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ULTRA-WIDEBAND TECHNOLOGIES FOR SEAMLESS ACCESS CONTROL

Abstract

A system according to one embodiment includes a first computing device comprising ultra-wideband communication circuitry, and a second computing device comprising ultra-wideband communication circuitry configured to communicate with the ultra-wideband communication circuitry of the first computing device to determine the angle and distance of the first computing device relative to the second computing device.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] This application claims the benefit of U.S. Provisional Application No. 62/940,997 filed on Nov. 27, 2019, the contents of which are incorporated herein by reference in their entirety.

BACKGROUND

[0002] Ultra-wideband (UWB) technologies are based on the IEEE 802.15.4 (wireless) standard, which is used to combine sensors and actuators into a single wireless network and can be used to determine the relative position of peer devices with a high degree of accuracy. For example, UWB can be used to determine the relative position of peer devices with a line of sight of up to two hundred meters. In contrast to narrow band wireless technologies, the wider bandwidth in UWB technologies provides very stable connectivity with little to no interference and offers high precision positioning, even in congested multi-path signal environments.

SUMMARY

[0003] One embodiment is a unique system, components, and methods for using ultra-wideband technologies for seamless access control. Other embodiments include apparatuses, systems, devices, hardware, methods, and combinations for using ultra-wideband technologies for seamless access control.

[0004] According to an embodiment, a method may include communicating, via a Bluetooth communication circuitry of a first computing device associated with an access control device that controls access to a passageway, with a second computing device over a Bluetooth communication connection established between the first computing device and the second computing device to determine that the second computing device includes ultra-wideband (UWB) communication circuitry for UWB-based communication, waking the UWB communication circuitry of the second computing device from a low power state in response to the Bluetooth communication, and determining, by the first computing device based on at least one UWB communication signal received from the second computing device, a location of the second computing device relative to the first computing device.

[0005] In some embodiments, the method may further include determining, by the first computing device, whether the location of the second computing device relative to the first computing device is a location that indicates an intent of a user of the second computing device to access the passageway.

[0006] In some embodiments, determining whether the location is a location that indicates an intent of a user of the second computing device to access the passageway may include determining an angle of arrival of the at least one UWB communication signal at a plurality of antennas of the first computing device.

[0007] In some embodiments, determining whether the location is a location that indicates an intent of a user of the second computing device to access the passageway may include determining a distance of the second computing device relative to the first computing device based on a time of flight of the at least one UWB communication signal from the second computing device to a

plurality of antennas of the first computing device.

[0008] In some embodiments, communicating with the second computing device over the Bluetooth communication connection may further include receiving access credentials from the second computing device with respect to access to the access control device.

[0009] In some embodiments, the method may further include communicating, from the first computing device, an alert to the second computing device in response to determining that the second computing device is approaching an area that a user of the second computing device is unauthorized to access.

[0010] In some embodiments, the method may further include determining, by the first computing device, a duration of time for which the access control device is to retain open a barrier that secures the passageway based on the location of the second computing device.

[0011] In some embodiments, the method may further include modifying at least one environmental factor of a room secured by the access control device based on the location of the second computing device.

[0012] In some embodiments, the first computing device may include the access control device.

[0013] According to another embodiment, a system may include an access control device configured to control access to a passageway, a first computing device associated with the access control device, the first computing device comprising a first Bluetooth Low Energy (BLE) communication circuitry and a first ultra-wideband (UWB) communication circuitry, and a second computing device comprising a second BLE communication circuitry and a second UWB circuitry, wherein the first computing device is configured to communicate with the second computing device over a BLE communication connection established between the first computing device and the second computing device to determine that the second computing device is capable of UWB-based communication, wherein the second computing device is configured to wake the second UWB communication circuitry from a low power state in response to the BLE communication, and wherein the first computing device is further configured to determine a location of the second computing device relative to the first computing device based on at least one UWB communication signal received from the second computing device.

[0014] In some embodiments, the first computing device may be further configured to determine whether the location of the second computing device relative to the first computing device is a location that indicates an intent of a user of the second computing device to access the passageway.

[0015] In some embodiments, to determine whether the location is a location that indicates an intent of a user of the second computing device to access the passageway may include to determine an angle of arrival of the at least one UWB communication signal at a plurality of antennas of the first computing device.

[0016] In some embodiments, to determine whether the location is a location that indicates an intent of a user of the second computing device to access the passageway may include to determine a distance of the second computing device relative to the first computing device based on a time of flight of the at least one UWB communication signal from the second computing device to a plurality of antennas of the first computing device.

[0017] In some embodiments, to communicate with the second computing device over the BLE communication connection may further include to receive access credentials from the second computing device with respect to access to the access control device.

[0018] In some embodiments, the first computing device may be further configured to communicate an alert to the second computing device in response to a determination that the second computing device is approaching an area that a user of the second computing device is unauthorized to access.

[0019] In some embodiments, the first computing device may be further configured to determine a duration of time for which the access control device is to retain open a barrier that secures the passageway based on the location of the second computing device.

[0020] In some embodiments, the first computing device may include the access control device.

