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**Chen et al.**

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(54) **MACHINE LEARNING BASED OBJECT IDENTIFICATION**

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(22) Filed: **Sep. 7, 2021**

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**G01S 7/41** (2006.01)  
**G01S 13/42** (2006.01)  
**G01S 13/89** (2006.01)

(52) **U.S. Cl.**  
CPC ..... **G01S 7/412** (2013.01); **G01S 13/42** (2013.01); **G01S 13/89** (2013.01)

(58) **Field of Classification Search**  
CPC ..... G01S 7/412; G01S 13/42; G01S 13/89  
See application file for complete search history.

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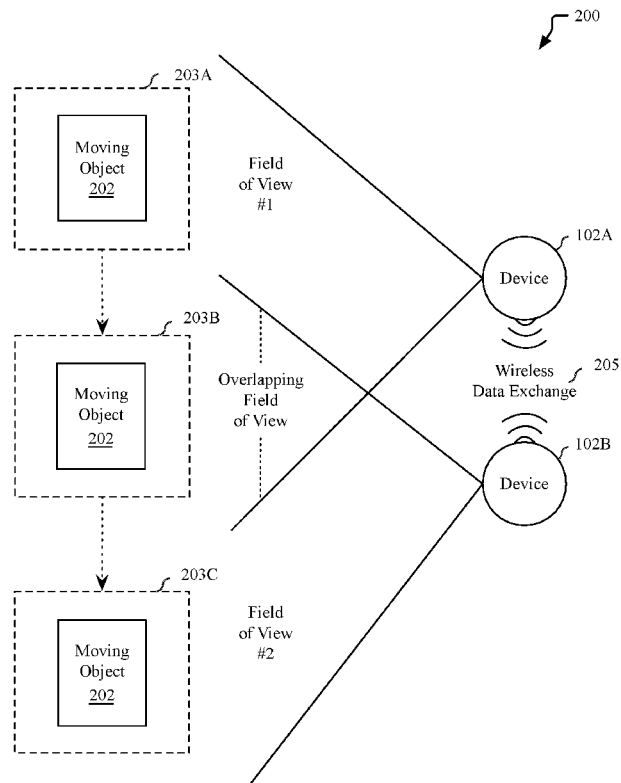
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(57) **ABSTRACT**

Embodiments described herein provide techniques to enable spatial sensor data from multiple devices to be fused into a single coordinate space. This fused sensor data can then be processed into a point cloud. Point cloud data can then be transformed to enable the classification of objects detected within the sensor data. Features within multiple feature spaces can be extracted from the point cloud data for use in classification. Classification of objects can also be used to correlate objects detected by multiple sensor equipped devices to determine a coordinate space transformation between those devices.

