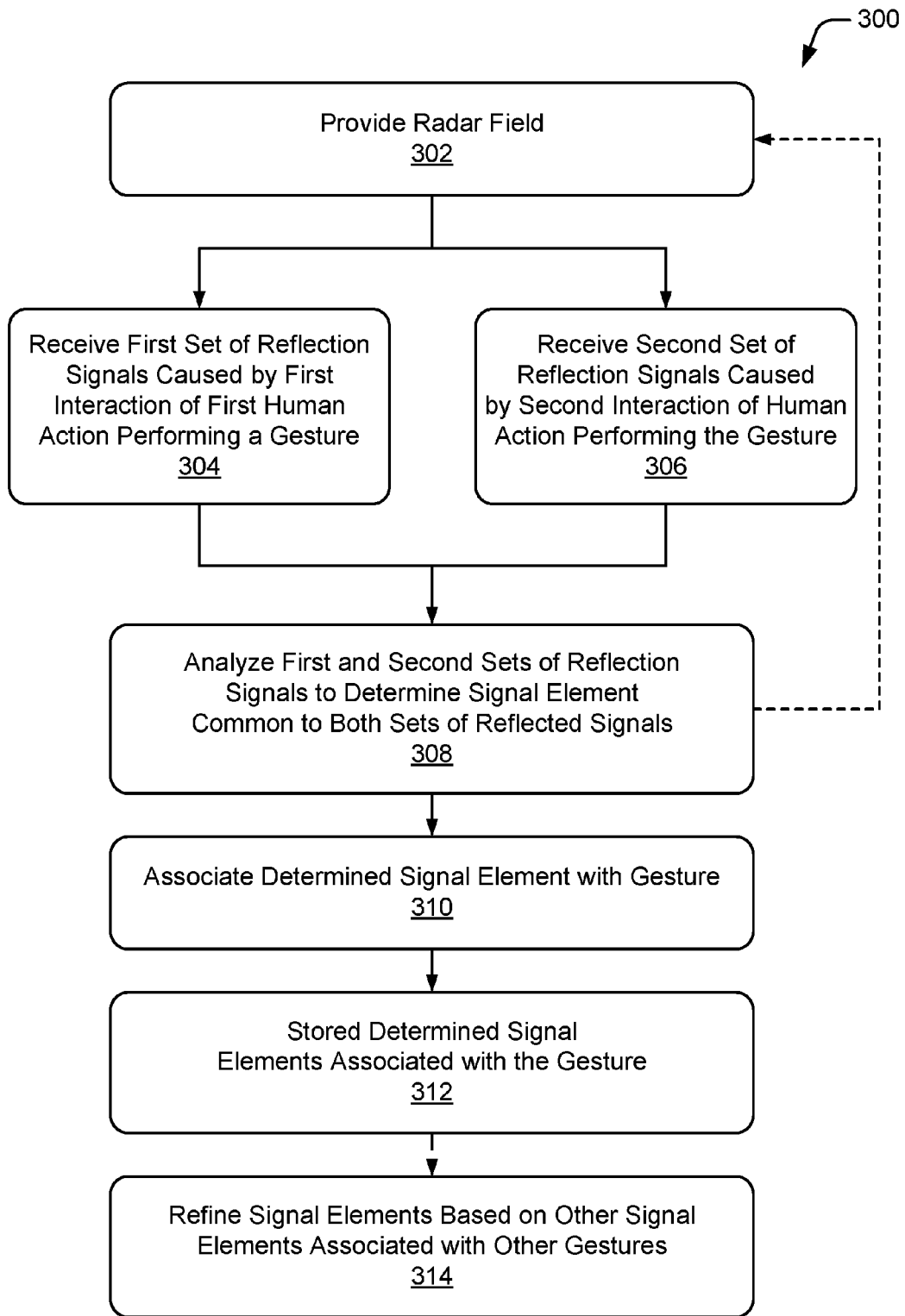


Fig. 3

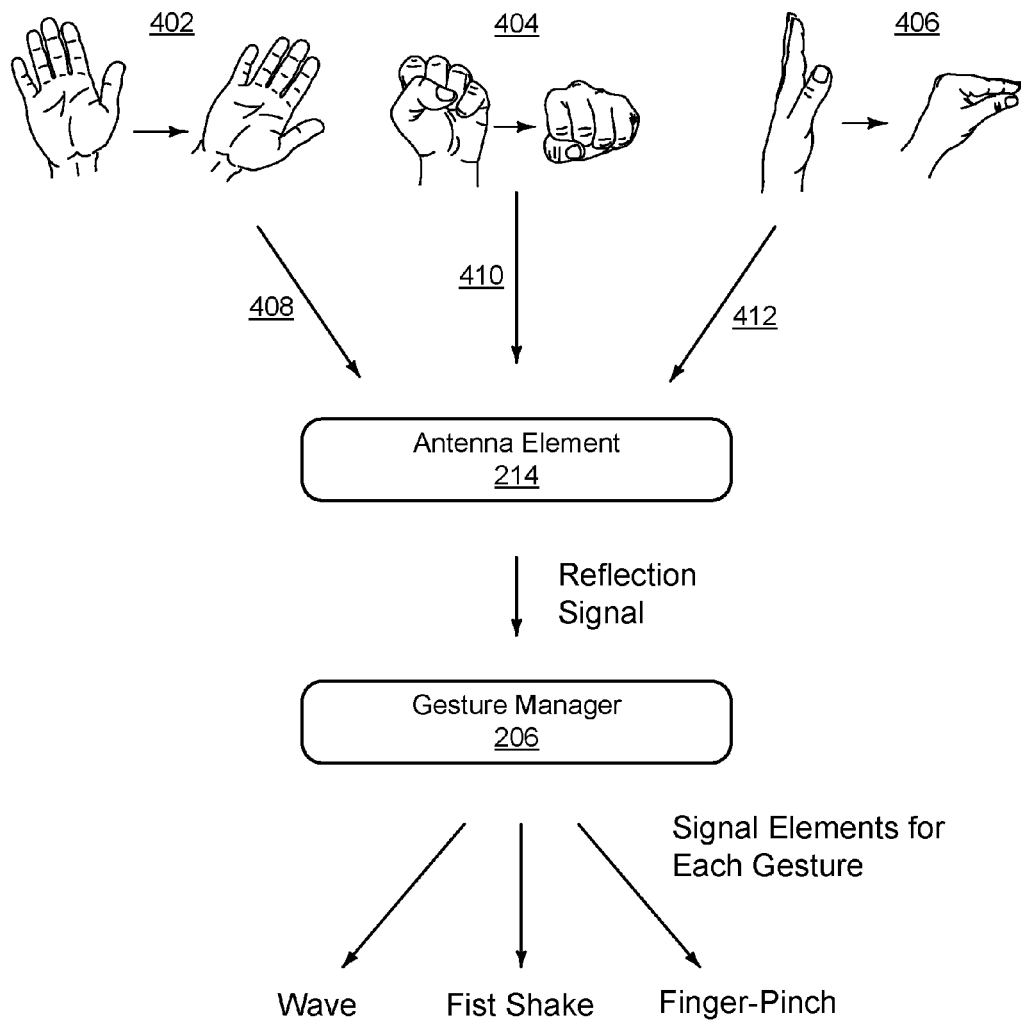


Fig. 4

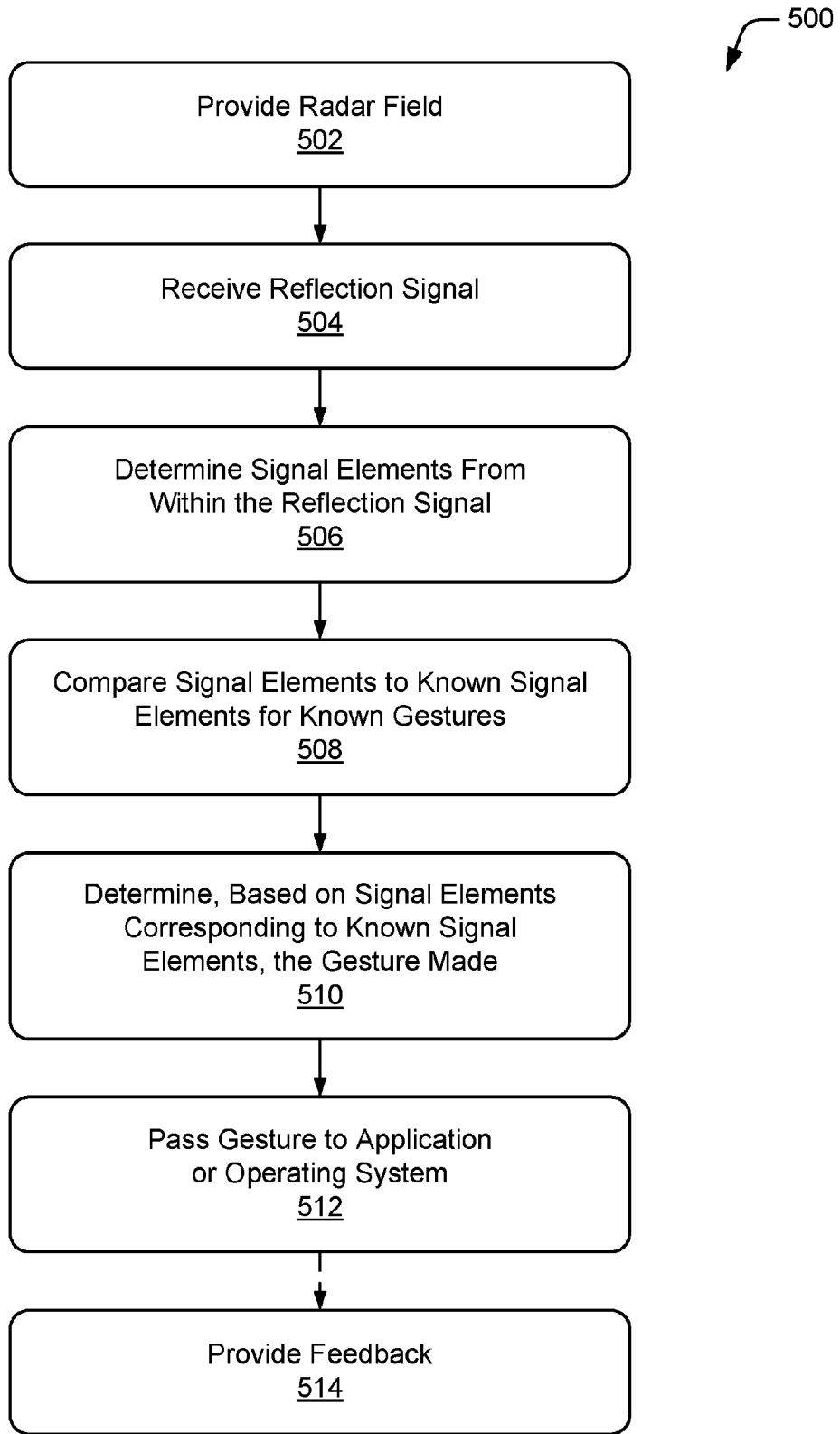


Fig. 5

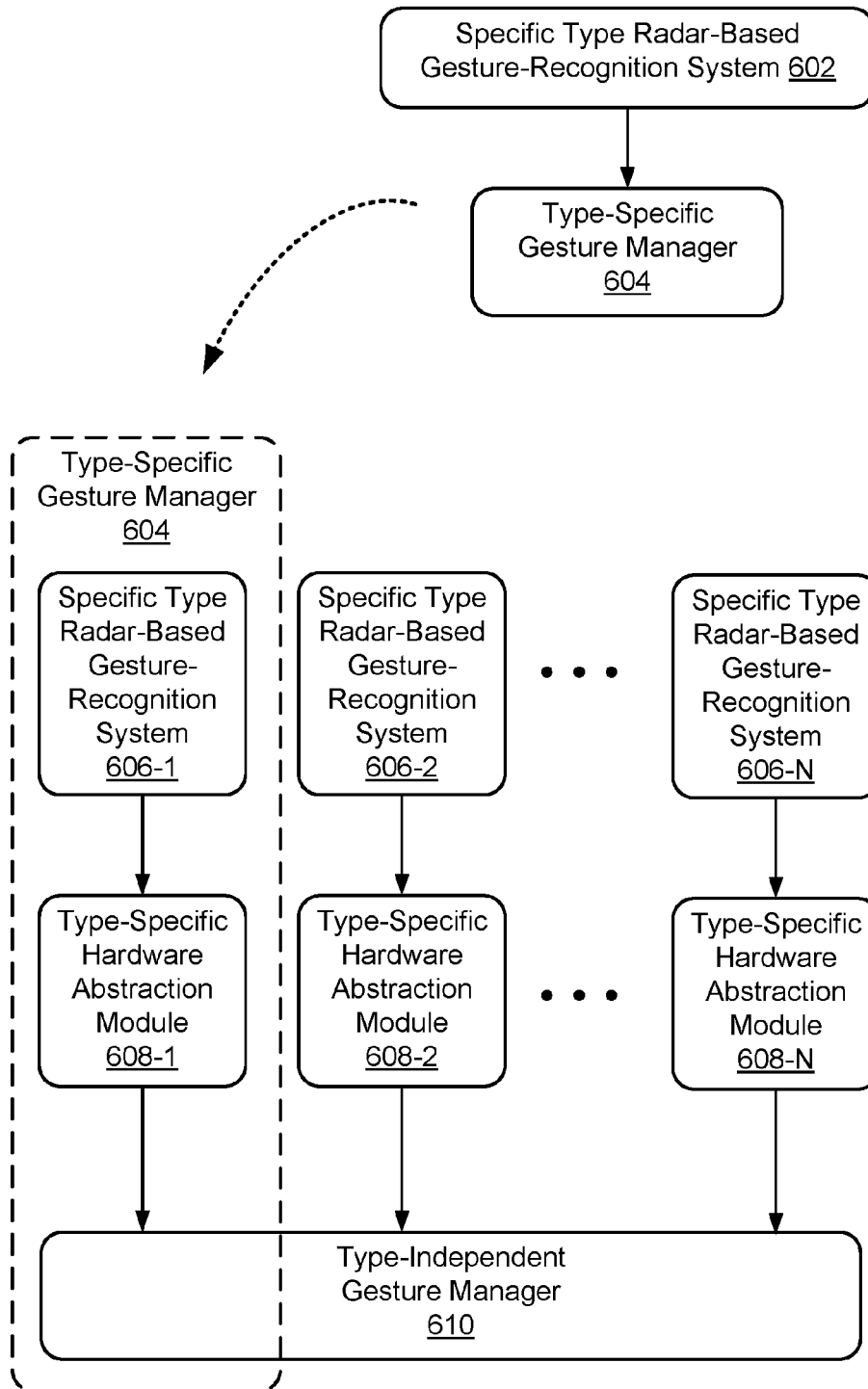


Fig. 6