[0021] According to yet another embodiment, a first computing device may include a Bluetooth Low Energy (BLE) communication circuitry, an ultra-wideband (UWB) communication circuitry, a processor, and a memory comprising a plurality of instructions stored thereon that, in response to execution by the processor, causes the first computing device to communicate with a second computing device over a BLE communication connection established between the first computing device and the second computing device to determine that the second computing device is capable of UWB-based communication, and determine a location of the second computing device relative to the first computing device based on at least one UWB communication signal received from the second computing device in response to UWB communication circuitry of the second computing device being awakened based on the BLE communication with the first computing device.

[0022] In some embodiments, the plurality of instructions may further cause the first computing device to determine whether the location of the second computing device relative to the first computing device is a location that indicates an intent of a user of the second computing device to access a passageway controlled by an access control device associated with the first computing device.

[0023] In some embodiments, to determine whether the location is a location that indicates an intent of a user of the second computing device to access the passageway may include to determine an angle of arrival of the at least one UWB communication signal at a plurality of antennas of the first computing device, and determine a distance of the second computing device relative to the first computing device based on a time of flight of the at least one UWB communication signal from the second computing device to a plurality of antennas of the first computing device.

[0024] This summary is not intended to identify key or essential features of the claimed subject matter, nor is it intended to be used as an aid in limiting the scope of the claimed subject matter. Further embodiments, forms, features, and aspects of the present application shall become apparent from the description and figures provided herewith.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0025] The concepts described herein are illustrative by way of example and not by way of limitation in the accompanying figures. For simplicity and clarity of illustration, elements illustrated in the figures are not necessarily drawn to scale. Where considered appropriate, references labels have been repeated among the figures to indicate corresponding or analogous elements.

[0026] FIG. 1 is a simplified block diagram of at least one embodiment of using ultra-wideband technologies for seamless access control; and

[0027] FIG. 2 is a simplified block diagram of at least one embodiment of a computing system.

DETAILED DESCRIPTION

[0028] Although the concepts of the present disclosure are susceptible to various modifications and alternative forms, specific embodiments have been shown by way of example in the drawings and will be described herein in detail. It should be understood, however, that there is no intent to limit the concepts of the present disclosure to the particular forms disclosed, but on the contrary, the intention is to cover all modifications, equivalents, and alternatives consistent with the present disclosure and the appended claims.

[0029] References in the specification to “one embodiment,” “an embodiment,” “an illustrative embodiment,” etc., indicate that the embodiment described may include a particular feature, structure, or characteristic, but every embodiment may or may not necessarily include that particular feature, structure, or characteristic. Moreover, such phrases are not necessarily referring

to the same embodiment. It should further be appreciated that although reference to a “preferred” component or feature may indicate the desirability of a particular component or feature with respect to an embodiment, the disclosure is not so limiting with respect to other embodiments, which may omit such a component or feature. Further, when a particular feature, structure, or characteristic is described in connection with an embodiment, it is submitted that it is within the knowledge of one skilled in the art to implement such feature, structure, or characteristic in connection with other embodiments whether or not explicitly described. Additionally, it should be appreciated that items included in a list in the form of “at least one of A, B, and C” can mean (A); (B); (C); (A and B); (B and C); (A and C); or (A, B, and C). Similarly, items listed in the form of “at least one of A, B, or C” can mean (A); (B); (C); (A and B); (B and C); (A and C); or (A, B, and C). Further, with respect to the claims, the use of words and phrases such as “a,” “an,” “at least one,” and/or “at least one portion” should not be interpreted so as to be limiting to only one such element unless specifically stated to the contrary, and the use of phrases such as “at least a portion” and/or “a portion” should be interpreted as encompassing both embodiments including only a portion of such element and embodiments including the entirety of such element unless specifically stated to the contrary.

[0030] The disclosed embodiments may, in some cases, be implemented in hardware, firmware, software, or a combination thereof. The disclosed embodiments may also be implemented as instructions carried by or stored on one or more transitory or non-transitory machine-readable (e.g., computer-readable) storage media, which may be read and executed by one or more processors. A machine-readable storage medium may be embodied as any storage device, mechanism, or other physical structure for storing or transmitting information in a form readable by a machine (e.g., a volatile or non-volatile memory, a media disc, or other media device).

[0031] In the drawings, some structural or method features may be shown in specific arrangements and/or orderings. However, it should be appreciated that such specific arrangements and/or orderings may not be required. Rather, in some embodiments, such features may be arranged in a different manner and/or order than shown in the illustrative figures unless indicated to the contrary. Additionally, the inclusion of a structural or method feature in a particular figure is not meant to imply that such feature is required in all embodiments and, in some embodiments, may not be included or may be combined with other features.

[0032] Referring now to FIG. 1, in the illustrative embodiment, a system **100** includes an ultra-wideband (UWB) device **102** and an ultra-wideband (UWB) device **104**. As described in greater detail below, the UWB devices **102**, **104** may be configured to communicate with one another via UWB-based communication and/or other communication protocols/techniques in order to enable various seamless access control features. It should be appreciated that UWB-enabled devices described herein (e.g., the UWB devices **102**, **104**) may be referred to as UWB devices/tags, and those devices/tags may take various form factors depending on the particular embodiment.