**19 Claims, 19 Drawing Sheets**



100

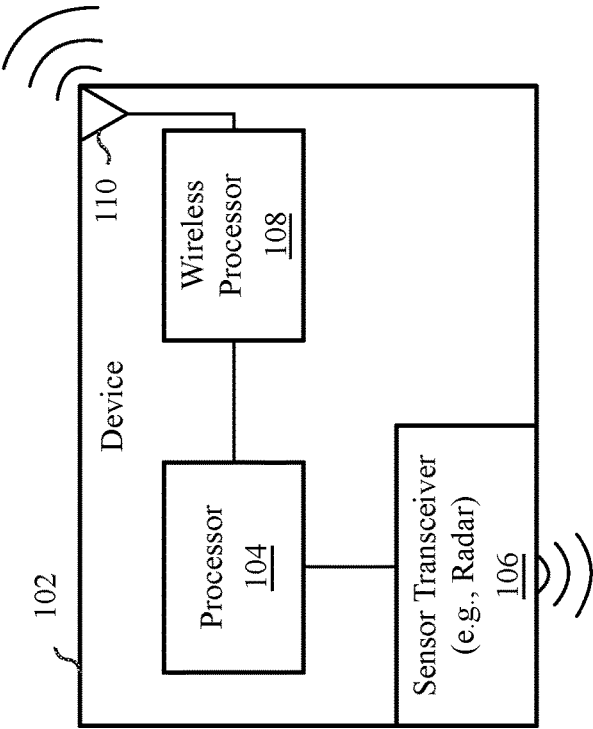


FIG. 1

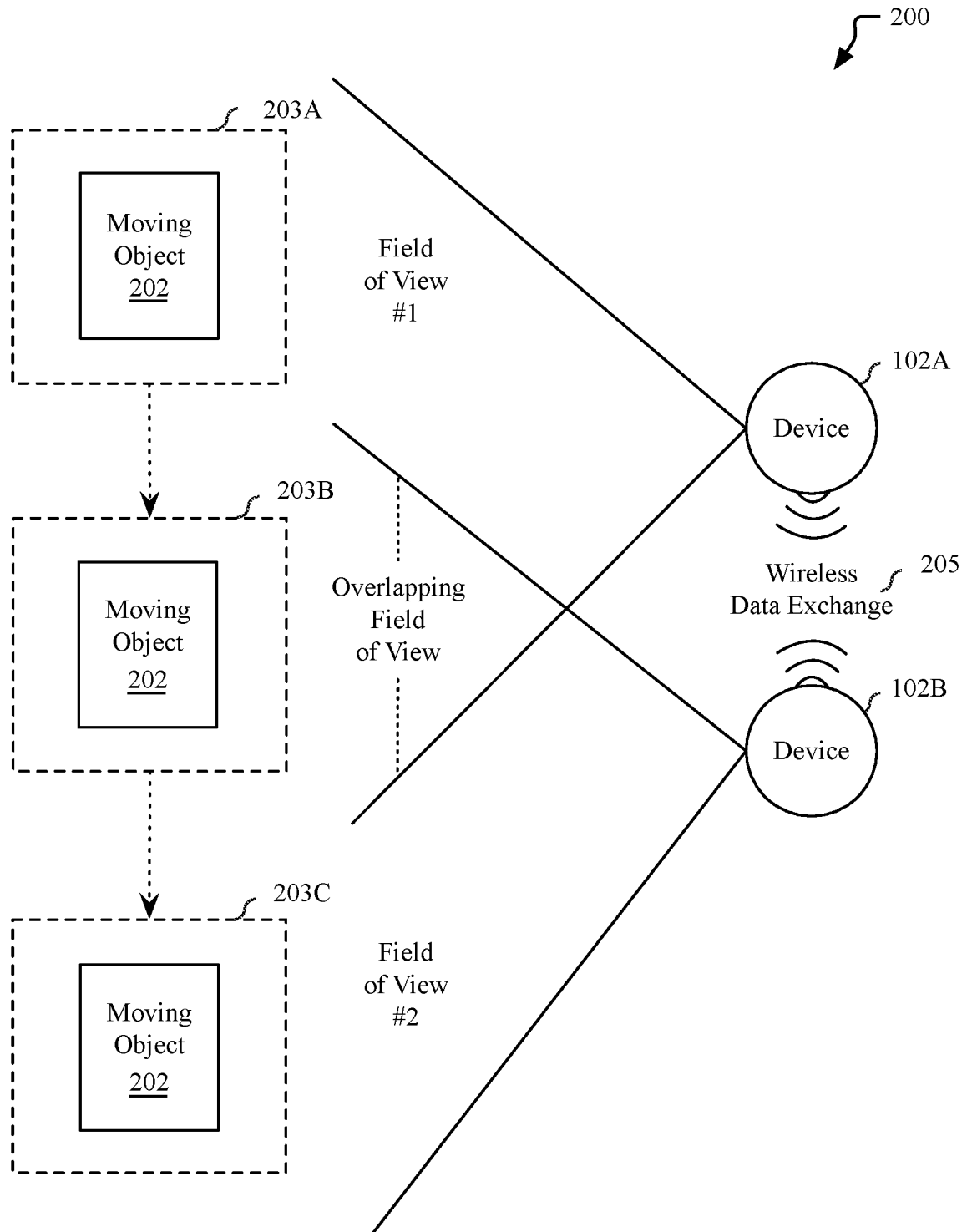


FIG. 2A

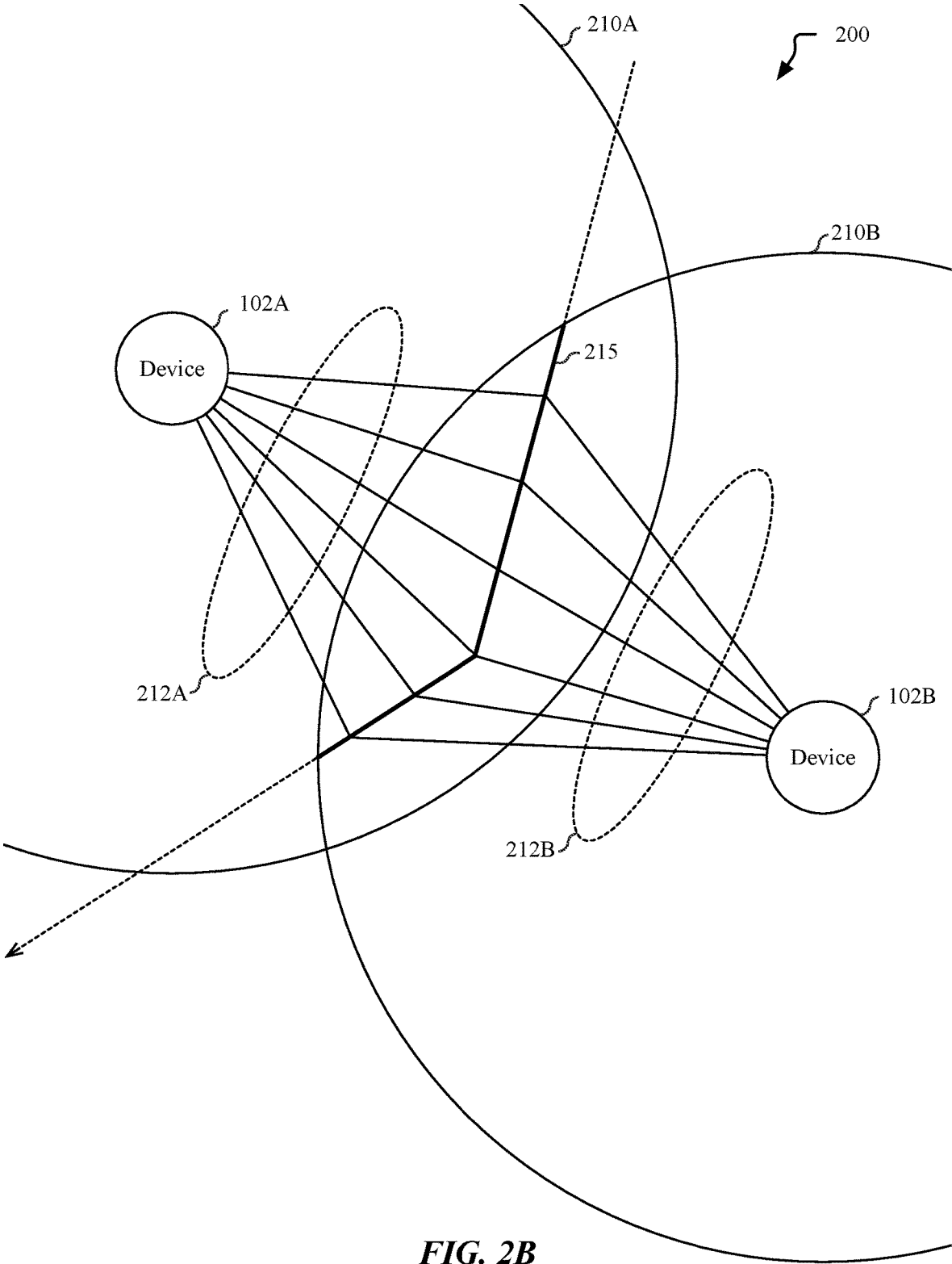


FIG. 2B

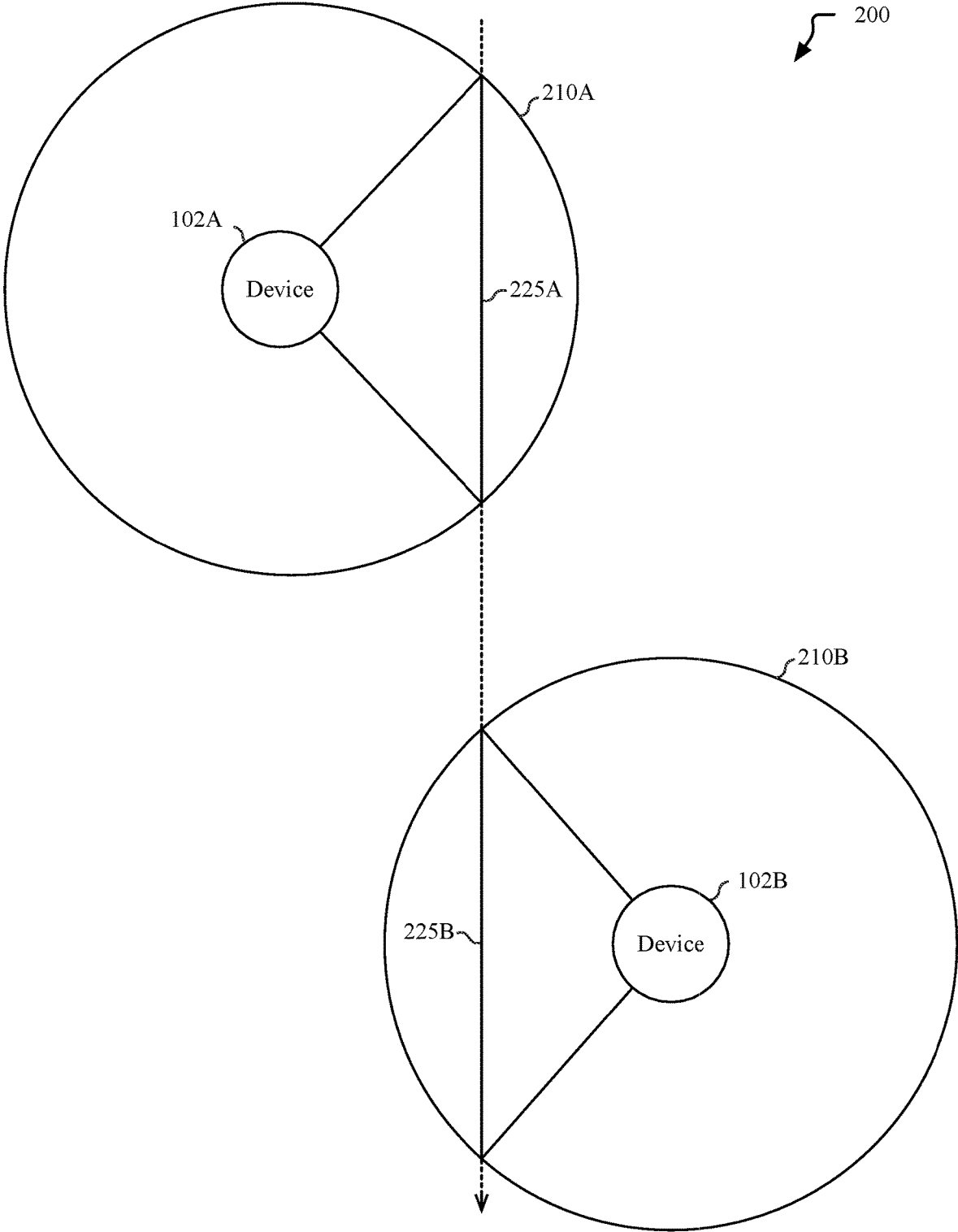
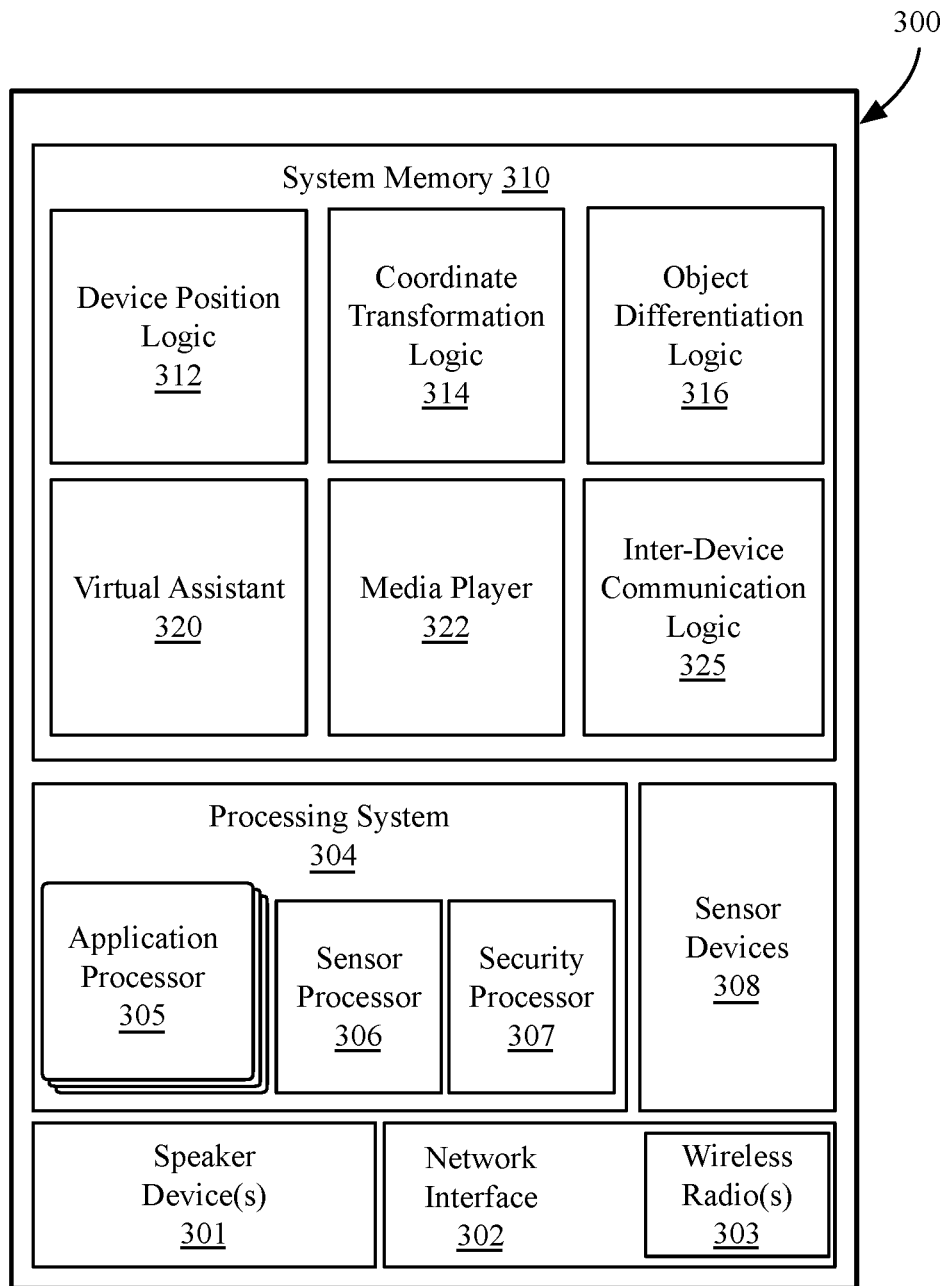