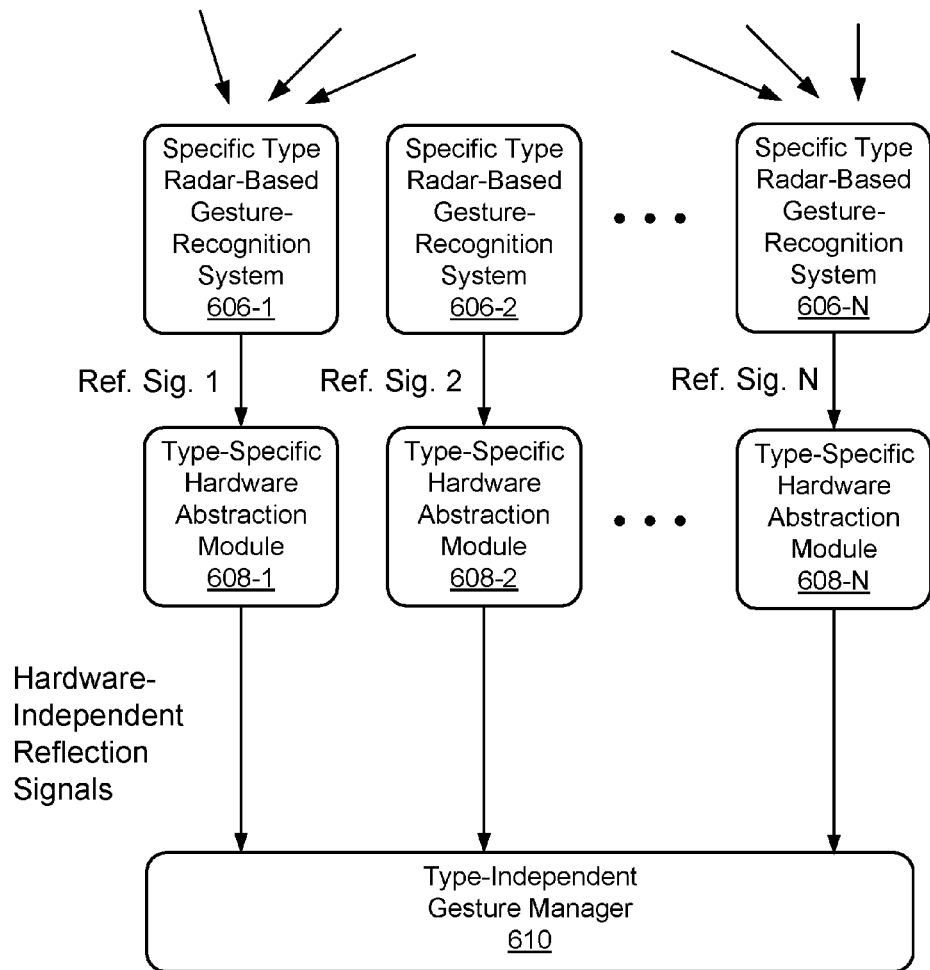
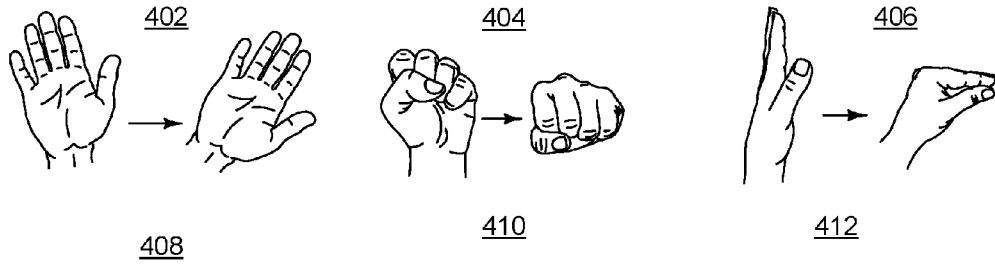


Fig. 7

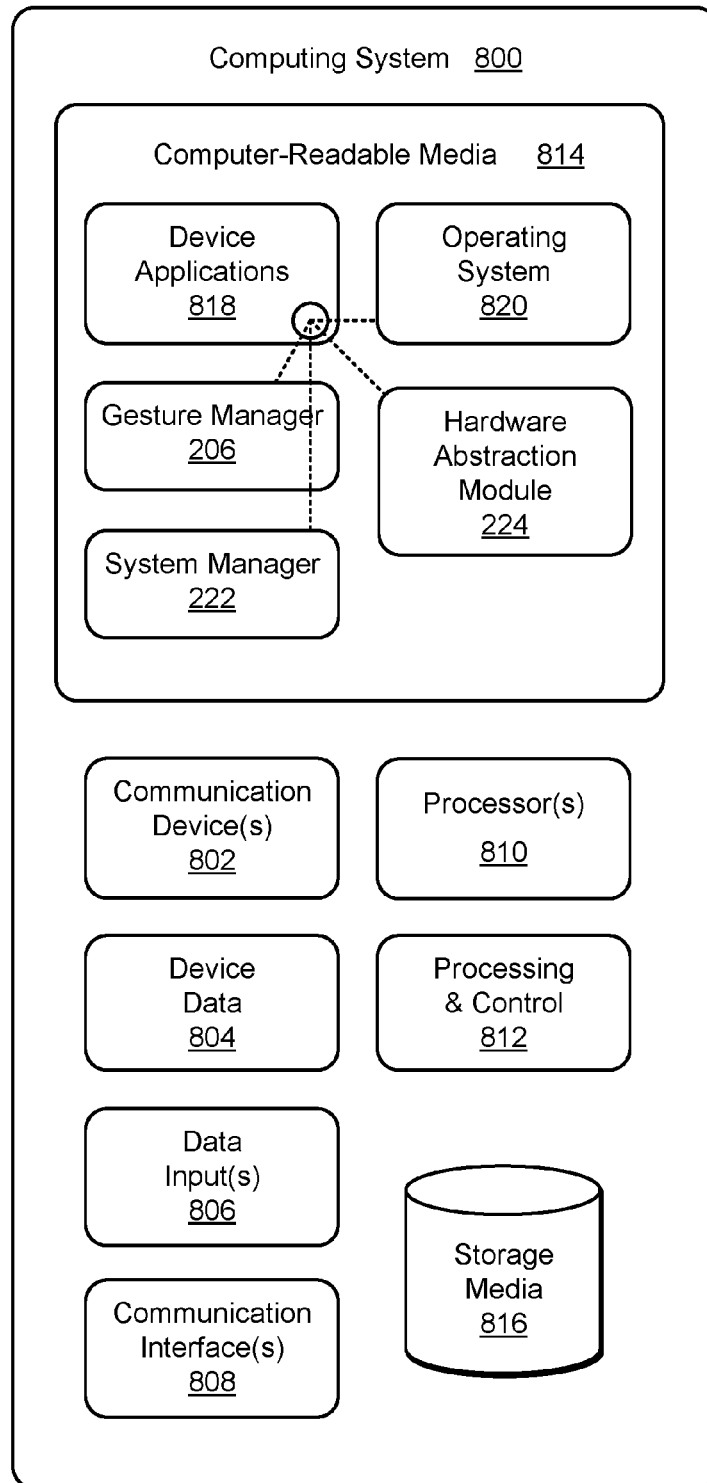


Fig. 8

WIDE-FIELD RADAR-BASED GESTURE RECOGNITION

RELATED APPLICATION

[0001] This application claims priority to U.S. Provisional Patent Application Ser. No. 62/155,357 filed Apr. 30, 2015, the disclosure of which is incorporated by reference herein in its entirety.