[0033] As shown in the illustrative embodiment of FIG. 1, the UWB device **102** includes an antenna system **110**, communication circuitry **112**, and one or more sensors **114**. Similarly, the UWB device **104** includes an antenna system **120**, communication circuitry **122**, and one or more sensors **124**. Although only two UWB devices **102**, **104** are depicted in reference to FIG. 1, it should be appreciated that additional UWB devices may be included in the system **100** in other embodiments. It should be further appreciated that the UWB devices **102**, **104** may communicate with other devices that are not UWB-enabled in some embodiments. In some embodiments, one or more of the UWB devices **102**, **104** may omit the sensors **114**, **124**.

[0034] It should be appreciated that each of the UWB devices **102**, **104** may be embodied as any type of device capable of communicating using UWB technology (e.g., using the IEEE 802.15.4 (wireless) standard) and otherwise suitable for performing the functions described herein. In some embodiments, one or more of the UWB devices **102**, **104** may be embodied as an access control device, credential reader device, electronic lock, mobile device, accessory device, non-vehicular device, and/or other device capable of communicating using one or more UWB technologies. More

specifically, in some embodiments in which a UWB device **102**, **104** is embodied as an access control device, the access control device may be embodied as any type of device capable of controlling and/or facilitating access through a passageway (e.g., defined in a building). For example, in various embodiments, the access control device may be embodied as an electronic lock (e.g., a mortise lock, a cylindrical lock, or a tubular lock), an exit device (e.g., a pushbar or pushpad exit device), a door closer, an auto-operator, a motorized latch/bolt (e.g., for a sliding door), barrier control device (e.g., battery-powered), or a peripheral controller of a barrier to a passageway. Accordingly, in some embodiments, the access control device may include a lock mechanism configured to be positioned in a locked state in which access to the passageway is denied, or may be positioned in an unlocked state in which access to the passageway is permitted. In some embodiments, the lock mechanism includes a deadbolt, latch bolt, lever, and/or other mechanism adapted to move between the locked and unlocked state and otherwise perform the functions described herein. However, it should be appreciated that the lock mechanism may be embodied as any another mechanism suitable for controlling access through a passageway in other embodiments.

[0035] Depending on the particular embodiment, an access control device may include a credential reader or be electrically/communicatively coupled to a credential reader configured to communicate with active and/or passive credentials. For example, in some embodiments, one or more of the credentials may be embodied as a passive credential device having a credential identifier (e.g., a unique ID) stored therein and is “passive” in the sense that the credential device is configured to be powered by radio frequency (RF) signals received from a credential reader. In other words, such passive credentials do not have an independent power source but, instead, rely on power that is induced from RF signals transmitted from other devices in the vicinity of the credential. In particular, in some embodiments, one or more of the passive credentials may be embodied as a proximity card, which is configured to communicate over a low frequency carrier of nominally 125 kHz, and/or a smartcard, which is configured to communicate over a high frequency carrier frequency of nominally 13.56 MHz. However, it should be appreciated that, in other embodiments, one or more of the credentials may be embodied as a virtual credential (e.g., a Bluetooth transmitted credential) stored on the mobile device **106** and/or other computing device of a particular user. For example, the credential device may be “active” in the sense that the credential device has an independent power source (e.g., a rechargeable battery).

[0036] In some embodiments, the UWB device **102** may be embodied as the initiator for UWB-based communication, whereas in other embodiments, the UWB device **104** may be embodied as the initiator for UWB-based communication. Similarly, in some embodiments, the UWB device **104** may be embodied as the responder for UWB-based communication, whereas in other embodiments, the UWB device **102** may be embodied as the responder for UWB-based communication.

[0037] As indicated above, the illustrative UWB device **102** includes an antenna system **110** and communication circuitry **112**. Additionally, in some embodiments, the UWB device **102** may include one or more sensors **114**.

[0038] The antenna system **110** may include a plurality of antennas positioned apart from one another such that a signal is received by the various antennas at different points in time, thereby permitting the UWB device **102** to determine the angle of arrival (AoA) of the signal relative to the UWB device **102**. Depending on the particular embodiment, the antennas of the antenna system **110** may be selected and/or positioned to permit a two-dimensional determination of the angle of arrival (e.g., using two or more antennas) or a three-dimensional determination of the angle of arrival (e.g., using three or more antennas). In other embodiments, the antenna system **110** may include only a single antenna and/or another number of antennas. For example, in embodiments in which the UWB device **102** serves at an initiator for UWB-based communication, the antenna system **110** may include at least two antennas, whereas in embodiments in which the UWB device