FIG. 2C



**FIG. 3**

400

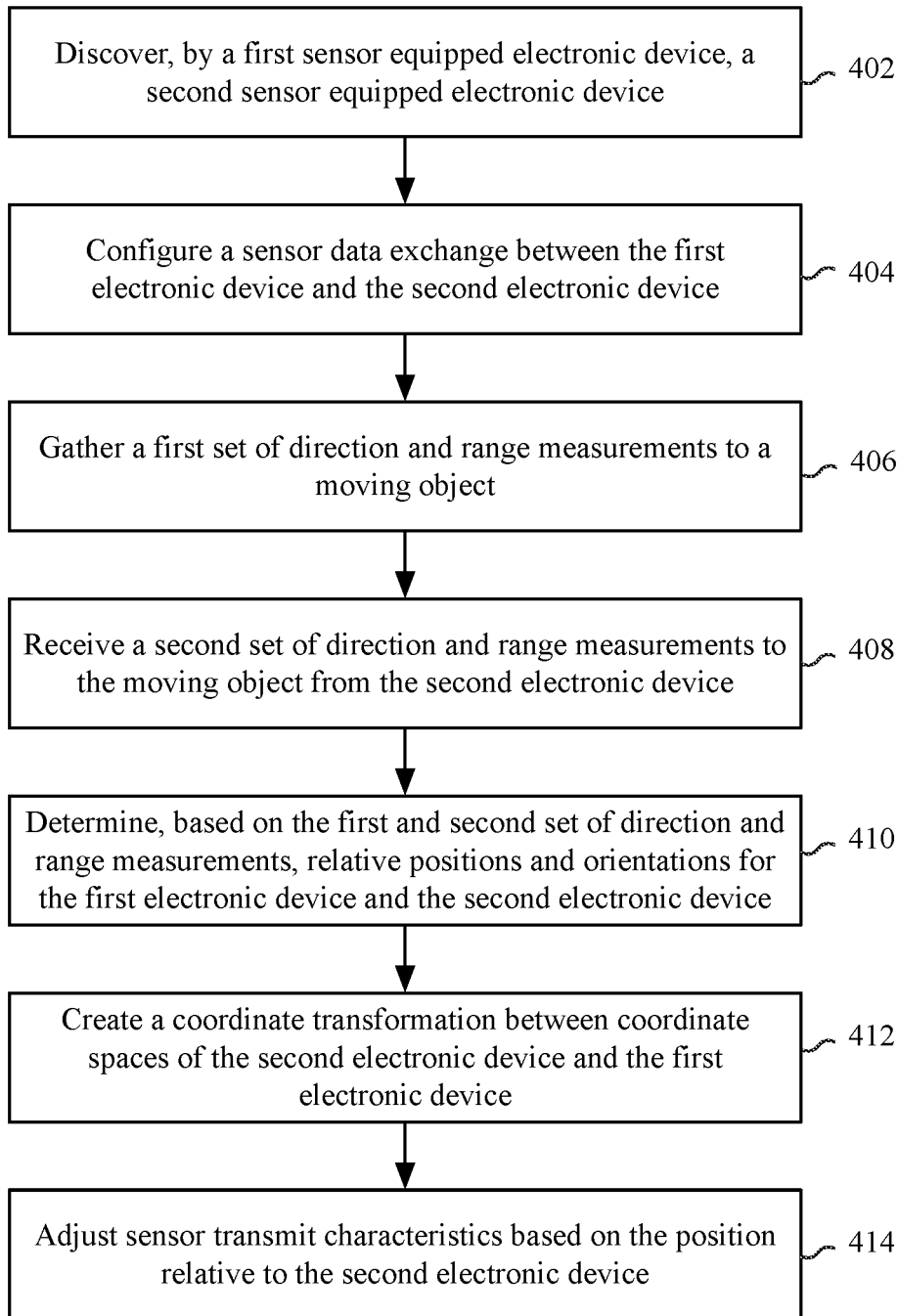


FIG. 4

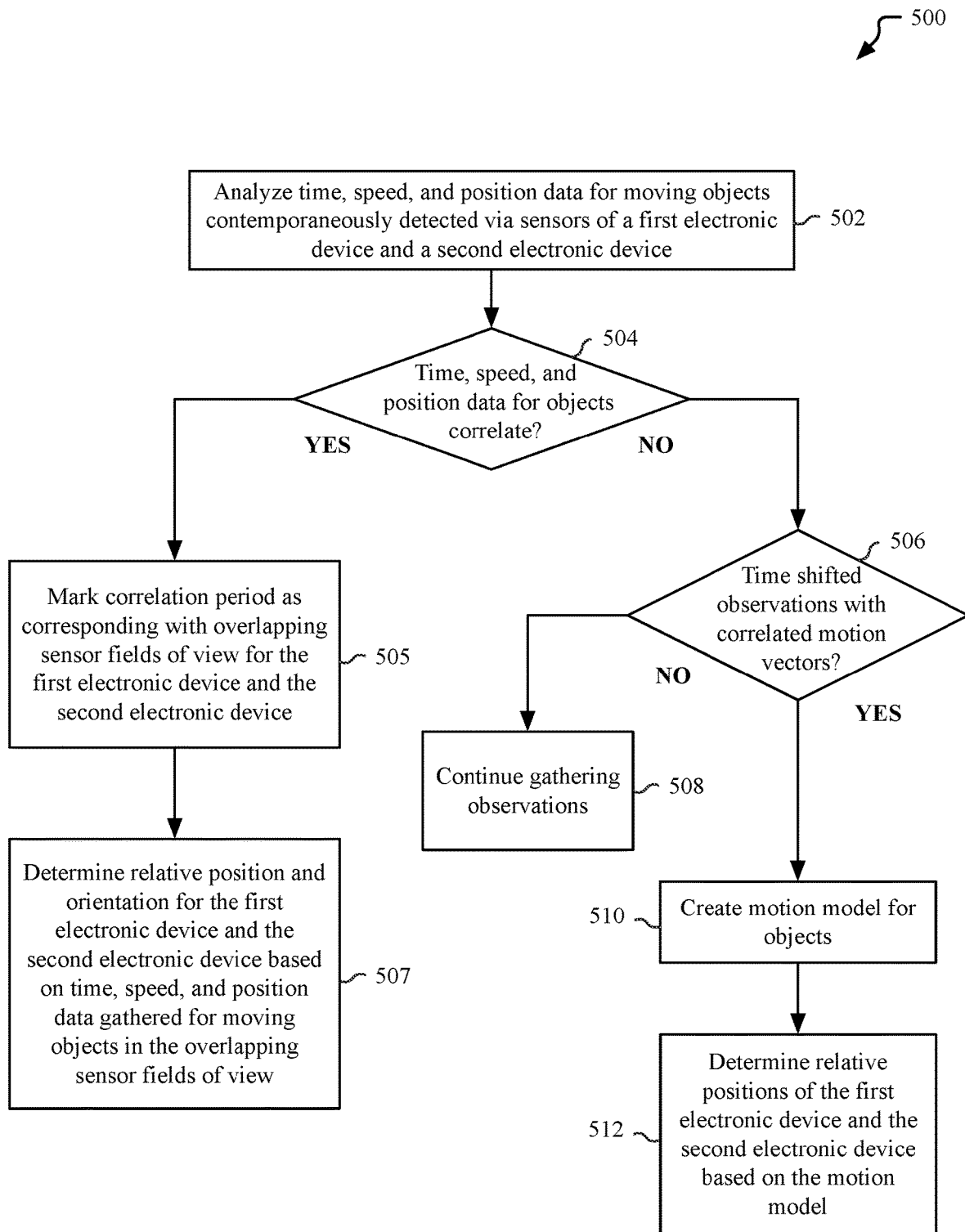
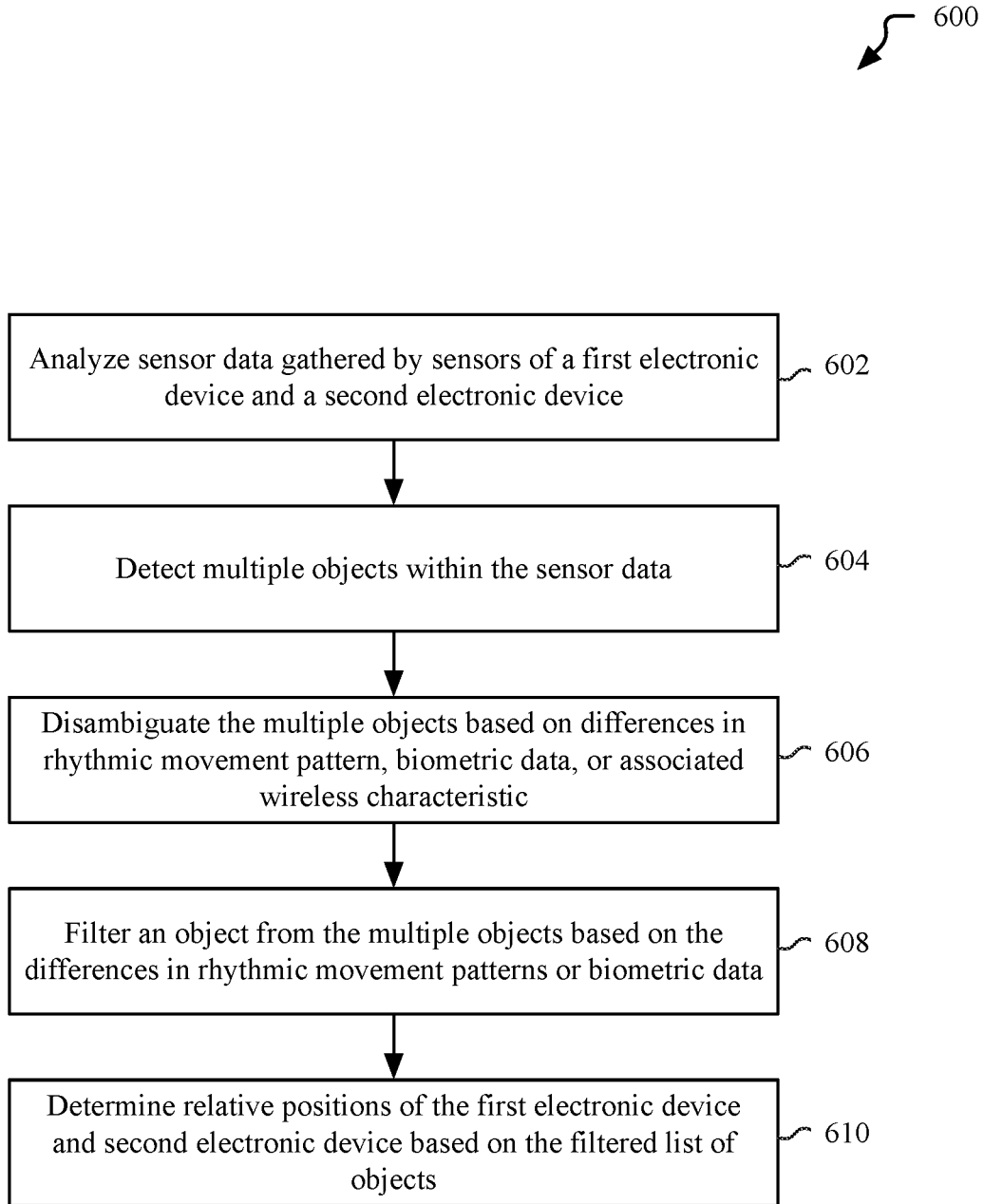
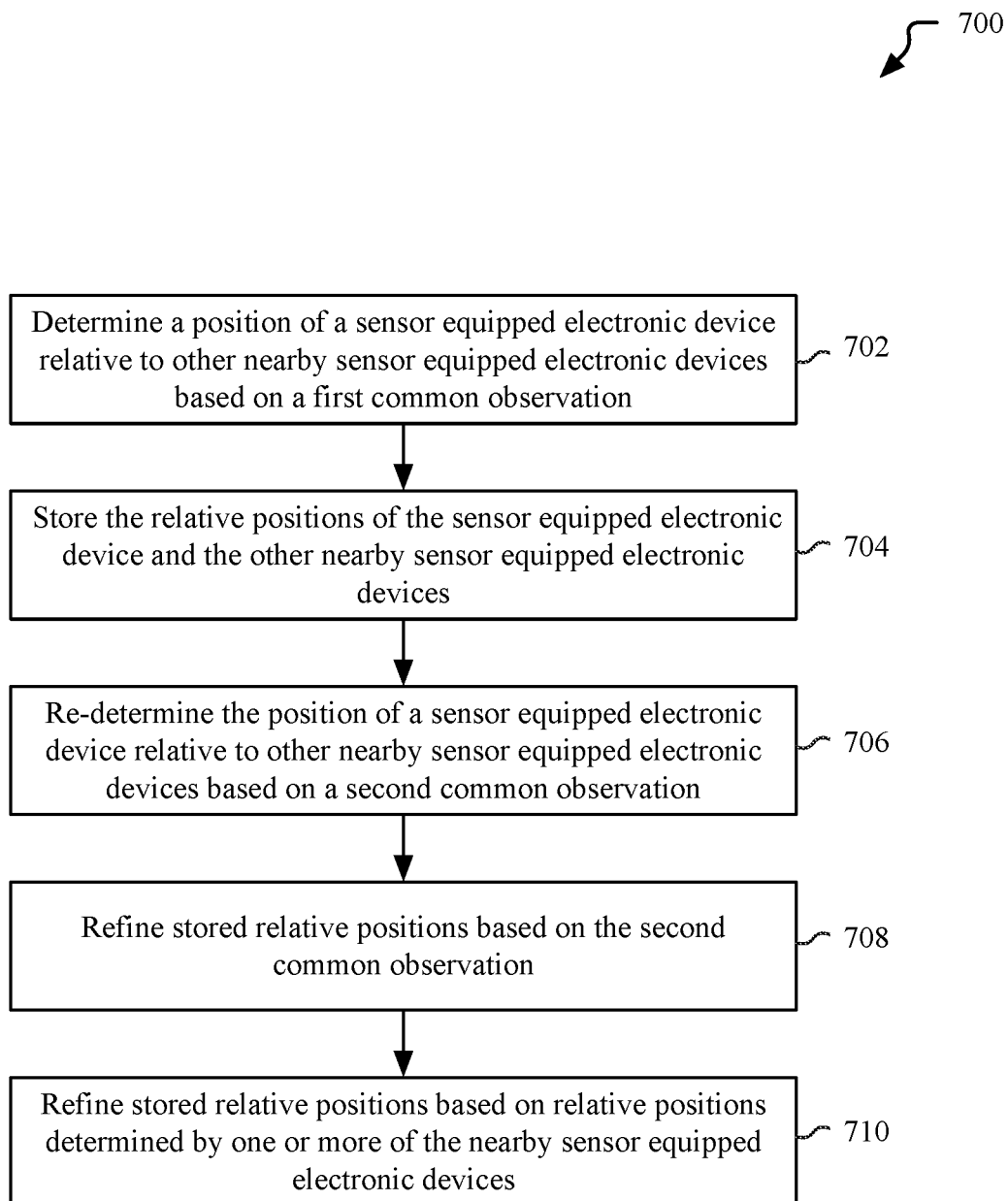