BACKGROUND

[0002] Small-screen computing devices continue to proliferate, such as smartphones and computing bracelets, rings, and watches. Like many computing devices, these small-screen devices often use virtual keyboards to interact with users. On these small screens, however, many people find interacting through virtual keyboards to be difficult, as they often result in slow and inaccurate inputs. This frustrates users and limits the applicability of small-screen computing devices. This problem has been addressed in part through screen-based gesture recognition techniques. These screen-based gestures, however, still struggle from substantial usability issues due to the size of these screens.

[0003] To address this problem, optical finger- and hand-tracking techniques have been developed, which enable gesture tracking not made on the screen. These optical techniques, however, have been large, costly, or inaccurate thereby limiting their usefulness in addressing usability issues with small-screen computing devices.

[0004] One other manner has recently been developed where gestures are tracked using radar. Current radar techniques, however, often require a large antenna array and suffer from numerous practical difficulties. These large antenna arrays use thin-beam scanning techniques to locate a large number of points in space, including points of a human action (e.g., fingers, arm, or hand). These techniques track these points of a human action and the other points in space and then determine which points are associated with the human action and which are not. With these action points determined, the techniques track their movement and, based on these movements of the points of the action, reconstruct the action throughout the movement. With this reconstructed movement, the techniques then determine a gesture associated with those movements. This permits some rudimentary gesture recognition but is limited by the large antenna array and the computational difficulties and resource requirements inherent in using thin-beam scanning techniques.

SUMMARY

[0005] This document describes techniques and devices for wide-field radar-based gesture recognition. These techniques and devices can accurately recognize gestures that are made in three dimensions, such as non-screen or “in-the-air” gestures. These in-the-air gestures can be made from varying distances, such as from a person sitting on a couch to control a television, a person standing in a kitchen to control an oven or refrigerator, or centimeters from a computing watch’s small-screen display.

[0006] This summary is provided to introduce simplified concepts concerning wide-field radar-based gesture recognition, which is further described below in the Detailed Description. This summary is not intended to identify essen-

tial features of the claimed subject matter, nor is it intended for use in determining the scope of the claimed subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] Embodiments of techniques and devices for wide-field radar-based gesture recognition 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 an example environment in which wide-field radar-based gesture recognition can be implemented.

[0009] FIG. 2 illustrates the wide-field radar-based gesture-recognition system and computing device of FIG. 1 in detail.

[0010] FIG. 3 illustrates an example method for determining signal elements for a gesture.

[0011] FIG. 4 illustrates gestures made and signal elements determined based on those gestures.

[0012] FIG. 5 illustrates an example method enabling wide-field radar-based gesture recognition using the signal elements determined at FIG. 3.

[0013] FIG. 6 illustrates example type-specific and type-independent gesture managers, including example type-specific hardware abstraction modules.

[0014] FIG. 7 illustrates an example of gestures made and signal elements determined using type-specific hardware abstraction modules.

[0015] FIG. 8 illustrates an example computing system embodying, or in which techniques may be implemented that enable use of, wide-field radar-based gesture recognition.

DETAILED DESCRIPTION

[0016] Overview

[0017] This document describes techniques and devices enabling wide-field radar-based gesture recognition. These techniques and devices enable a great breadth of gestures and uses for those gestures, such as gestures to use, control, and interact with various devices, from smartphones to refrigerators. The techniques and devices are capable of providing a wide radar field that can sense gestures using relatively small radar systems, even those that can be included within small devices. Furthermore, these techniques need not track and reconstruct points of a human action to determine gestures, which has various advantages described below.

[0018] This document now turns to an example environment, after which example wide-field radar-based gesture-recognition systems and radar fields, example methods, example techniques and devices for development of hardware abstraction modules, and an example computing system are described.

[0019] Example Environment

[0020] FIG. 1 is an illustration of example environment **100** in which techniques using, and an apparatus including, a wide-field radar-based gesture-recognition system **102** may be embodied. Environment **100** includes two example devices and techniques for using wide-field radar-based gesture-recognition system **102**, in the first, wide-field radar-based gesture-recognition system **102-1** provides a radar field of intermediate size to interact with one of computing

devices **104**, desktop computer **104-1**, and in the second, wide-field radar-based gesture-recognition system **102-2** provides a radar field of small size to interact with computing watch **104-2**.

[0021] Desktop computer **104-1** includes, or is associated with, wide-field radar-based gesture-recognition system **102-1**. These devices work together to improve user interaction with desktop computer **104-1**. Assume, for example, that desktop computer **104-1** includes a touch screen **108** through which display and user interaction can be performed. This touch screen **108** can present some challenges to users, such as needing a person to sit in a particular orientation, such as upright and forward, to be able to touch the screen. Further, the size for selecting controls through touch screen **108** can make interaction difficult and time-consuming for some users. Consider, however, wide-field radar-based gesture-recognition system **102-1**, which provides radar field **106-1** enabling a user's hands to interact with desktop computer **104-1**, such as with small or large, simple or complex gestures, including those with one or two hands, and in three dimensions. As is readily apparent, a large volume through which a user may make selections can be substantially easier and provide a better experience over a flat surface, such as that of touch screen **108**.

[0022] Similarly, consider wide-field radar-based gesture-recognition system **102-2**, which provides radar field **106-2**, which enables a user to interact with computing watch **104-2** from a near distance, enabling finger, hand, and arm gestures. By so doing, user selections can be made simpler and easier than a small screen of a small computing device, such as that of computing watch **104-2**.

[0023] Wide-field radar-based gesture-recognition systems **102** can interact with applications or an operating system of computing devices **104**, or remotely through a communication network by transmitting input responsive to recognizing gestures. Gestures can be mapped to various applications and devices, thereby enabling control of many devices and applications. Many complex and unique gestures can be recognized by wide-field radar-based gesture-recognition systems **102**, thereby permitting precise and/or single-gesture control, even for multiple applications. Wide-field radar-based gesture-recognition systems **102**, whether integrated with a computing device, having computing capabilities, or having few computing abilities, can each be used to interact with various devices and applications.

[0024] In more detail, consider FIG. 2, which illustrates wide-field radar-based gesture-recognition system **102** as part of one of computing device **104**. Computing device **104** is illustrated with various non-limiting example devices, the noted desktop computer **104-1**, computing watch **104-2**, as well as smartphone **104-3**, tablet **104-4**, computing ring **104-5**, computing spectacles **104-6**, and microwave **104-7**, though other devices may also be used, such as home automation and control systems, entertainment systems, audio systems, other home appliances, security systems, netbooks, and e-readers. Note that computing device **104** can be wearable, non-wearable but mobile, or relatively immobile (e.g., desktops and appliances).