102 serves as a responder for UWB-based communication, the antenna system **110** may include one or more antennas. In various embodiments, the antennas may be embodied as chip antennas, patch antennas, whip antennas, trace antennas, and/or other suitable antennas. Further, in various embodiments, the antennas may be positioned on one or more planes in a PCB, and the antenna system **110** may be positioned in any location suitable for performing the functions described herein. For example, in embodiments in which the antenna system **110** is associated with an access control device, the antenna system **110** may be positioned on either side of a corresponding door/barrier, within the door/barrier, or within the frame/trim for the door/barrier. In particular, in some embodiments, the antenna system **110** may be secured to a wall adjacent the door/barrier. [0039] The communication circuitry **112** of the UWB device **102** may be configured to use the antenna system **110** to communicate with other devices (e.g., the UWB device **104**) via UWB-based communication. In some embodiments, the communication circuitry **112** may further enable one or more other communication technologies (e.g., wireless or wired communications) and associated protocols (e.g., Ethernet, Bluetooth (including Bluetooth Low Energy (BLE), Wi-Fi (e.g., infrastructure or ad hoc mode), Wi-Fi Direct, Zigbee, Near Field Communication (NFC), WiMAX, etc.) to effect communication with other devices depending on the particular embodiment (e.g., using the same or different antennas and/or antenna system **110**).

[0040] In some embodiments, the UWB device **102** may include one or more sensors **114** configured to generate sensor data (e.g., by virtue of one or more signals), which may be interpreted by a processor of the UWB device **102** to determine one or more characteristics associated with the UWB device **102**. For example, in various embodiments, the sensors **114** may detect various characteristics of the physical environment of the UWB device **102** (e.g., internal and/or external to the UWB device **102**), electrical characteristics of the UWB device **102**, electromagnetic characteristics of the UWB device **102** and/or its surroundings, and/or other suitable characteristics. In particular, the UWB device **102** may include a door position sensor configured to generate sensor data (e.g., by virtue of one or more signals) associated with a door position status, which may be interpreted by the UWB device **102** to determine whether the door is in a closed position or an open position (and/or a position therebetween), and/or a latchbolt sensor configured to generate sensor data (e.g., by virtue of one or more signals) associated with a latchbolt status, which may be interpreted by the UWB device **102** to determine whether the latchbolt is in an extended position or a retracted position. In various embodiments, additional and/or alternative sensors other than those described above may be included in the UWB device **102**. For example, the sensors may include environmental sensors (e.g., temperature sensors, air pressure sensors, humidity sensors, light sensors, etc.), inertial sensors (e.g., accelerometers, gyroscopes, etc.), magnetometers, proximity sensors, optical sensors, electromagnetic sensors, audio sensors (e.g., microphones), motion sensors, cameras, piezoelectric sensors, pressure sensors, switches (e.g., reed switches), and/or other types of sensors.

[0041] It should be appreciated that the UWB device **104** may include components similar to the components of the UWB device **102** described above and, therefore, the descriptions of those components have not been repeated herein for clarity of the description. For example, in some embodiments, the antenna system **120** of the UWB device **104** may be similar to the antenna system **110** of the UWB device **102**, the communication circuitry **122** of the UWB device **104** may be similar to the communication circuitry **112** of the UWB device **102**, and/or the sensors **124** of the UWB device **102** may be similar to the sensors **114** of the UWB device **102**. Further, it should be appreciated that the UWB device **102** and/or the UWB device **104** may include other components, sub-components, and/or devices commonly found in a computing device, which are not discussed herein for brevity of the description. Additionally, in some embodiments, one or more of the components of the UWB device **102** may be omitted from the UWB device **104** (e.g., the sensors **114**).

[0042] It should be appreciated that each of the UWB device **102** and/or the UWB device **104** may

be embodied as one or more computing devices similar to the computing device **200** described below in reference to FIG. 2. For example, one or more of the UWB devices **102**, **104** may include a processing device **202** and a memory **206** having stored thereon operating logic **208** for execution by the processing device **202** for operation of the corresponding device.

[0043] Referring now to FIG. 2, a simplified block diagram of at least one embodiment of a computing device **200** is shown. The illustrative computing device **200** depicts at least one embodiment of a UWB device **102**, **104** illustrated in FIG. 1. Depending on the particular embodiment, computing device **200** may be embodied as a UWB-enabled device, reader device, access control device, accessory device, server, desktop computer, laptop computer, tablet computer, notebook, netbook, Ultrabook™, mobile computing device, cellular phone, smartphone, wearable computing device, personal digital assistant, Internet of Things (IoT) device, monitoring device, camera device, control panel, processing system, router, gateway, and/or any other computing, processing, and/or communication device capable of performing the functions described herein.

[0044] The computing device **200** includes a processing device **202** that executes algorithms and/or processes data in accordance with operating logic **208**, an input/output device **204** that enables communication between the computing device **200** and one or more external devices **210**, and memory **206** which stores, for example, data received from the external device **210** via the input/output device **204**.

[0045] The input/output device **204** allows the computing device **200** to communicate with the external device **210**. For example, the input/output device **204** may include a transceiver, a network adapter, a network card, an interface, one or more communication ports (e.g., a USB port, serial port, parallel port, an analog port, a digital port, VGA, DVI, HDMI, Fire Wire, CAT 5, or any other type of communication port or interface), and/or other communication circuitry. Communication circuitry of the computing device **200** may be configured to use any one or more communication technologies (e.g., wireless or wired communications) and associated protocols (e.g., Ethernet, Bluetooth®, Wi-Fi®, WiMAX, etc.) to effect such communication depending on the particular computing device **200**. The input/output device **204** may include hardware, software, and/or firmware suitable for performing the techniques described herein.