FIG. 5





**FIG. 6**



**FIG. 7A**

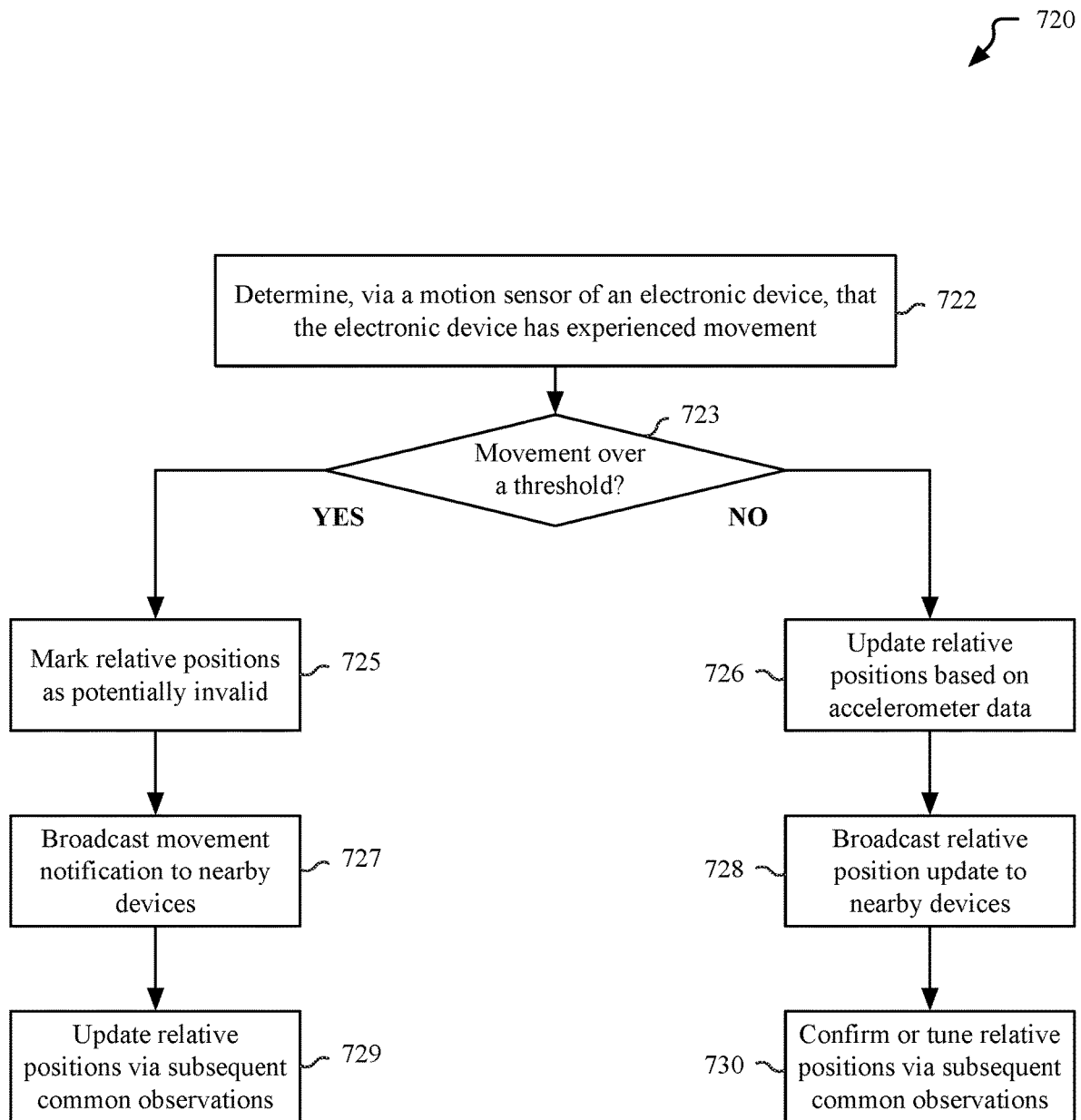


FIG. 7B

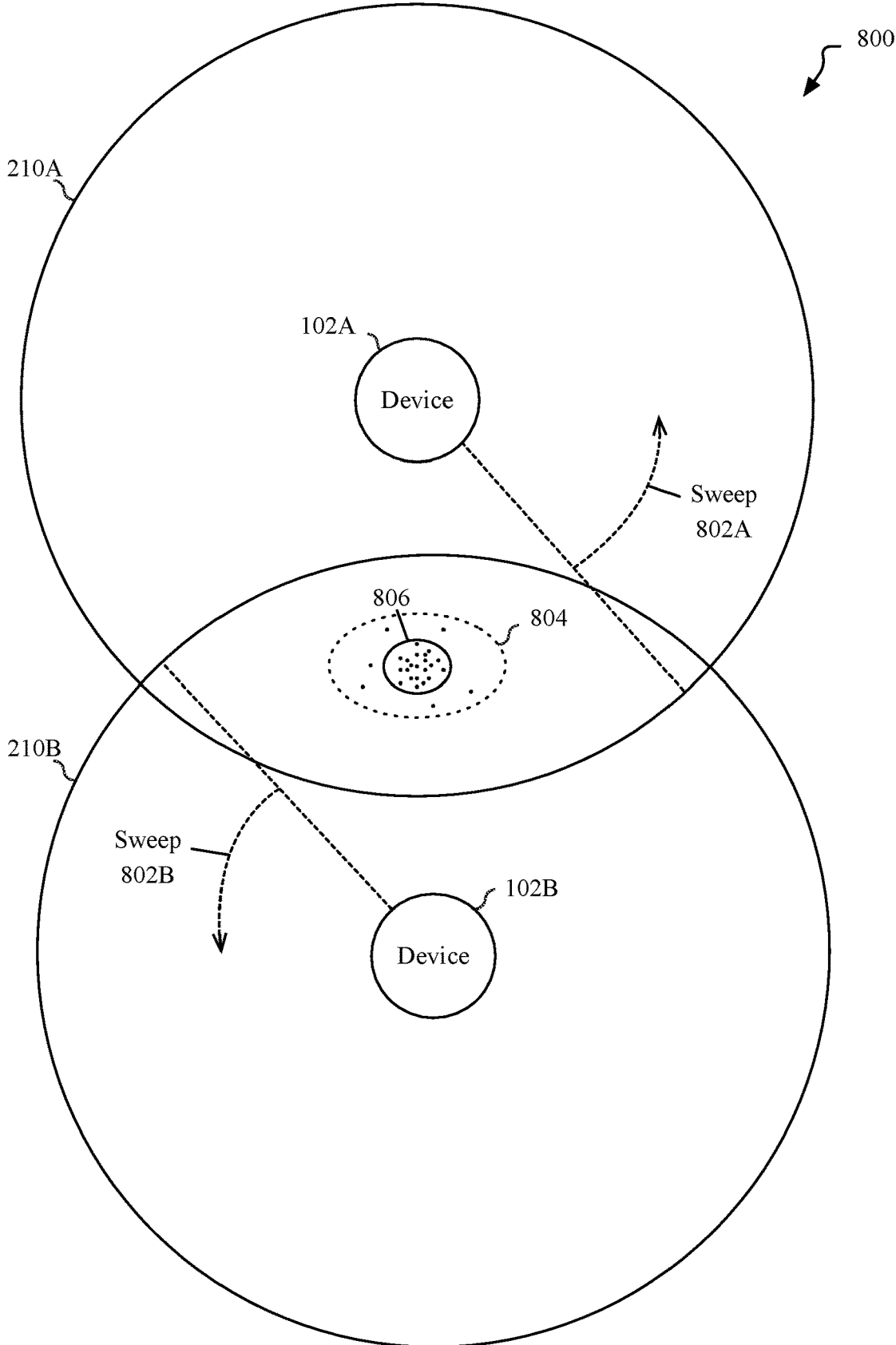


FIG. 8

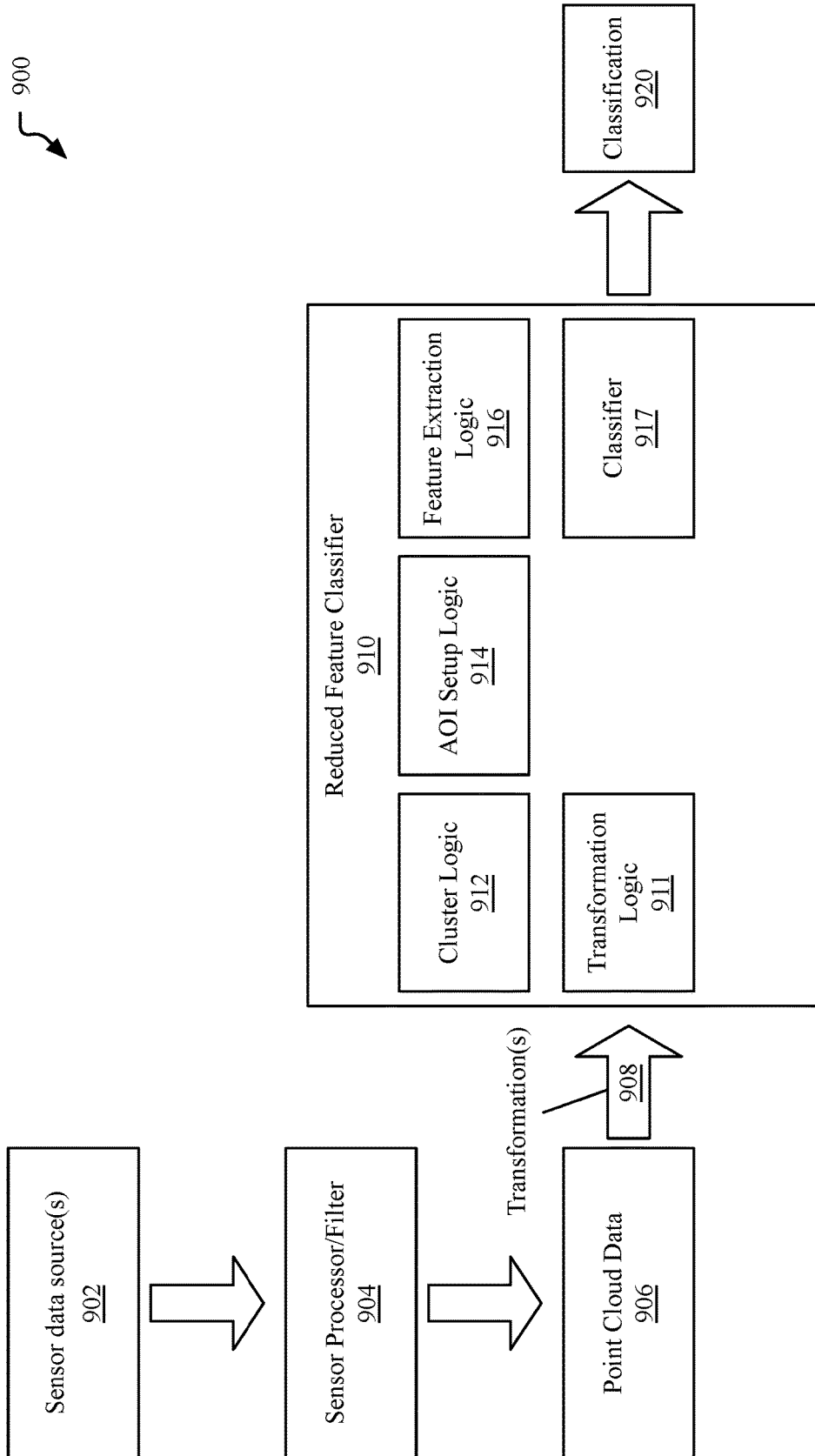
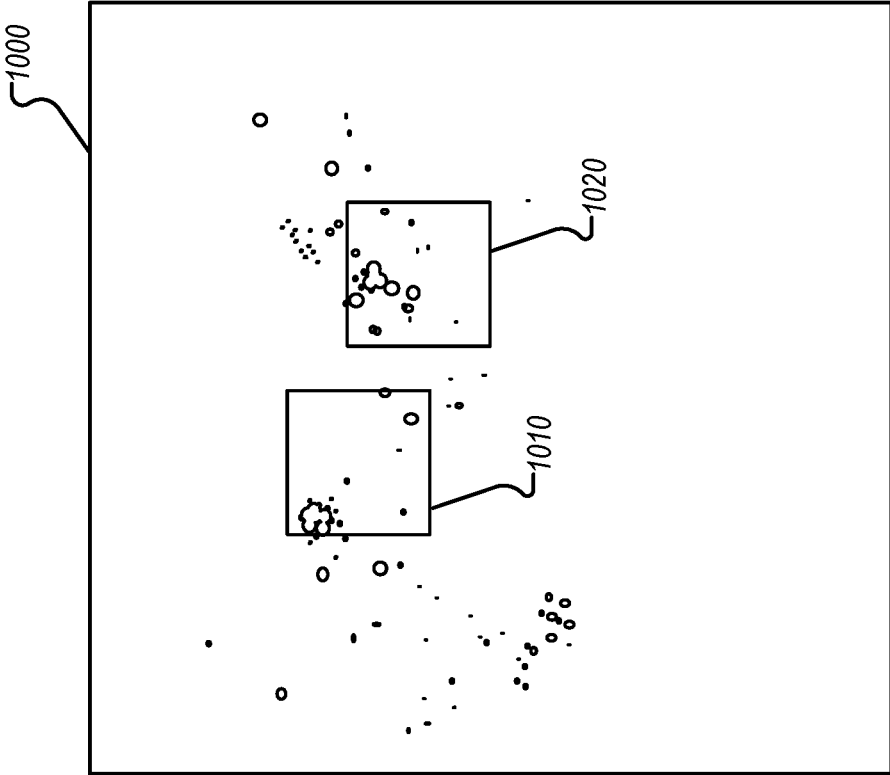
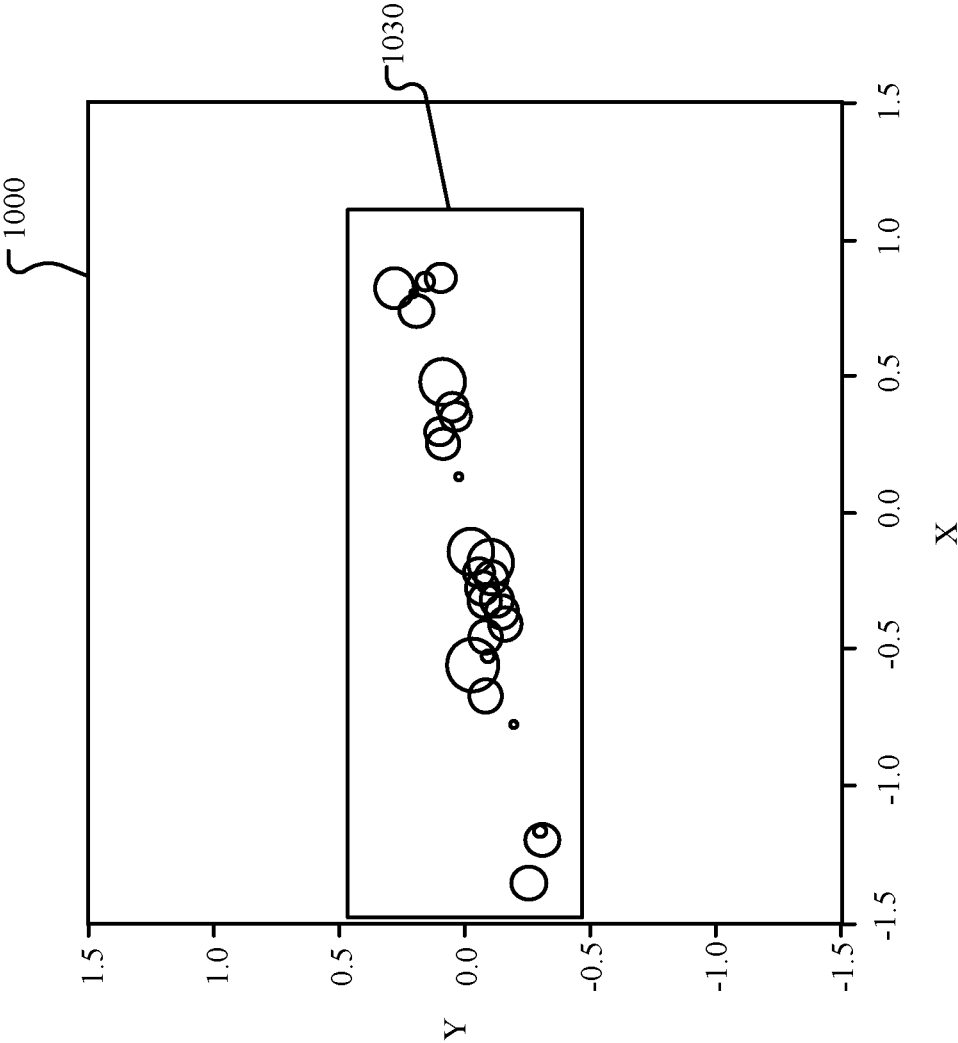