[0025] Note also that wide-field radar-based gesture-recognition system **102** can be used with, or embedded within, many different computing devices or peripherals, such as in walls of a home to control home appliances and systems (e.g., automation control panel), in automobiles to control internal functions (e.g., volume, cruise control, or even

driving of the car), or as an attachment to a laptop computer to control computing applications on the laptop.

[0026] Further, radar fields **106** can be invisible and penetrate some materials, such as textiles, thereby further expanding how the wide-field radar-based gesture-recognition system **102** can be used and embodied. While examples shown herein generally show one wide-field radar-based gesture-recognition system **102** per device, multiples can be used, thereby increasing a number and complexity of gestures, as well as accuracy and robust recognition.

[0027] Computing device **104** includes one or more computer processors **202** and computer-readable media **204**, which includes memory media and storage media. Applications and/or an operating system (not shown) embodied as computer-readable instructions on computer-readable media **204** can be executed by processors **202** to provide some of the functionalities described herein. Computer-readable media **204** also includes gesture manager **206** (described below).

[0028] Computing device **104** may also include network interfaces **208** for communicating data over wired, wireless, or optical networks and display **210**. By way of example and not limitation, network interface **208** may communicate data over a local-area-network (LAN), a wireless local-area-network (WLAN), a personal-area-network (PAN), a wide-area-network (WAN), an intranet, the Internet, a peer-to-peer network, point-to-point network, a mesh network, and the like.

[0029] Wide-field radar-based gesture-recognition system **102**, as noted above, is configured to sense gestures. To enable this, wide-field radar-based gesture-recognition system **102** includes a radar-emitting element **212** and an antenna element **214**.

[0030] Generally, radar-emitting element **212** is configured to provide wide-field radar in contrast to narrow-beam-scanning radar fields. In one embodiment, a large contiguous field is used, rather than a beam-scanning field. The reflections in that field can then be received by one or multiple antennas. This reflection signal includes many signals and signal elements, and therefore may be referred to as a reflection signal or a set of reflection signals, but in both cases multiple signal elements are included. In one case, a large radar field and large-field reflections are received at one receiver but the signal received is processed by digitally breaking up the received reflections. The broken-up signals are then analyzed separately. This can be referred to as beam steering though no beams are actually formed in the large radar field. Other digital processing may be used, such as phase arrays in which fields of different phases are admitted, each for analysis of the reflection signals.

[0031] In another embodiment multiple fields are used but from different directions or having other differences, such as different frequencies or phases, and which can be received by one or multiple dedicated receivers (e.g., antenna elements **214**).

[0032] More specifically, these fields include numerous kinds of radar fields, such as those from continuous wave and pulsed radar systems, and may exclude phased antenna arrays. Pulsed radar systems are often of shorter transmit time and higher peak power, and include both impulse and chirped radar systems. Pulsed radar systems have a range based on time of flight and a velocity based on frequency

shift. Chirped radar systems have a range based on time of flight (pulse compressed) and a velocity based on frequency shift.

[0033] Continuous wave radar systems are often of relatively longer transmit time and lower peak power. These continuous wave radar systems include single tone, linear frequency modulated (FM), and stepped FM types. Single tone radar systems have a very limited range based on the phase and a velocity based on frequency shift. Linear FM radar systems have a range based on frequency shift at a velocity also based on frequency shift. Stepped FM radar systems have a range based on phase or time of flight and a velocity based on frequency shift. While these five types of radar systems are noted herein, others may also be used, such as sinusoidal modulation scheme radar systems.

[0034] Radar fields provided by these types of radar systems vary from a small size, such as zero or one or so millimeters to 1.5 meters, or an intermediate size, such as about one to about 30 meters. In the intermediate size, antenna element **214** is configured to receive and process reflections of the radar field to provide large-body gestures based on reflections from human tissue caused by body, arm, or leg movements, though smaller and more-precise gestures can be sensed as well. Example intermediate-sized radar fields include those in which a user makes gestures to control a television from a couch, change a song or volume from a stereo across a room, turn off an oven or oven timer (a near field would also be useful), turn lights on or off in a room, and so forth.

[0035] Radar-emitting element **212** can instead be configured to provide a wide radar field from little if any distance from a computing device or its display, including radar fields that are a full contiguous field in contrast to beam-scanning radar field. Examples are illustrated in FIG. 1 with radar fields **106**.

[0036] Radar-emitting element **212** can be configured to provide the wide-field radars of the various types set forth above. Antenna element **214** is configured to receive reflections of, or sense interactions in, the radar field. In some cases, reflections include those from human tissue that is within the radar field, such as a hand or arm movement. Antenna element **214** can include one or many antennas or sensors, such as an array of radiation sensors, the number in the array based on a desired resolution and whether the field is a surface or volume.

[0037] The field provided by radar-emitting element **212** can be a three-dimensional (3D) volume (e.g., hemisphere, cube, volumetric fan, cone, or cylinder) to sense in-the-air gestures, though a surface field (e.g., projecting on a surface of a person) can instead be used. Antenna element **214** is configured, in some cases, to receive reflections from interactions in the radar field of two or more targets (e.g., fingers, arms, or persons) and provide a composite signal.

[0038] Example radar fields **106** are illustrated in FIG. 1 in which a user may perform complex or simple gestures with his or her arm, body, finger, fingers, hand, or hands (or a device like a stylus) that interrupts the radar field. Example gestures include the many gestures usable with current touch-sensitive displays, such as swipes, two-finger pinch, spread, rotate, tap, and so forth. Other gestures are enabled that are complex, or simple but three-dimensional, examples include the many sign-language gestures, e.g., those of American Sign Language (ASL) and other sign languages worldwide. A few examples of these are: an up-and-down

gesture, which in ASL means “Yes”; an open index and middle finger moving to connect to an open thumb, which means “No”; a flat hand moving up a step, which means “Advance”; a flat and angled hand moving up and down; which means “Afternoon”; clenched fingers and open thumb moving to open fingers and an open thumb, which means “taxicab”; an index finger moving up in a roughly vertical direction, which means “up”; and so forth. These are but a few of many gestures that can be sensed as well as be mapped to particular devices or applications, such as the advance gesture to skip to another song on a web-based radio application, a next song on a compact disk playing on a stereo, or a next page or image in a file or album on a computer display or digital picture frame.

[0039] Returning to FIG. 2, wide-field radar-based gesture-recognition system **102** also includes a transmitting device configured to transmit a reflection signal to a remote device, though this need not be used when wide-field radar-based gesture-recognition system **102** is integrated with computing device **104**. When included, the reflection signal can be provided in a format usable by a remote computing device sufficient for the remote computing device to determine the gesture in those cases where the gesture is not determined by wide-field radar-based gesture-recognition system **102** or computing device **104**.

[0040] In more detail, radar-emitting element **212** can be configured to emit microwave radiation in a 1 GHz to 300 GHz range, a 3 GHz to 100 GHz range, and narrower bands, such as 57 GHz to 63 GHz, to provide the radar field. This range affects antenna element **214**'s ability to receive interactions, such as to follow locations of two or more targets to a resolution of about two to about 25 millimeters. Radar-emitting element **212** can be configured, along with other entities of wide-field radar-based gesture-recognition system **102**, to have a relatively fast update rate, which can aid in resolution of the interactions.