[0046] The external device **210** may be any type of device that allows data to be inputted or outputted from the computing device **200**. For example, in various embodiments, the external device **210** may be embodied as the UWB device **102** and/or the UWB device **104**. Further, in some embodiments, the external device **210** may be embodied as another computing device, switch, diagnostic tool, controller, printer, display, alarm, peripheral device (e.g., keyboard, mouse, touch screen display, etc.), and/or any other computing, processing, and/or communication device capable of performing the functions described herein. Furthermore, in some embodiments, it should be appreciated that the external device **210** may be integrated into the computing device **200**.

[0047] The processing device **202** may be embodied as any type of processor(s) capable of performing the functions described herein. In particular, the processing device **202** may be embodied as one or more single or multi-core processors, microcontrollers, or other processor or processing/controlling circuits. For example, in some embodiments, the processing device **202** may include or be embodied as an arithmetic logic unit (ALU), central processing unit (CPU), digital signal processor (DSP), and/or another suitable processor(s). The processing device **202** may be a programmable type, a dedicated hardwired state machine, or a combination thereof. Processing devices **202** with multiple processing units may utilize distributed, pipelined, and/or parallel processing in various embodiments. Further, the processing device **202** may be dedicated to performance of just the operations described herein, or may be utilized in one or more additional applications. In the illustrative embodiment, the processing device **202** is programmable and executes algorithms and/or processes data in accordance with operating logic **208** as defined by programming instructions (such as software or firmware) stored in memory **206**. Additionally or

alternatively, the operating logic **208** for processing device **202** may be at least partially defined by hardwired logic or other hardware. Further, the processing device **202** may include one or more components of any type suitable to process the signals received from input/output device **204** or from other components or devices and to provide desired output signals. Such components may include digital circuitry, analog circuitry, or a combination thereof.

[0048] The memory **206** may be of one or more types of non-transitory computer-readable media, such as a solid-state memory, electromagnetic memory, optical memory, or a combination thereof. Furthermore, the memory **206** may be volatile and/or nonvolatile and, in some embodiments, some or all of the memory **206** may be of a portable type, such as a disk, tape, memory stick, cartridge, and/or other suitable portable memory. In operation, the memory **206** may store various data and software used during operation of the computing device **200** such as operating systems, applications, programs, libraries, and drivers. It should be appreciated that the memory **206** may store data that is manipulated by the operating logic **208** of processing device **202**, such as, for example, data representative of signals received from and/or sent to the input/output device **204** in addition to or in lieu of storing programming instructions defining operating logic **208**. As shown in FIG. 2, the memory **206** may be included with the processing device **202** and/or coupled to the processing device **202** depending on the particular embodiment. For example, in some embodiments, the processing device **202**, the memory **206**, and/or other components of the computing device **200** may form a portion of a system-on-a-chip (SoC) and be incorporated on a single integrated circuit chip.

[0049] In some embodiments, various components of the computing device **200** (e.g., the processing device **202** and the memory **206**) may be communicatively coupled via an input/output subsystem, which may be embodied as circuitry and/or components to facilitate input/output operations with the processing device **202**, the memory **206**, and other components of the computing device **200**. For example, the input/output subsystem may be embodied as, or otherwise include, memory controller hubs, input/output control hubs, firmware devices, communication links (i.e., point-to-point links, bus links, wires, cables, light guides, printed circuit board traces, etc.) and/or other components and subsystems to facilitate the input/output operations.

[0050] The computing device **200** may include other or additional components, such as those commonly found in a typical computing device (e.g., various input/output devices and/or other components), in other embodiments. It should be further appreciated that one or more of the components of the computing device **200** described herein may be distributed across multiple computing devices. In other words, the techniques described herein may be employed by a computing system that includes one or more computing devices. Additionally, although only a single processing device **202**, I/O device **204**, and memory **206** are illustratively shown in FIG. 2, it should be appreciated that a particular computing device **200** may include multiple processing devices **202**, I/O devices **204**, and/or memories **206** in other embodiments. Further, in some embodiments, more than one external device **210** may be in communication with the computing device **200**.

[0051] As indicated above, it should be appreciated that the system **100** leverages the UWB devices **102**, **104** to implement various seamless access control features. In doing so, it should be appreciated that UWB utilizes multiple antennas (e.g., of the antenna system(s) **110**, **120**) to calculate angle of arrival (AoA) of an incoming signal, which provides the direction from which a signal is coming. Although Bluetooth technologies are also capable of similar calculations, the system **100** leverages UWB to provide improved distance calculations relative to Bluetooth. More specifically, Bluetooth uses the signal strength of a signal (e.g., via RSSI) to estimate the distance of a computing device from which a signal was transmitted; however, signal strength is susceptible to various types of errors due to the types of materials through which a signal travels, RF reflections, and/or factors. On the other hand, UWB relies on time of flight (ToF) calculations of a signal to determine an accurate distance on the radial (e.g., to within 10 cm). Because the pulses of

data in the UWB protocols occur so quickly, UWB does not suffer from the RF reflection errors that limit Bluetooth protocols. In essence, the signal is already processed when using UWB before an RF reflection has an opportunity to become an error factor with UWB communication.