FIG. 9



**FIG. 10A**



**FIG. 10B**

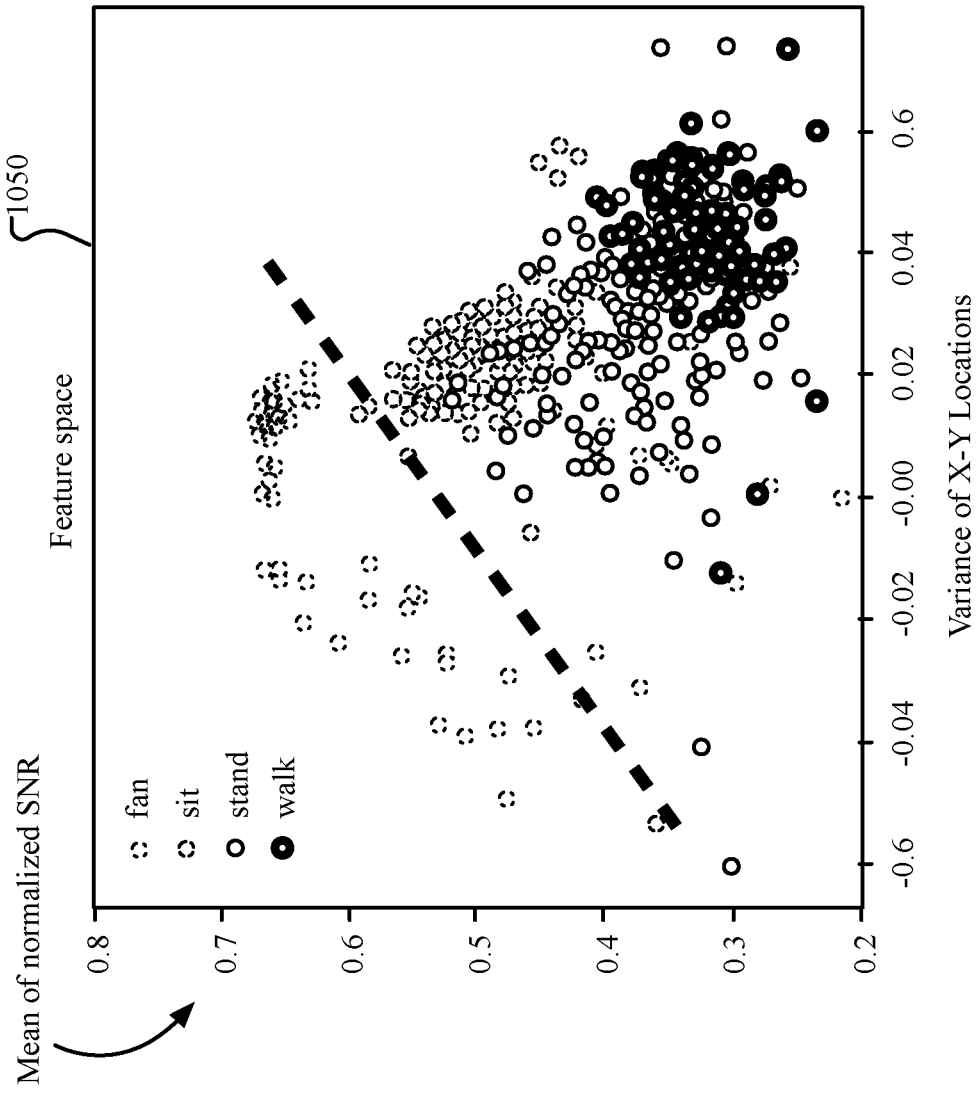
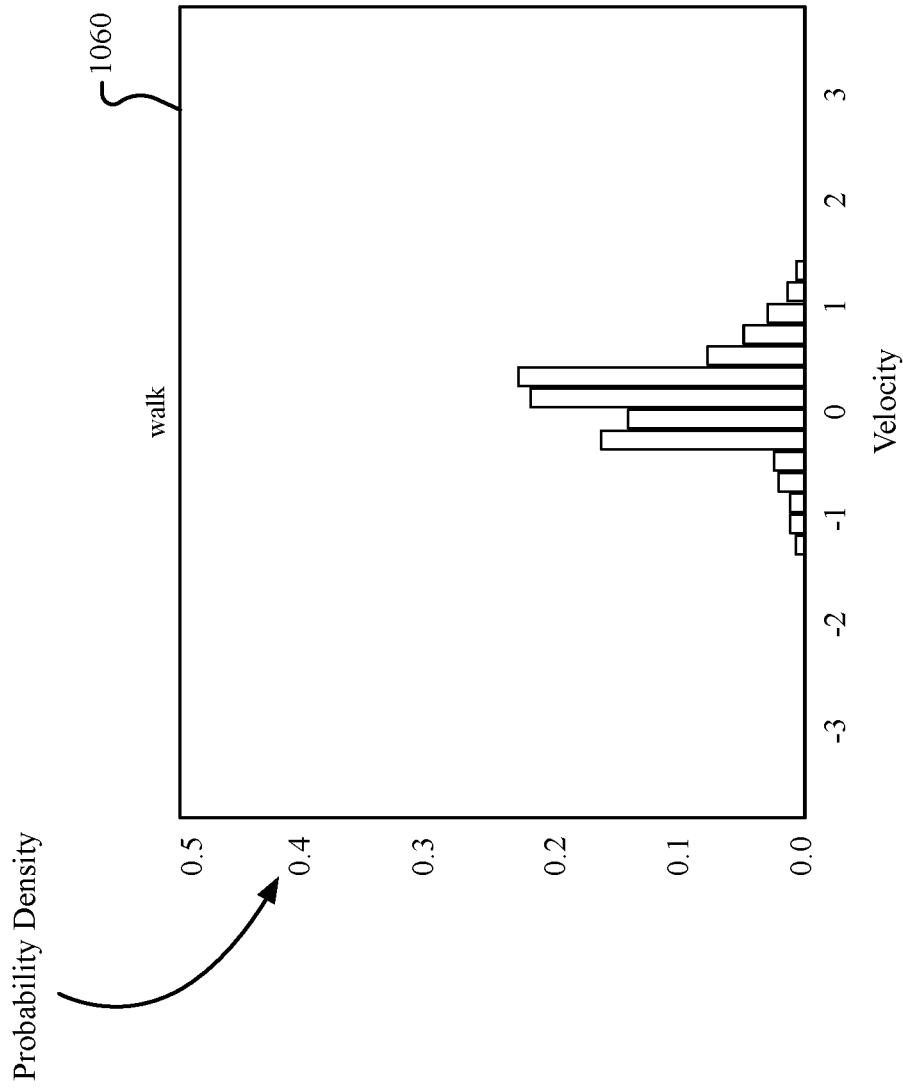
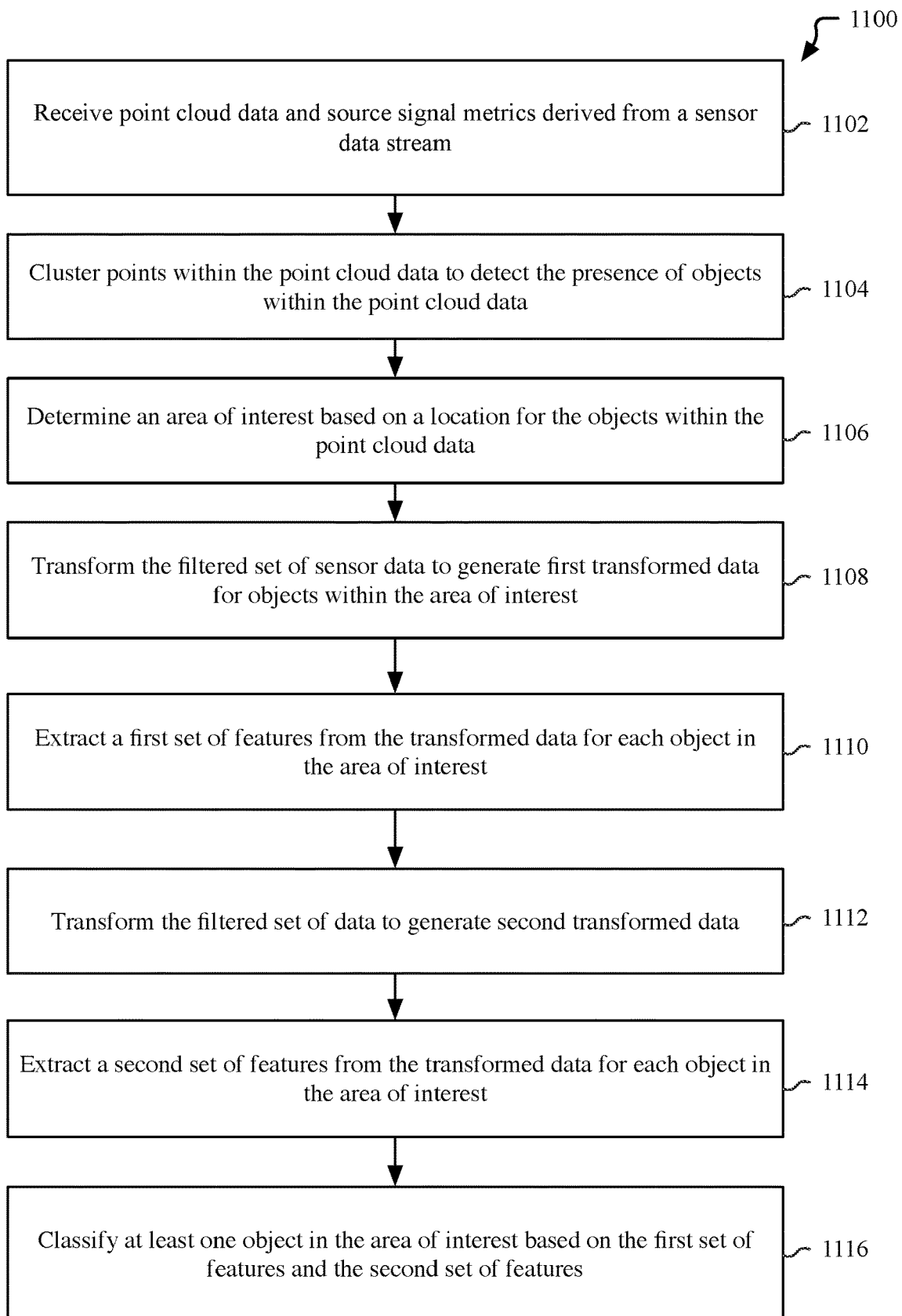