[0041] By selecting particular frequencies, wide-field radar-based gesture-recognition system **102** can operate to substantially penetrate clothing while not substantially penetrating human tissue. Thus, a person wearing gloves or a long sleeve shirt that could interfere with sensing gestures with some conventional techniques, can still be sensed with wide-field radar-based gesture-recognition system **102**.

[0042] Wide-field radar-based gesture-recognition system **102** may also include one or more system processors **218** and system media **220** (e.g., one or more computer-readable storage media). System media **220** includes system manager **222** and hardware abstraction module **224**. System manager **222** can perform various operations, including determining a gesture based on the reflection signal, mapping the determined gesture to a pre-configured control gesture associated with a control input for an application associated with touch screen **108**, and causing transceiver **216** to transmit the control input to the remote device effective to enable control of the application (if remote). This is but one of the ways in which the above-mentioned control through wide-field radar-based gesture-recognition system **102** can be enabled. Operations of system manager **222** are provided in greater detail as part of methods **300** and **500** below. Hardware abstraction module **224** is part of an alternative embodiment described in FIGS. 6 and 7 below.

[0043] These and other capabilities and configurations, as well as ways in which entities of FIGS. 1 and 2 act and interact, are set forth in greater detail below. These entities

may be further divided, combined, and so on. The environment **100** of FIG. **1** and the detailed illustrations of FIG. **2** illustrate some of many possible environments and devices capable of employing the described techniques.

[0044] Example Methods

[0045] FIGS. **3** and **5** depict methods enabling wide-field radar-based gesture recognition. Method **300** determines signal elements that can be used to enable determination of a gesture from a later-received reflection signal having the signal elements. Method **500** determines a gesture from reflection signals based on signal elements associated with the gesture. These methods are shown as sets of blocks that specify operations performed but are not necessarily limited to the order or combinations shown for performing the operations by the respective blocks. In portions of the following discussion reference may be made to environment **100** of FIG. **1** and as detailed in FIG. **2**, 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.

[0046] In more detail, method **300** builds, through many iterations, a database of signal elements associated with particular gestures. In effect, method **300** learns from reflected signals that a particular gesture is being performed. Method **300** may do so for each of the various different types of radar systems, though in an alternative embodiment set forth following methods **300** and **500**, hardware abstraction layers for each of those radar systems can be developed to permit a hardware-independent gesture manager.

[0047] At **302** a radar field is provided. As shown in FIG. **2**, system manager **222** may cause radar-emitting element **212** of wide-field radar-based gesture-recognition system **102** to provide (e.g., project or emit) one of the described radar fields noted above.

[0048] At **304**, a first set of reflection signals caused by a first interaction of a first human action performing a gesture within the radar field is received. This set of reflection signals represents a first time period during which the first human action interacts with the radar field. By way of a first example, assume that a test person performs a particular gesture in the radar field. This test person can continue to perform this particular gesture or another person can perform the particular gesture, e.g. at different angles, with different hand or finger sizes, in different positions, in different orientations, and with different clothes, background, and other aspects that may affect the reflected signal. Thus, the reflection signals include signal elements other than those caused by the gesture being performed. This can intentionally be part of the learning process by providing, in some cases, one object and motion that is relatively consistent, with other objects and motions that are inconsistent. This may aid in the learning process described below.

[0049] At **306**, a second set of reflection signals caused by a second interaction of a second human action performing the gesture within the radar field is received. This second set of reflection signals represents a second time period during which the first or second human action interacts with a radar field. Continuing the ongoing example, method **300** receives a second set of reflection signals, though as shown in the dashed arrow in FIG. **3**, the techniques may perform operations with many different persons, iterations of the same gesture, and so forth to better understand the signal elements associated with gestures being made.

[0050] At **308**, the first and second sets of reflection signals are analyzed to determine a signal element common to both sets of the reflection signals. In more detail, analyzing the multiple reflection signals determines the signal element common to both of the reflection signals. This can be performed by breaking the reflection signals into many signal elements and determining which of the signal elements correspond to both the first interaction and the second interaction for the same gesture. This is somewhat simplified, as iterations of many gestures being performed may be needed to accurately determine the signal elements that correspond to the gesture, such as 50, 100, or even hundreds of iterations.

[0051] As part of this, numerous signal elements are likely to be associated with objects and movements, or even noise, having nothing to do with the gesture itself. These numerous signal elements, to some extent, can be ignored if no correlation with the gesture is found.

[0052] In some cases, this analysis is not based on tracking points or elements of a human action, such as determining particular points and orientation of those points, reconstructing the action, then determining how the body part moves or changes in order to determine the gesture being performed.

[0053] At **310**, the signal element is associated with the gesture effective to enable a later received reflection signal caused by another interaction by a different (or same) human action to be associated with the gesture. At **312**, these determined signal elements are stored in association with the gesture performed.

[0054] By way of one illustration, consider FIG. **4**, which shows three different gestures being performed, one at a time with multiple iterations, to determine the signal elements associated with the gesture. The gestures illustrated include a hand wave gesture **402**, a first shake gesture **404** (an American Sign Language (ASL) gesture for “Yes”), and a pinch finger gesture **406**.

[0055] In this first case, hand wave gesture **402** is performed multiple times, with multiple reflection signals **408** being received by antenna element **214**. Antenna element **214** passes the reflection signals to gesture manager **206**, which performs the analysis described for operation **308**. In the second case, first shake gesture **404** is performed multiple times, with multiple reflection signals **410** being received by antenna element **214**. Antenna element **214** then passes the reflection signals to gesture manager **206**, which determines signal elements for first shake gesture **404**. Likewise, in the third case, pinch finger gesture **406** is performed multiple times within the radar field, at which point reflection signals are received by antenna element **214**, which passes these to gesture manager **206**. Gesture manager **206** then determines signal elements for the pinch finger gesture **406**. Each of these recorded signal elements can later be used to determine gestures performed in real-life rather than as part of determining gestures themselves, though a feedback loop enabling continued improvement of the signal elements is also contemplated based on accuracies or inaccuracies of gesture recognition performed by users in their normal course of life.

[0056] Optionally, at **314**, signal elements determined for the gesture can be refined based on other signal elements associated with other gestures. Consider, for example, a case where method **300** is performed for each of the three gestures shown in FIG. **4**, resulting in three different determined signal elements. These different signal elements can

be used to refine each other. Assume that one set of signal elements are determined for first shake gesture 404 and a second set of signal elements are determined for pinch finger gesture 406. At 314, the first set and the second set can be analyzed and compared, and, based on this, the weight of various signal elements can be decreased or increased. Thus, if similar, the signal elements may be reduced in weight or removed. If dissimilar, increased. If unique, also increased. Further, the signal elements determined for the third gesture—hand wave gesture 402, can also be used to refine either or both the signal elements for the other gestures.

[0057] Method 500 determines a gesture from reflection signals based on signal elements associated with the gesture. Thus, the single elements determined at method 300 are used to determine gestures at method 500.

[0058] At 502, a radar field is provided, such as the wide radar fields noted above. By way of example, consider FIG. 2 in which wide-field radar-based gesture recognition system 102 includes radar emitting element 212, antenna elements 214, and system manager 222. Radar emitting element 212 provides a wide radar field.

[0059] At 504, a reflection signal is received. As shown in FIG. 2, antenna element 214 receives a reflection signal based on some interaction with the provided radar field. This reflection signal is passed to system manager 222 for analysis.