[0052] It should be appreciated that the system **100** may be used to provide various mechanisms for improved building intelligence. For example, in some embodiments, instead of defaulting to a “locked” status, the access control devices securing doors in a building may default to an “unlocked” status and, in conjunction with monitoring of various UWB tags/devices by the system **100**, those access control devices may change to a “locked” status depending on which persons are in the vicinity. For example, an access control device may communicate with UWB tags/devices as they approach or are otherwise nearby the access control device and, as long as only users associated with those UWB tags/device are within a certain region relative the access control device (e.g., within a threshold distance, within a threshold angle, on a particular side, and/or otherwise), the access control device may remain in a locked state. However, if an unauthorized user or UWB tag/device comes within the region (e.g., within the threshold distance, within the threshold angle, on the particular side, and/or otherwise), the access control device may transition to a locked state (e.g., before such user has an opportunity to pass through a passageway controlled/secured by the access control device). In some embodiments, once no unauthorized users or UWB tags/devices remain within such region, the access control device may transition back to the default unlocked state so as to provide seamless access to authorized users.

[0053] In some embodiments, various devices in a commercial facility, office facility, industrial facility, and/or other suitable facility may be “tagged” with a UWB device, which may be leveraged to determine the position of those tagged devices with a high level of accuracy. As such, the UWB devices and protocols may be leveraged to ensure that various devices are returned to their proper locations. For example, a “digital signature” may be used for office asset tracking. Further, in some embodiments, the accuracy associated with UWB device microlocation can be leveraged for personalized environments. For example, a UWB-enabled mobile device or tag of a user may be tracked to determine that a particular person is within a room (e.g., an office) rather than simply ascertaining the lock mechanism for that room has been unlocked. Based on the presence, or lack thereof, of a particular user, the system **100** may modify the lighting, temperature, and/or other environmental factors of the room to provide a UWB-enabled personalized environment for the user.

[0054] In some embodiments, the system **100** may utilize UWB for various types of “people counting” and people tracking. For example, in an emergency situation, the system **100** may determine the number of people in the building just prior to the emergency alert and how many people are remaining at any given point during the emergency (e.g., via UWB-enabled tags/phones). Further, the system **100** may couple UWB-based location tracking with video monitoring in a building to monitor and detect user tailgating (i.e., a user following an authorized user into a building without having provided his/her own credentials for access). In another embodiment, UWB-based location tracking of people may allow an access control device to remain unlocked with free ingress/egress while detecting the user's credential as they pass through. Such a system may also be used in conjunction with video monitoring, for example, in order to capture images of unauthorized users passing through the secure passageway. Additionally, in some embodiments, the identification of a person's location within a building (e.g., in 3D) may be used in conjunction with an interface (e.g., a smartphone application) to direct a person to the nearest exist (e.g., in the case of a fire or other emergency).

[0055] In some embodiments, the system **100** may utilize UWB to perform direction monitoring of UWB-enabled devices (e.g., the UWB devices **102**, **104**). For example, in certain circumstances (e.g., a retirement facility, restricted healthcare facility, etc.), a reader, access control device, and/or other UWB device may be positioned near an entryway of a building and the residents/users may be tagged (e.g., via respective mobile devices). If a particular UWB tag/device is walking toward

the entryway without authorization to leave, the corresponding access control device may lock/secure the door to prevent exit. Further, in some circumstances, the system **100** may allow a UWB tag/device to leave a building but track the departure (and/or entry) of such devices in order to gain an understanding of which people are coming/going to/from the building. Further, UWB location tracking may also enable detailed arrival monitoring. For example, when a child arrives at home, rather than simply getting an indication that the door has been unlocked, the system **100** may determine that the child has unlocked the door and entered the residence.

[0056] In some embodiments, the system **100** may utilize UWB for enhanced zone control. For example, every relevant person (e.g., every employee) may have a UWB tag/badge/device that generates an alert when that person enters (or approaches) an area that the person is unauthorized to access. For example, on the shop floor of a facility, there may be restricted areas due to safety concerns, so somebody may get an alert if they are entering or approaching an unauthorized area. Further, in some embodiments, the person may be alerted even if authorized in order to ensure the person is optimally aware of his/her surroundings in the unsafe area. As indicated above, enhanced zone control may be further accomplished by dynamically changing access control restrictions as a user/visitor enters various areas. Further, the movement of people and/or goods may be monitored to ensure that they go through the right steps at the right time, which can reduce human error (e.g., accidentally skipping a step in a sequence). As another example, a door lock (e.g., an office door lock or conference room door lock) may unlock when the person comes within a certain range (e.g., a predefined range) of the door and the person is authorized to access the room for use (e.g., by reserving the room).