FIG. 10C





**FIG. 10D**



**FIG. 11**

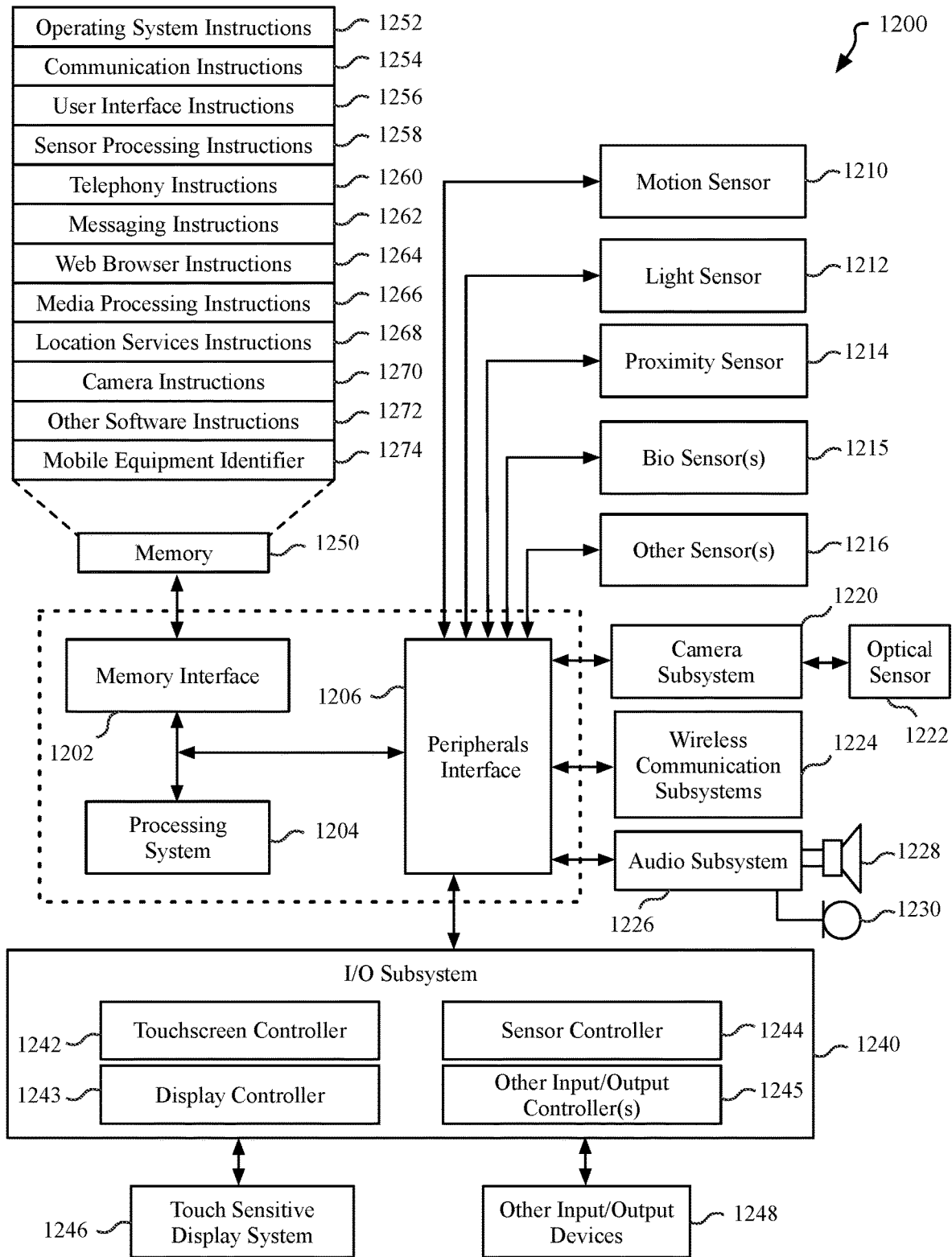
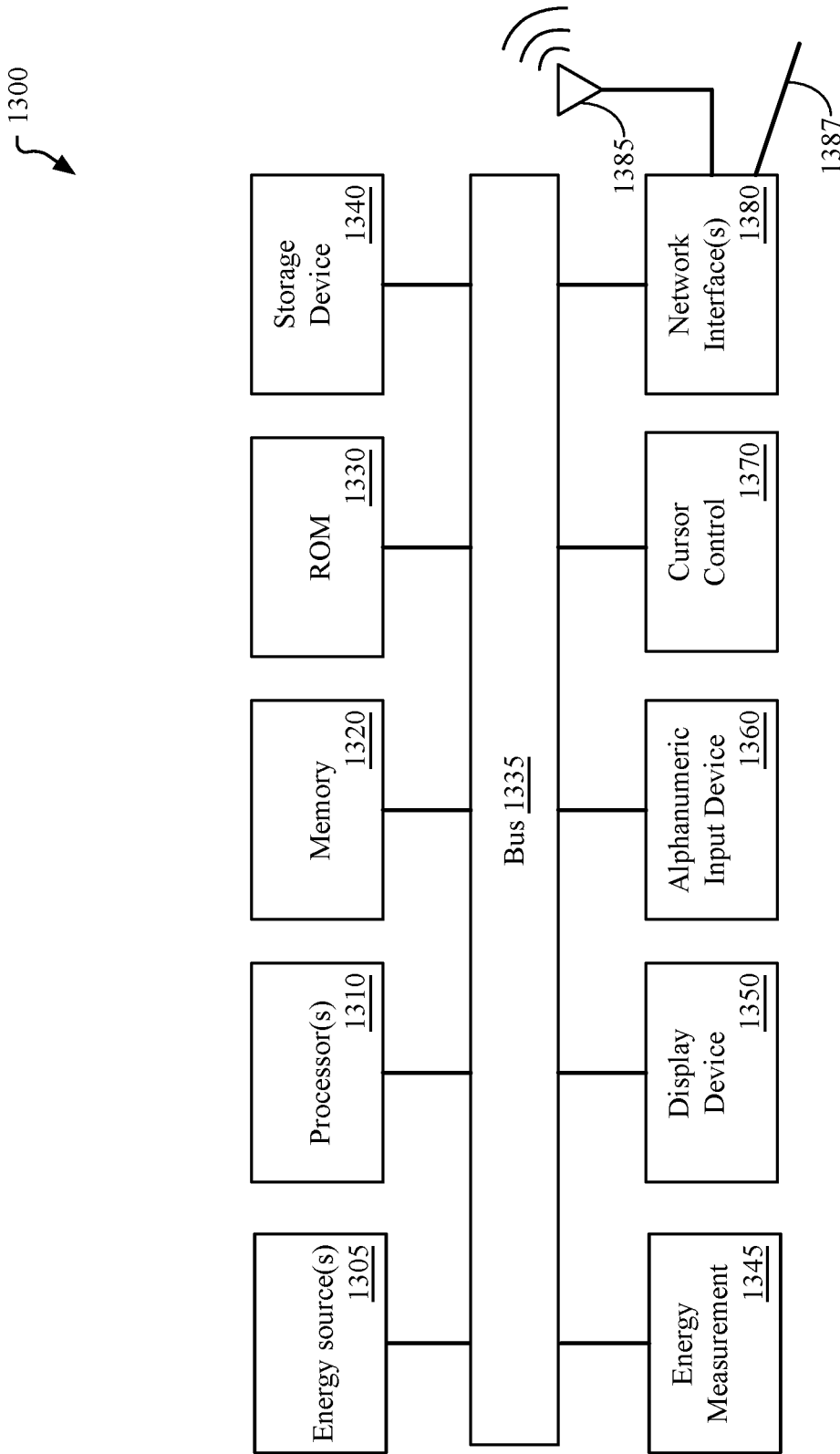


FIG. 12



**FIG. 13**

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**MACHINE LEARNING BASED OBJECT IDENTIFICATION**

## CROSS-REFERENCE

The present application claims the benefit of U.S. Provisional Application No. 63/083,528, entitled "Machine Learning Based Object Identification," filed Sep. 25, 2020.

## FIELD

Embodiments described herein relate generally to a system and method of performing object detection based on spatial sensor data. More specifically, determining between human and non-human objects within the spatial sensor data.

## BACKGROUND OF THE DESCRIPTION

Radar sensors can be used by electronic devices to give those devices a degree of spatial awareness. The required range accuracy and angular resolution of those sensors can vary based on the intended purpose of the sensor data. Collision avoidance systems for vehicles or autonomous robots may be required to have higher resolution sensors relative to sensors that are designed to simply detect motion or the simple existence of a nearby object. For devices that are movable and positional, but not autonomously mobile, the radar sensor used by those devices may be a relatively lower power sensor with a lower angular resolution relative to navigational radar sensors. Machine learning can be used to train models to differentiate between objects detected by the lower power sensors. However, traditional machine learning models may be too complex to be performed efficiently on consumer electronic devices.

## SUMMARY OF THE DESCRIPTION

Embodiments described herein provide systems and methods to techniques to distinguish between, for example, human and non-humans with point cloud data detected via radar sensors. Objects may be detected as a point cloud of detected radar reflections that are centered on the detected object. Sensor processing logic can then be used to filter out artifacts and anomalies in the returned signal. The point cloud data can be processed, transformed, and buffered over a period of time. A classifier that has been trained on a reduced feature set can distinguish between whether the radar data indicates, for example, a human, non-human, living, or non-living object.

One embodiment provides a system to perform object classification at a stationary electronic device, where the system comprises a radar sensor and one or more processors including a sensor processor and an application processor. The one or more processors are configured to receive a set of processed and filtered radar sensor data including point cloud data and signal to noise metrics associated with the point cloud data, cluster data points within the point cloud data to detect the presence of one or more objects within a scene, determine an area of interest based on the location and the number of objects, and transform the filtered set of sensor data to generate first transformed data for objects within the area of interest. The system can then extract a first set of features from the transformed data for each object in the area of interest, transform the filtered set of data to generate second transformed data, and then extract a second set of features from the transformed data for each object in

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the area of interest. The system then classifies at least one object in the area of interest based on the first set of features and the second set of features. In one embodiment the classification is performed to determine whether the one or more objects within the scene are human or non-human.

The above summary does not include an exhaustive list of all embodiments in this disclosure. All systems and methods can be practiced from all suitable combinations of the various aspects and embodiments summarized above, and also those disclosed in the Detailed Description below.

## BRIEF DESCRIPTION OF THE DRAWINGS

The present invention is illustrated by way of example and not limitation in the figures of the accompanying drawings in which like references indicate similar elements, and in which:

FIG. 1 is a block diagram of a network operating environment for an electronic device;

FIG. 2A-2C illustrate a system including multiple electronic devices;

FIG. 3 illustrates an electronic device that includes hardware and software logic to enable the fusion of measurements from sensors of multiple devices into a single coordinate space;

FIG. 4 illustrates a method of fusing measurements from sensors of multiple devices into a single coordinate space;

FIG. 5 illustrates a method for a sensor equipped electronic device to determine the position of the electronic device relative to other sensor equipped electronic devices

FIG. 6 illustrates a method for a sensor equipped electronic device to differentiate between multiple objects within sensor data;

FIG. 7A-7B illustrate methods to refine determined relative positions over a period of time;

FIG. 8 illustrates a sensor system that includes multiple devices having fused radar sensors;

FIG. 9 illustrates an object classification system to enable the identification of object types using within sensor data using a reduced set of features;

FIG. 10A-10D illustrates sensor point cloud transformations and feature spaces that facilitate differentiation between specific object types using a reduced set of features;

FIG. 11 illustrates a method of sensor point cloud transformation that enables differentiation between specific object types using a reduced set of features;

FIG. 12 is a block diagram of a device architecture for a mobile or embedded device, according to an embodiment; and

FIG. 13 is a block diagram of a computing system, according to an embodiment.