[0060] At 506, signal elements from within the reflection signal are determined. This can be performed in the numerous different manners described above and below. Both type-independent and type-specific gesture managers can be used.

[0061] At 508, signal elements of the received reflection signal are compared with known signal elements for known gestures. These known signal elements are those provided by the process performed at method 300 noted above. Consider again, the examples shown in FIG. 4, in which a wave gesture 402 is illustrated. Assume, for this example, that a user is attempting to interact with a computing watch having a wide-field radar-based gesture recognition system through a wave gesture. The user performs the gesture within the radar field, which is within some number of centimeters or even a meter or two of the radar field provided by the radar system of the computing watch, and which causes a reflection signal to be received by the antenna element. This reflection signal is analyzed by system manager 222, which includes access to the signal elements known to be associated with various gestures. System manager 222 compares these and determines that the signal elements of the reflected signal and known signal elements correspond.

[0062] At 510, the gesture made is determined based on the correspondence between the signal elements and the known signal elements for the corresponding gesture. Continuing the ongoing example, system manager 222 determines that the user has performed a wave gesture.

[0063] At 512, the gesture is passed to an application or operating system. This application or operating system can be the active operating system for the entity to which it is passed, can be based on manners known in the art for passive gestures. Concluding the ongoing example, the application or operating system receives the wave gesture and responds accordingly. As part of, or prior to passing the gesture, gesture manager 206 may determine for which application or device the gesture is intended. Doing so may be based on

identity-specific gestures, a current device to which the user is currently interacting, and/or based on controls through which a user may interact with an application. Controls can be determined through inspection of the interface (e.g., visual controls), published APIs, and the like.

[0064] Optionally, at 514, feedback is provided. This feedback can be responsive to the gesture recognition failing or succeeding. Assume that the user performs the wave gesture in this example and that it was not recognized as a wave gesture. Assume also that the user indicates this or otherwise it is determined that the gesture was not properly recognized, such as the user continuing to perform the gesture until a wave gesture is recognized. System manager 222 passes this failure to gesture manager 206 or an entity associated therewith, so that set of known signal elements can be altered or improved for recognizing wave gestures. Likewise, successful gesture recognition can be provided to improve recognition by gesture manager 206.

[0065] In some cases method 300 or 500 operates on a device remote from the device being controlled. In this case the remote device includes entities of computing device 104 of FIGS. 1 and 2, and passes the gesture through one or more communication manners, such as wirelessly through transceivers and/or network interfaces (e.g., network interface 208 and transceiver 216). This remote device does not require all the elements of computing device 104—wide-field radar-based gesture-recognition system 102 may pass reflection signals sufficient for another device having gesture manager 206 to determine and use the gesture.

[0066] Operations of methods 300 and 500 can be repeated, such as by determining for multiple other applications and other controls through which the multiple other applications can be controlled. Methods 500 may then indicate various different controls to control various applications associated with either the application or the actor. In some cases, the techniques determine or assign unique and/or complex and three-dimensional controls to the different applications, thereby allowing a user to control numerous applications without having to select to switch control between them. Thus, an actor may assign a particular gesture to control one software application on computing device 104, another particular gesture to control another software application, and still another for a thermostat or stereo. This gesture can be used by multiple different persons, or may be associated with that particular actor once the identity of the actor is determined.

[0067] The preceding discussion describes methods relating to wide-field radar-based gesture recognition. Aspects of these methods may be implemented in hardware (e.g., fixed logic circuitry), firmware, software, manual processing, or any combination thereof. These techniques may be embodied on one or more of the entities shown in FIGS. 1, 2, 4, 6, and 8 (computing system 800 is described in FIG. 8 below), which may be further divided, combined, and so on. Thus, these figures illustrate some of the many possible systems or apparatuses capable of employing the described techniques. The entities of these figures generally represent software, firmware, hardware, whole devices or networks, or a combination thereof.

[0068] Example Alternative Hardware Abstraction Modules

[0069] As noted in part above, gesture manager 206 can determine the signal elements for each gesture based on the radar system being used. Thus, if there are substantial

differences between radar fields between those performed for method 300 and later radar fields provided by other radar systems or similar radar systems that have substantial differences in the reflected signals, the accuracy of a gesture recognition may suffer. This can be countered, however, by tailoring each set of signal elements for each gesture to the radar system being used. In an alternative embodiment, a hardware abstraction layer is built for each of the different radar systems obviating, to a large extent, the need to have different gesture managers or different signal elements for each gesture, though these hardware abstraction layers are each trained in a manner similar to methods 300.

[0070] By way of illustration, consider FIG. 6, which shows a specific type of radar-based gesture recognition system 602 and a type-specific gesture manager 604. These are illustrations of the gesture manager and various types of radar systems noted above, where the radar system is used as part of the learning process to determine the signal elements specific to that radar type. Alternatively, consider various specific types of radar-based gesture recognition systems 606-1 and 606-2, through some arbitrary number "N" of these radar systems, shown at 606-N. See also specific types of hardware abstraction modules 224 matched to the respective type of radar system, these abstraction modules shown at 608-1, 608-2, and 608-N. Type-specific gesture manager 604, as shown in the dashed-line box, is an illustration of its dependence on the type of radar system and showing the corresponding components 606-1, 608-1, and a portion of type-independent gesture manager 610. Note however, that type-independent gesture manager 610 is independent, to a large extent, of the type of radar system as will be described in FIG. 7.

[0071] Consider also FIG. 7, in which case the various gestures 402, 404, and 406, are performed multiple times and reflection signals are received, 408, 410, and 412, respectively by the specific type radar-based gesture recognition system 606-1 (and each system through system "N"). Note that, for each of these specific types of systems, the reflection signal is shown differently at Ref. Sig. 1, Ref. Sig. 2, and Ref. Sig. N. Similarly to methods 300, signal elements are determined for the particular gestures, though in this case the abstraction modules make this determination and then provide hardware-independent reflection signals, as shown in FIG. 7. These hardware-independent reflection signals are then received by type-independent gesture manager 610, which then determines the gesture performed at methods 500.

[0072] In more detail, techniques in which type-specific hardware abstraction modules 608 can be developed are shown below. These techniques may also be used to aid in developing signal elements for type-specific gesture manager 604 as well. These techniques may therefore be used as embodiments of method 300. In some cases, hardware abstraction modules 608 can operate in single tone, stepped FM, linear FM, impulse, and chirped radar systems. As noted in part above, single tone radar architectures can be of a 60 GHz continuous wave with a single tone or stepped frequency. Stepped FM radar architectures can be of a 96 GHz continuous wave stepped frequency. Linear FM can be a 60 GHz frequency modulated continuous wave. Impulse radar architectures can be of a 60 GHz impulse. And chirped radar architectures have a chirped radar field. Note that radar architectures produce equivalent data products, with time and frequency domains being interchangeable.

[0073] Example Computing System

[0074] FIG. 8 illustrates various components of example computing system 800 that can be implemented as any type of client, server, and/or computing device as described with reference to the previous FIGS. 1-7 to implement wide-field radar-based gesture recognition.