[0057] In some embodiments, the system **100** may include a kiosk that tracks users (e.g., via login) during defined times. Depending on the circumstances, the users may be tracked at different times, at different rates, and/or according to different criteria. For example, full-time employees may be tracked differently than visitors, and/or the ping rate may be increased during certain events (e.g., emergencies) to change the frequency at which user locations are updated. In some embodiments, visitors may use their UWB phone/tag/device to permit tracking, for example, by accepting location monitoring via an agreement (e.g., by tapping a kiosk or otherwise launching an authorization application). It should be appreciated that “tap to track” techniques may be employed (e.g., via temporary authorization) in various public and/private locations (e.g., children's museums, zoos, public facilities, etc.).

[0058] It should be appreciated that the UWB device **102** may be used in conjunction with a bay door, for example, to open and/or close bay doors automatically and in a seamless manner based on the location of an authorized user. Further, in some embodiments, the system **100** may leverage UWB in order to determine and alert various users of the existence of something (e.g., a piece of moving or stationary equipment) on the opposing side of the bay door. In some embodiments, the UWB device **102** may be used in conjunction with other types of openings and barriers including, for example, garage doors. Further, in some embodiments, a UWB tag may be placed on a pet's collar such that a pet door may be locked when the pet is not within the immediate vicinity of the pet door.

[0059] As indicated above, in some embodiments, the UWB technology may be used in conjunction with other technologies. For example, UWB communication has a relatively higher power draw than Bluetooth communication, which affects battery-powered devices. As such, in some embodiments, the UWB device **102** may utilize BLE, for example, as a first order communication technology (e.g., to determine that the device **102** is within proximity of another UWB-enabled device) before awaking the UWB circuitry from a low power state (e.g., a sleep state). Further, in some embodiments, the BLE technology may also be used to transmit access credentials such that the UWB technology is limited to location tracking. Additionally, UWB may be used as part of a larger intent algorithm (e.g., multifactor intent calculation and/or multifactor authentication) in which rate/direction of approach, angle, and/or other characteristics may be

considered. One of the multifactor authentication technologies may include voice recognition. It should be appreciated that the system **100** may utilize geofencing, GPS, Wi-Fi, and/or other technologies in conjunction with UWB in other embodiments.

[0060] In some embodiments, it should be appreciated that the UWB device **102** and/or other device that is determining the location of other devices may not be stationary and, therefore, the location and/or orientation of that device may be determined. For example, if the UWB device **102** is an electronic lock mounted to a door, the UWB device **102** may determine whether the door is open or closed in order to provide accurate meaning to angle of arrival calculations of the UWB device **102**. As such, in some embodiments, the UWB device **102** may determine the relative angle of the electronic lock relative to a reference position (e.g., closed) based on sensor data generated by one or more sensors **114** (e.g., magnetometer, gyroscope, etc.). In other embodiments, the UWB device **102** may be positioned on the door frame such that UWB can be leveraged to determine the door position.

[0061] Depending on the particular embodiment, various other data may be exchanged (e.g., via UWB and/or other communication technologies). For example, in some embodiments, device firmware, commissioning data, audit data, and/or other suitable data may be exchanged via UWB communication. In some embodiments, somebody's mobile device may be tied into the guest network when they arrive at a location (e.g., via a transmitted Wi-Fi credential) and/or the Wi-Fi circuitry may be “forced on” in response to exchange of such credentials. In other embodiments, an identification may be transferred via UWB to avoid creating a new account for a particular system. In some embodiments, the system **100** may utilize UWB to gather data regarding people passing through gates and/or other waypoints at an event. In yet other embodiments, UWB may be leveraged to track the way a person is moving and generate a unique signature associated with that person's movement. Further, machine learning and tracking techniques may subsequently be used to identify that person based on the person's unique movement signature.

[0062] In some embodiments, an auto-operator may leverage UWB tags/badges in order to determine the amount of time to keep a barrier open. For example, rather than having a timed opening, the auto-operator may track the location of the person passing through the corresponding barrier and close the barrier only after and/or immediately after the person has safely passed through the passageway. In doing so, the auto-operator may ensure regulatory compliance (e.g., ADA compliance) while simultaneously conserve energy (e.g., by limiting the amount of air that passes through the barrier while open).

[0063] In some embodiments, the UWB device **102** may be used in order to improve school safety. For example, in some embodiments, a system **100** may be employed in order to ensure that a student cannot lock a classroom door without an authorized person (e.g., a teacher) whom bears a UWB device being in the classroom. Further, in some embodiments, UWB location monitoring and direction monitoring may be used in conjunction with school buses to ensure the location of all students within and around a school bus are known. Additionally, as indicated above, the number of persons within the school and direction of travel of students within and/or outside of the school may be ascertained in emergency situations.

[0064] In some embodiments, multiple UWB devices **102** may be used in the system **100** in order to establish a crowd-sourced network for precise location identification. For example, rather than a simple indication that a UWB device/tag has been identified within a particular radius (e.g., within a “bubble”), the system **100** may indicate the precise location (e.g., via direction/distance relative to the identifying device). Accordingly, in some embodiments, an interior building “GPS” may be established using the network of UWB devices. In some embodiments, dead reckoning, AI driven auto/dynamic access adjusting, and/or other features may be implemented. Further, in some embodiments, the system **100** may establish a “door viewer” application. In some embodiments, UWB may be used for baggage handling/tracking.