## DETAILED DESCRIPTION

Embodiments described herein provide techniques to enable spatial sensor data from multiple devices to be fused into a single coordinate space. This fused sensor data can then be processed into a point cloud. Point cloud data can then be transformed to enable the classification of objects detected within the sensor data. Features within multiple feature spaces can be extracted from the point cloud data for use in classification. Classification of objects can also be used to correlate objects detected by multiple sensor equipped devices to determine a coordinate space transformation between those devices.

The following description and drawings are illustrative and are not to be construed as limiting. Various embodi-

ments and aspects will be described with reference to details discussed below, and the accompanying drawings will illustrate the various embodiments. Numerous specific details are described to provide a thorough understanding of various embodiments. However, in certain instances, well-known or conventional details are not described in order to provide a

concise discussion of embodiments. The terminology used in this description is for the purpose of describing particular embodiments only and is not intended to be limiting of the invention. As used in the description of the invention and the appended claims, the singular forms “a”, “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will also be understood that the term “and/or” as used herein refers to and encompasses any and all possible combinations of one or more of the associated listed items. It will be further understood that the terms “comprises” and/or “comprising,” when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

Some processes are described below in terms of some sequential operations. However, it should be appreciated that some of the operations described may be performed in a different order. Moreover, some operations may be performed in parallel rather than sequentially.

FIG. 1 is a block diagram of a network operating environment 100 for an electronic device 102. The electronic device 102 can be a variety of electronic devices, such as a smart speaker device, television, or television set top box. Aspects of the electronic device 102 may also be found in other electronic devices, such as smart home appliances and electronic devices. Exemplary smart home appliances and electronic devices include thermostats, refrigerators, washers, dryers, lighting control systems, and the like.

In one embodiment the electronic device 102 includes a processor 104 having multiple processor cores. The processor cores can enable the processor 104 to function as one or more of an application processor, signal processor, sensor processor, and secure processor. The device 102 can also include a wireless processor 108 coupled with an antenna 110. The wireless processor 108 can enable the electronic device 102 to communicate over a wireless network, such as but not limited to a Wi-Fi network, Bluetooth personal area network, or mobile data network (e.g., long-term evolution (LTE), 5G, etc.). The electronic device 102 can also include a sensor transceiver 106. In one embodiment the sensor transceiver 106 is a low power radar sensor that enables the electronic device 102 to determine the position of the appliance relative to surfaces and objects in the environment surrounding the smart home appliance. The field of view of the sensor transceiver 106 can vary based on the type of sensor. In one embodiment the sensor transceiver 106 has a 360 degree field of view and may be capable of sweeping that view multiple times a second. The sensor transceiver 106 may be relatively precise at range detection for objects within the environment, but may have a relatively limited angular resolution. In other embodiments, the field of view and/or sweep area of the sensor transceiver 106 may be focused to less than 360 degrees and sweep the focused view at a higher sweep rate. In one embodiment, the device includes an MIMO radar sensor that includes a set of antennas spaced around the electronic device 102, enabling the device to sense the entire field of view simultaneously without requiring a sweep or scan.

In one embodiment, the ability to resolve moving objects within the environment of the electronic device 102 can be improved by combining sensor data from multiple devices. Multiple radar equipped electronic device 102 may communicate over a network to share radar sensor data between the devices. The communication can be performed wirelessly via a network connection that is enabled via the wireless processor 108. Each instance of the electronic device 102 can combine local sensor data with remote sensor data received from other devices to increase the angular resolution of the detected sensor data. The various electronic devices 102 may be multiple instance of the same type of device. Different types of electronic devices may also interact, where each device is capable of communicating wirelessly with other devices and has a sensor transceiver 106 that is able to gather sensor data about the spatial environment around the device. While radar is given as an example type of sensor, other types of sensor data can also be fused across multiple devices. For example, sensor data from lidar sensors or ultrasonic sensors may also be fused.

To perform the fusion of the sensor data from the multiple electronic devices, each device performs operations to determine the position of the device relative to the other devices. Traditional location determination techniques may be inapplicable to this task. For example, an instance of the electronic device 102 may not possess satellite-based positioning receivers. If satellite-based positioning receivers are present, the horizontal accuracy of satellite-based location determination for the electronic device 102 may be limited due to the devices being positioned in an indoor environment. Furthermore, radio-frequency positioning may not be able to determine the position of the device with sufficient accuracy. Accordingly, it would be advantageous to make use of an electromagnetic or sonic sensor determine the relative position of the devices. Once the relative position of the devices is determined, various advantages in sensor system management and sensor processing may be realized.

FIG. 2A-2C illustrate a system 200 including multiple electronic devices 102A-102B. FIG. 2A illustrates a view of a system 200 in which the multiple electronic devices 102A-102B are each equipped with spatial sensors and positioned such that the spatial sensors have an overlapping field of view. FIG. 2B illustrates an additional view of the system 200 in which the electronic devices 102A-102B have different overlapping field of view. FIG. 2C illustrates an additional view of the system 200 in which the electronic devices 102A-102B have a non-overlapping field of view. The precise field of view for a device can vary based on the types of sensors that are available to the device and the configuration of those sensors. Whether device sensors have overlapping fields of view can depend on, for example, the relative positions of the devices, the sensitivity of the sensors, and whether any obstructions are present in the environment.

The multiple electronic devices 102A-102B are each instances of electronic device 102 of FIG. 1. Each electronic device 102A-102B is equipped with a sensor transceiver, such as but not limited to a radar transceiver. Electronic devices 102A-102B may participate in wireless data exchange operations 205 that include advertising available services, discovering the presence of other devices, and discovering services that are available at those other devices. The type of services offered by a device can depend on the type of device.

The wireless data exchange operations 205 can be performed over a wireless network or via direct wireless communications. For example, the electronic devices 102A-

102B maybe connected to a common network via an infrastructure Wi-Fi access point. The electronic devices 102A-102B may also discover the other devices presence via wireless advertisement signals that are transmitted via Wi-Fi Direct, Bluetooth, or other wireless protocols (e.g., Zigbee, Z-wave). The wireless data exchange operations 205 can also include the exchange of identifier information and device capabilities. The identifier information can identify the type of device and/or a user account identifier that is associated with the device. The capabilities can specify, for example, the types of sensors that are equipped on each device and whether the sensor data can be shared with other devices. Electronic devices 102A-102B can share location information if any of the devices have been able to determine a location for the devices. The locations may be coarse locations, such as a general geographic region, or location identifiers that have meaning to one or more users of the electronic device (e.g., home, office, etc.). If a more precise location can be determined for a device, the precise location can be shared between devices. In one embodiment, devices can shared determined relative locations if the relative locations of two or more devices have been determined.

As shown in FIG. 2A, using techniques described herein, the electronic devices 102A-102B can use sensor measurements of commonly detected objects that pass within the sensor field of view of the devices to determine the relative positions of the devices to each other. In the event that the electronic devices 102A-102B are not aware of each other's position, each device can calculate the position of the other device if those devices are able to track the same moving object 202. Each device 102A-102B can determine direction and range measurement to the object as the object moves. If a device has both sets of measurements, the device can solve for the position of the other device. The moving object 202 can be anything resolvable by the spatial sensors of the electronic devices 102A-102B, including humans, animals, or self-locomoting devices.

For example, a moving object 202 at a position 203A within the field of view (Field of View #1) of a first electronic device 102A may be detected as the device transits the field of view of the first electronic device 102A. As the device transits the field of view of the first electronic device 102A, a range measurement may be gathered during each cycle or sweep of the sensor on the device. Multiple range measurements can be gathered and combined to determine a path that is followed by the moving object. The range measurements can be gathered by the first electronic device 102A-102B as the moving object 202 moves from position 203A to position 203B, then from position 203B to position 203C, which is outside of the field of view of the first device 102A. Likewise, as the moving object 202 transits into the field of view (Field of View #2) of a second electronic device 102B, multiple range measurements can be gathered and combined to determine a path that is followed by the moving object. Range measurements can be gathered by the second electronic device 102B as the moving object 202 moves from position 203B to position 203C, then outside of the field of view of the second electronic device 102B.

In one scenario, the electronic devices 102A-102B have an overlap in their fields of view. For example, the illustrated electronic devices 102A-102B each have a view of position 203B. Accordingly, sensor readings may be gathered by each of the devices 102A-102B as the moving object 202 transits the overlapping field of view that includes position 203B. Using the sensor data collected by the other device for the commonly detected moving object as the object moves

within the common field of view, each electronic devices 102A-102B can determine a set of relative positions to the moving object 202 and plot a path for the object. One or more of the electronic devices 102A-102B can then compare the locally detected path with the remotely detected path to determine the position of the other device. For example, an offset on the local coordinate space of each device to the other devices can be determined by computing a coordinate space transformation that will equalize the paths. This coordinate space transformation can then be used to enable objects detected by one of the electronic devices (e.g., electronic device 102A) to be positioned within the coordinate space of the other electronic device (e.g., electronic device 102B). While in this scenario the electronic devices 102A-102B have a portion of the scene that they both observe, the devices need not be positioned such that they can observe each other.

As shown in FIG. 2B, the electronic devices 102A-102B can have sensor fields of view 210A-210B and are positioned such that a portion of those fields of view 210A-210B overlap. An object (e.g., moving object 202) can move into and out of the fields of view 210A-210B. When the object moves through the fields of view 210A-210B, a path for the object can be observed. The portion of the path (215) that is observed by both electronic devices 102A-102B can be used to enable the electronic devices 102A-102B to determine their relative positions. In one embodiment, the path taken by the object can be computed based on a set of range measurements 212A-212B made by the electronic devices 102A-102B. Electronic device 102A can gather range measurements 212A, while electronic device 102B can gather range measurements 212B.

Until the electronic devices 102A-102B are able to determine their relative positions, the devices may not have information on whether the devices have overlapping sensor fields of view 210A-210B. Instead, the electronic devices 102A-102B can compare the range measurements for any moving objects that are detected and then determine if any detected objects are commonly detected objects. For example, commonly detected objects can be determined when an object is observed by each of the electronic devices 102A-102B within a period of time and the path of the object that is detected by one device appears to be a transformation of the path detected by another device. The nature of the transformation of the path and the ranges in the set of range measurements 212A-212B can then be processed to enable the electronic devices to determine their relative positions.

As shown in FIG. 2C, the electronic devices 102A-102B may be positioned such that the fields of view 210A-210B do not overlap. In the scenario in which there is no overlap in the fields of view of the electronic devices 102A-102B, but the moving object 202 is observed by both devices, then the sensor measurements can be used calculate a motion vector (e.g., speed and direction) for the object and generate a motion model for the detected object. The motion model can then be used to estimate the objects position with respect to each device over time. This estimate can then be compared to objects that are detected by sensors of other devices. Multiple observations can be used and the relative positions of the electronic devices 102A-102B can be refined over time.

For example, a moving object can traverse the field of view 210A of a sensor of the first electronic device 102A. The path 225A of the object while within the field of view 210A can be used to calculate a motion vector  $y$  for the object. The motion vector can be a mathematical model that describes the observed motion of the object through space.

The motion vector  $y$  may be used to estimate a future position of the object, assuming the object does not significantly change the direction or speed of its motion after leaving the field of view 210A of the sensor first electronic device 102A. If the path 225B of the moving object passes into the field of view 210B of the sensor of the second electronic device 102B at a time consistent with the estimation calculated by first electronic device 102A, the first and second electronic device may presume a relative distance that is based on the travel time of the moving object between devices. For example, if an object passes a reference point in the field of view 210A of the sensor of the first electronic device 102A while moving at one meter per second and passes the same reference point in the field of view 210B of the sensor of the second electronic device 102B four seconds later, the electronic devices 102A-102B may store one data point that indicates that the devices may be four meters apart. This stored data point may be aggregated with other data points that were determined based on other detected objects to refine the estimated distance over time. Analysis of the paths of the detected object enables the electronic devices 102A-102B to determine the relative orientation of their coordinate spaces and compute a transformation matrix that enables the coordinates of an object as detected by one of the electronic devices to be translated into the coordinate space of the other electronic device.