[0075] Computing system 800 includes communication devices 802 that enable wired and/or wireless communication of device data 804 (e.g., received data, data that is being received, data scheduled for broadcast, data packets of the data, etc.). Device data 804 or other device content can include configuration settings of the device, media content stored on the device, and/or information associated with a user of the device (e.g., an identity of an actor performing a gesture). Media content stored on computing system 800 can include any type of audio, video, and/or image data. Computing system 800 includes one or more data inputs 806 via which any type of data, media content, and/or inputs can be received, such as human utterances, interactions with a radar field, user-selectable inputs (explicit or implicit), messages, music, television media content, recorded video content, and any other type of audio, video, and/or image data received from any content and/or data source.

[0076] Computing system 800 also includes communication interfaces 808, 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. Communication interfaces 808 provide a connection and/or communication links between computing system 800 and a communication network by which other electronic, computing, and communication devices communicate data with computing system 800.

[0077] Computing system 800 includes one or more processors 810 (e.g., any of microprocessors, controllers, and the like), which process various computer-executable instructions to control the operation of computing system 800 and to enable techniques for, or in which can be embodied, wide-field radar-based gesture recognition. Alternatively or in addition, computing system 800 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 812. Although not shown, computing system 800 can include a system bus or data transfer system that couples the various components within the device. 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.

[0078] Computing system 800 also includes computer-readable media 814, 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. A 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 rewritable compact disc (CD), any type of a digital versatile disc (DVD), and the like. Computing system 800 can also include a mass storage media device (storage media) 816.

[0079] Computer-readable media **814** provides data storage mechanisms to store device data **804**, as well as various device applications **818** and any other types of information and/or data related to operational aspects of computing system **800**. For example, an operating system **820** can be maintained as a computer application with computer-readable media **814** and executed on processors **810**. Device applications **818** 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. Device applications **818** also include system components, engines, or managers to implement wide-field radar-based gesture recognition, such as gesture manager **206**, system manager **222**, and in cases where gesture manager **206** is type-independent, hardware abstraction module **224**.

[0080] Conclusion

[0081] Although techniques using, and apparatuses including, wide-field radar-based gesture recognition 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 wide-field radar-based gesture recognition.

What is claimed is:

1. A computer-implemented method comprising:
 - providing, by an emitter of a radar system, a radar field;
 - receiving, at a receiver of the radar system, a first set of reflection signals caused by a first interaction of a first human action performing a gesture within the radar field, the first set of reflection signals representing a first time period during which the first human action interacts with the radar field;
 - receiving, at the receiver of the radar system, a second set of reflection signals caused by a second interaction of a second human action performing the gesture within the radar field, the second set of reflection signals representing a second time period during which the second human action interacts with the radar field;
 - analyzing the first and second sets of reflection signals to determine a signal element common to the first and second sets of reflection signals; and
 - associating the signal element with the gesture effective to enable a later received reflection signal caused by an interaction by a different human action to be associated with the gesture.
2. The computer-implemented method as described in claim 1, wherein analyzing the first and second sets of reflection signals to determine the signal element common to the first and second sets of reflection signals comprises breaking the first and second sets of reflection signals into many signal elements and determining which of the signal elements corresponds to both the first interaction of the first human action performing the gesture and the second interaction of the second human action performing the gesture.
3. The computer-implemented method as described in claim 1, wherein analyzing the first and second sets of reflection signals is not based on tracking points or elements of the first or second human action.
4. The computer-implemented method as described in claim 1, where in the radar field is a full contiguous field.

5. The computer-implemented method as described in claim 1, wherein the radar system is not a phased antenna array.

6. The computer-implemented method as described in claim 1, further comprising receiving multiple other sets of reflection signals caused by multiple other interactions of the first, second, or other human actions performing the gesture within the radar field and wherein analyzing the first and second sets of reflection signals analyzes the first set of reflection signals, the second set of reflection signals, and the multiple other sets of reflection signals.

7. The computer-implemented method as described in claim 6, wherein the radar field in which the first, second, and other sets of reflection signals is received is a same radar field provided by a same emitter of the same radar system.

8. The computer-implemented method as described in claim 1, further comprising refining the signal element associated with the gesture based on other signal elements associated with other gestures.

9. A computer-implemented method comprising:

- providing a wide radar field;
- receiving a reflection signal for a gesture made within the wide radar field;
- determining signal elements of the reflection signal;
- comparing the signal elements of the reflection signal to known signal elements associated with known gestures;
- determining, based on the signal elements of the reflection signal corresponding to the known signal elements, that the gesture made in the wide radar field is one of the known gestures; and
- passing the one of the known gestures to an application or operating system.

10. The method of claim 9, further comprising:

- receiving a second reflection signal for a second gesture;
- determining second signal elements of the second reflection signal;
- comparing the second signal elements of the second reflection signal to the known signal elements associated with the known gestures;
- determining, based on the second signal elements not corresponding to the known signal elements, that the second gesture was not properly recognized; and
- altering the known signal elements for the gesture based on the determined second signal elements.

11. The method of claim 9, further comprising:

- receiving, from a user, multiple reflection signals from multiple iterations of a unique gesture made within the wide radar field, the unique gesture not being one of the known gestures;
- determining signal elements of the reflection signals, the signal elements sufficient to determine that a later-received reflection signal for a later-received gesture of the user matches the unique gesture; and
- associating the determined signal elements to the unique gesture.

12. The method of claim 11, further comprising associating the unique gesture to a control of an application, the associating responsive to an assignment of the control and the application selected by the user.

13. The method of claim 9, wherein determining the signal elements of the reflection signal digitally breaks up the reflection signal and analyzes, one at a time, each of the broken-up signals.

14. The method of claim **9**, wherein the wide radar field includes multiple radar fields from different directions or multiple radar fields having different frequencies or phases.

15. The method of claim **9**, wherein the wide radar field is a continuous-wave radar field or a contiguous radar field.

16. The method of claim **15**, wherein the continuous-wave radar field is a single tone, linear frequency modulated (FM), or stepped FM field.

17. The method of claim **9**, wherein the wide radar field is a pulsed-wave radar field, an impulse radar field, or a chirped radar field.

18. An apparatus comprising:

a wide-field radar-based gesture-recognition system comprising:

a radar-emitting element configured to provide a wide radar field; and

an antenna element configured to:

receive reflection signals from human tissue that is within the wide radar field; and

pass the received reflection signals; and

one or more computer-readable storage media having instructions stored thereon that, responsive to execution by the one or more computer processors, perform operations comprising:

causing the wide-field radar-based gesture-recognition system to provide a radar field with the radar-emitting element;

causing the wide-field radar-based gesture-recognition system to receive reflection signals for an interaction in the wide radar field with the antenna element;

determining, based on the received reflection signals, signal elements;

comparing the signal elements of the received reflection signal to known signal elements associated with known gestures;

determining, based on the signal elements corresponding to the known signal elements, that the interaction made in the wide radar field corresponds to one of the known gestures; and

passing the one of the known gestures to an application or operating system.

19. The apparatus of claim **18**, wherein the one or more computer-readable storage media is further configured to perform operations comprising:

receiving multiple reflection signals from multiple iterations of a complex gesture made within the wide radar field, the complex gesture not being one of the known gestures;

determining signal elements of the multiple reflection signals, the signal elements sufficient to determine that a later-received reflection signal for a later-received gesture matches the complex gesture; and

associating the determined signal elements to the complex gesture.

20. The apparatus of claim **18**, wherein the operation of determining the signal elements of the reflection signal digitally breaks up the reflection signal and analyzes, one at a time, each of the broken-up signals.

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