Claims

1-20. (canceled)

21. A method, comprising: communicating, via a Bluetooth communication circuitry of a first computing device associated with an access control device that controls access to a passageway, with a second computing device over a Bluetooth communication connection established between the first computing device and the second computing device to determine that the second computing device includes ultra-wideband (UWB) communication circuitry for UWB-based communication and receive access credentials from the second computing device with respect to access to the access control device; waking the UWB communication circuitry of the second computing device from a low power state in response to the Bluetooth communication; determining, by the first computing device based on at least one UWB communication signal received from the second computing device, a location of the second computing device relative to the first computing device; and communicating, from the first computing device, an alert to the second computing device in response to determining that the second computing device is approaching the passageway.

22. The method of claim 21, further comprising evaluating, by the first computing device, the access credential to determine whether a user of the second computing device is authorized to access the passageway.

23. The method of claim 22, wherein evaluating the access credential comprises determining that the user of the second computing device is unauthorized to access the passageway; and wherein communicating the alert to the second computing device comprises communicating an alert that the second computing device is approaching an area that the user of the second computing device is unauthorized to access.

24. The method of claim 23, further comprising: maintaining a lock mechanism of the access control device in a default unlocked state; and transitioning the lock mechanism of the access control device to a locked state in response to determining that the second computing device is approaching the passageway and the user of the second computing device is unauthorized to access the passageway.

25. The method of claim 24, further comprising transitioning the lock mechanism of the access control device back to the default unlocked state in response to determining that the second computing device is outside of a predefined region relative to the access control device.

26. The method of claim 24, further comprising transitioning the lock mechanism of the access control device back into the default unlocked state in response to determining that no unauthorized users are within a predefined region relative to the access control device.

27. The method of claim 26, wherein the predefined region is defined by a threshold angle and threshold distance relative to the access control device.

28. The method of claim 22, wherein evaluating the access credential comprises determining that the user of the second computing device is authorized to access the passageway; and wherein communicating the alert to the second computing device comprises communicating an alert that the user of the second computing device is approaching an unsafe area.

29. The method of claim 21, further comprising determining, by the first computing device, whether the location of the second computing device relative to the first computing device is a location that indicates an intent of a user of the second computing device to access the passageway.

30. The method of claim 21, wherein the first computing device comprises the access control device.

31. A system, comprising: an access control device comprising a lock mechanism and configured to control access to a passageway; a first computing device associated with the access control device, the first computing device comprising a first Bluetooth Low Energy (BLE) communication

circuitry and a first ultra-wideband (UWB) communication circuitry; and a second computing device comprising a second BLE communication circuitry and a second UWB circuitry; wherein the first computing device is configured to communicate with the second computing device over a BLE communication connection established between the first computing device and the second computing device to determine that the second computing device is capable of UWB-based communication and to receive access credentials from the second computing device with respect to access to the access control device; wherein the second computing device is configured to wake the second UWB communication circuitry from a low power state in response to the BLE communication; wherein the first computing device is further configured to determine a location of the second computing device relative to the first computing device based on at least one UWB communication signal received from the second computing device; and wherein the first computing device is configured to communicate an alert to the second computing device in response to a determination that the second computing device is approaching the passageway.

32. The system of claim 31, wherein the first computing device is further configured to evaluate the access credential to determine whether a user of the second computing device is authorized to access the passageway.

33. The system of claim 32, wherein to evaluate the access credential comprises to determine that the user of the second computing device is unauthorized to access the passageway; and wherein to communicate the alert to the second computing device comprises to communicate an alert that the second computing device is approaching an area that the user of the second computing device is unauthorized to access.

34. The system of claim 33, wherein the access control device is configured to maintain the lock mechanism in a default unlocked state and to transition the lock mechanism to a locked state in response to a determination that the second computing device is approaching the passageway and the user of the second computing device is unauthorized to access the passageway.

35. The system of claim 34, wherein the access control device is further configured to transition the lock mechanism back to the default unlocked state in response to a determination that the second computing device is outside of a predefined region relative to the access control device.

36. The system of claim 34, wherein the access control device is further configured to transition the lock mechanism back into the default unlocked state in response to a determination that no unauthorized users are within a predefined region relative to the access control device.

37. The system of claim 36, wherein the predefined region is defined by a threshold angle and threshold distance relative to the access control device.

38. The system of claim 32, wherein to evaluate the access credential comprises to determine that the user of the second computing device is authorized to access the passageway; and wherein to communicate the alert to the second computing device comprises to communicate an alert that the user of the second computing device is approaching an unsafe area.

39. The system of claim 31, wherein the first computing device is further configured to determine whether the location of the second computing device relative to the first computing device is a location that indicates an intent of a user of the second computing device to access the passageway.

40. The system of claim 31, wherein the first computing device comprises the access control device.