To enable the use of a calculated motion vector  $y$  of a moving object to be used to estimate the relative positions of the electronic devices 102A-102B in the case of non-overlapping fields of view 210A-210B, the electronic devices 102A-102B include logic to enable the determination, within a probability threshold, that separate observations correspond with the same object. The specific technique used can vary based on the type of sensor in use. For example, in one embodiment the logic can use patterns within the motion of the detected object and compare the motion patterns. Differing motion patterns can be used to disambiguate between multiple objects. For example, where the movement of people within the fields of view 210A-210B are used to determine the relative positions and orientations of the electronic devices 102A-102B different people may be distinguish based on differences in movement patterns between those people. Different individuals may have different walking gaits or walking speeds. Sensor processing logic can analyze resonance in the doppler domain to distinguish between different individuals. Different individuals can be detected via harmonic analysis of the stride and/or gait of the individual.

Depending on the type of sensor that is used, relative differences in size may be used to distinguish between different individuals. For example, where the electronic devices 102A-102B are placed in a household that include companion animals, differences between movement patterns can be used to distinguish between different companion animals or between companion animals and humans. For example, differences in sizes may be used to distinguish between different companion animals and/or between companion animals and humans. Size differences between adults and children may also be detected.

Some sensors are also capable of performing biometric analysis of detected individuals. For example, heart rate may be determinable for a detected individual if the individual is within a range threshold. The heart rate may be used to distinguish between different individuals that are detected at different points in time. Heart rates may also be used to distinguish between multiple individuals that are detected currently.

In one embodiment, detected individuals are also distinguishable via detection of mobile devices (e.g., table computers, smartphones, wearable accessories) carried or worn by an individual. Where a trusted relationship exists between the electronic devices 102A-102B and a mobile device of a user, the electronic devices 102A-102B may be able to query a mobile device carried by an individual. Individuals may also be distinguishable based on network or wireless advertisements that are broadcast by a mobile device carried by a user.

In the case of a radar equipped device exemplary identification strategies are shown in Table 1 below.

TABLE 1

Detected Object Differentiation Strategies		
Strategy	Feature	Example Measurements
Imaging: 'instantaneous' identification based on 'appearance'	Shape	Depth profile
	Material/Size Size	RCS Field of View 2D point-cloud
Kinematics: 'rapid' identification based on short-term body-leave motion and/or shape-change	Rigid vs Non-Rigid Body	RCS variability Doppler Spread Depth profile variability
	Gait Analysis	Doppler Spread Range-Spread Cadence
Routine: identification based on long-term observation of routine/behavior	Biometrics	Heart Rate Breathing Rate Breathing Waveform
	Room-to-Room Pattern Favorite Seat	Home-level tracking Room-level localization
Device: bootstrap with device-based information and track	Favorite Pose Fidgety/Still while sitting Presence vs Time-of-day Dwell-time in location	Pose detection Room-level tracking Home-level tracking Home-level tracking
	Voice recognition iPhone/Watch ID	Smart Appliance Virtual Assistant UBE/BLE/WiFi from device

The above strategies can be used to differentiate between, for example, a human and a machine, a human and a companion animal, and an adult and a child. Some technique may be used to recognize an individual user of the device and/or differentiate between users in a family of users.

FIG. 3 illustrates an electronic device 300 that includes hardware and software logic to enable the fusion of measurements from sensors of multiple devices into a single coordinate space. The electronic device 300 can be any electronic device described herein. The electronic device 300 includes a processing system 304 including multiple types of processors and one or more memory devices that are configured as system memory 310. The processing system 304 includes a multi-core application processor 305, a sensor processor 306, and a security processor 307. The electronic device also includes one or more speaker devices 301 to enable playback of the audio portion of media, alarm, alert, notification, or telephone calls. A network interface 302 includes a network processor and one or more wireless radios 303. The network interface 302 can enable support for wireless networking protocols such as, but not limited to Bluetooth, Wi-Fi, near field communication (NFC), other wireless networking technologies. In some implementations, the network interface 302 may also support a wired network connection.



The electronic device **300** also includes a set of sensor devices **308**. The sensor devices **308** include a variety of sensors including but not limited to motion sensors, light sensors, proximity sensors, biometric sensors, audio sensors (e.g., microphones), and image sensors (e.g., cameras). The sensor devices **308** can also include an accelerometer, gyroscope, or other motion sensors that can detect and analyze the movement of the electronic device **300**. In one embodiment the audio sensors are configurable to perform ultrasonic spatial sensing to enable the electronic device **300** to self-orient within an environment. The sensor devices **308** can also include electromagnetic spatial sensors such as radar or lidar sensors that facilitate self-orientation of the device, enable power management functionality by detecting the presence of nearby users, and enabling or disabling one or more device functions when the presence of absence of individuals and/or users is detected near the electronic device **300**. The sensor processor **306** can enable low-power monitoring of always-on sensors within the suite of sensor devices **308**.

The system memory **310** can be a system virtual memory having an address space that includes volatile and non-volatile memory. The system memory **310** can store instructions for software logic that is executed by the processing system **304**. The software logic includes system logic such as device position logic **312**, coordinate transformation logic **314**, object differentiation logic **316**, and inter-device communication logic **325**. The software logic also include logic to enable user-facing functionality for the electronic device **300**, including but not limited to a virtual assistant **320** and a media player **322**.

The system logic is executed by various processors of the processing system **304**, including the application processor **305** and sensor processor **306**. For example, some aspects of the device position logic **312**, coordinate transformation logic **314**, and/or object differentiation logic **316** and may be executed at least in part by the sensor processor **306** and a portion of this logic may reside in memory associated with the sensor processor **306**. Some processing for the inter-device communication logic **325** may be performed by a network processor within the network interface **302**.

The device position logic **312** includes executable instructions to enable the determination of the position of the electronic device **300**. Device position can be based in part on a geospatial position, as externally specified or determined by a location services subsystem of the electronic device **300**. Device position also includes a position relative to certain other electronic devices that discovered via a network or that are detected via advertisements that are broadcast wirelessly by those devices. Relative position may be determined using the common object tracking technique described herein. The device position logic **312** can also store the relative positions determined by other nearby device. The relative positions can be the relative positions of the nearby devices with respect to the electronic device **300** or with respect to other devices. The device position logic **312** can also be used to determine the position of the electronic device **300** relative to any static objects or obstructions that may be relevant to the operation of the electronic device **300**. For example, where the electronic device **300** is intended for use as a smart speaker device that provides high quality audio playback, the device position logic **312** can use the sensor devices **308** to adjust audio output by the speaker devices **301** to account for walls, furniture, or obstructions near the electronic device **300**.

The mutually determined relative positions of multiple devices can be used to generate and refine a device position

map that includes multiple devices at a location. Coordinate transformation logic **314** can use this device map to generate and store coordinate space transformations that enables the locations of objects, items, or individuals that are detected via the sensors of one device in the map to be positioned within the coordinate space of other devices within the map, allowing each device to access a mesh network of sensors that is created by the combined sensor fields of view of the view of the various devices.

The inter-device communication logic **325** includes daemons and utilities to enable transport agnostic communication with other electronic devices. The inter-device communication logic **325** can enable device to device communication via a network and/or via a device-to-device wireless communication channel. The inter-device communication logic **325** enables coordinates of detected objects, as well as raw sensor data, to be transmitted from and received by the electronic device **300**.

The system memory **310** can also include instructions to enable user facing functionality on the electronic device, such as a virtual assistant **320** and a media player **322**. Such software logic can be executed partly or primarily by the application processor **305**. The virtual assistant **320** can be a voice activated virtual or digital assistant that can perform actions on behalf of a user, such as playing media via the media player **322**, sending text or instant messages, scheduling calendar events, and/or performing other functions that can be performed on the electronic device **300**. The media player **322** can enable the playback of various media types. Audio-based media (e.g., music, podcasts, etc.) may be played via the speaker devices **301**. In the event the electronic device **300** includes a display (not shown), playback of media having a video portion can be performed. Logic to facilitate functionality that is specific to the type of electronic device **300** may also reside in system memory. For example, where the electronic device is a smart appliance device, software logic to manage the functionality of the smart appliance device will also reside in system memory **310**.

FIG. 4 illustrates a method **400** of fusing measurements from sensors of multiple devices into a single coordinate space. The method **400** also includes operations to optimize sensor transmit power based on a determined relative distance between electronic devices equipped with electromagnetic spatial sensors (e.g., radar, lidar). The method **400** can be performed by hardware and software logic of an electronic device having a network interface and one or more electromagnetic spatial sensors, such as the electronic device **300** as in FIG. 3.

Method **400** include for a first sensor equipped electronic device to perform operations to discover a second sensor equipped electronic device (**402**). The first electronic device can discover the second electronic device via advertisement messages broadcast by the second electronic device over a network, via a wireless advertisement mechanism, or another advertisement and discovery mechanism. The first electronic device can then configure a sensor data exchange between the first electronic device and the second electronic device (**404**). The sensor data exchange can occur over a network connection or a point to point wireless connection that is established between the first electronic device and the second electronic device. Sensor data for the first electronic device can be streamed over the data exchange mechanism to the second electronic device. Sensor data for the second electronic device can be streamed by the second electronic device and received by the first electronic device.

The first electronic device and the second electronic device can each gather direction and range measurements to a moving object that is detected by the sensors of the devices. The first electronic device can gather a first set of direction and range measurements to a moving object (406), while the second electronic device can gather a second set of direction and range measurements to the moving object. The first electronic device can receive the second set of direction and range measurements to the moving object from the second electronic device (408).

The first electronic device can then determine, based on the first and second set of direction and range measurements, relative positions and orientations for the first electronic device and the second electronic device (410). The second electronic device can also make a determination. The determinations made by the first electronic device and the second electronic device can be correlated and each determination may be refined based on determination made by the other device. The first electronic device can then create a coordinate transformation between coordinate spaces of the second electronic device and the first electronic device (412). The second electronic device can create a similar transformation. The coordinate transformation enables coordinates for objects detected via sensors of either device, either moving or stationary, to be translated into the coordinate space of the other device.

The relative location determination can enable other optimizations. In one embodiment, the electronic devices can adjust sensor transmit characteristics based on the position relative to the second electronic device (414). For example, sensor transmit power can be increased or decreased according to the distance between the devices. High transmit power may enable longer range sensor visibility, but may cause interference with other devices if those devices are closely positioned. Transmit timing can also be adjusted. Time-multiplexing can be used to interleave signals from multiple devices. The manner in which these signals are interleaved can be tuned based on the distance between the devices.

FIG. 5 illustrates a method 500 for a sensor equipped electronic device to determine the position of the electronic device relative to other sensor equipped electronic devices. This method 500 can be performed when the various electronic devices have either overlapping or non-overlapping fields of view for electromagnetic spatial sensors.

A first electronic device as described herein can analyze time, speed, and position data for moving objects contemporaneously detected via sensors of the first electronic device and a second electronic device (502). Contemporaneously detected indicates that the object is detected in at least a portion of the sensor data during the same period of time or closely spaced within time. The time, speed, and position data can be generated based locally and remotely generated sensor data. Remote sensor data can be streamed to the first electronic device by the second electronic device and processed at the first electronic device. Sensor data gathered at the first electronic device can also be streamed to the second electronic device. Alternatively, time, speed, and position data can be generated by each electronic device and streamed to and received from the other electronic device. While first and second electronic devices are described, the method 500 can be performed by an electronic device in a mesh of electronic devices that includes two or more devices.

The electronic device can determine whether the time, speed, and position data for objects correlate (504). To determine a correlation, the first electronic device can determine whether the sensor data indicates that, for a period of

time, the first and second electronic device both detected the presence of an object having similar motion characteristics. Correlation in the time, speed, and position data indicates that the first and second electronic device likely have at least a partial overlap in the fields of view of sensors on the device. When a correlation is detected (YES, 504), the first electronic device can mark the correlation period as corresponding with overlapping sensor fields of view for the first electronic device and the second electronic device (505). The first electronic device can then determine relative position and orientation for the first electronic device and the second electronic device based on time, speed, and position data gathered for moving objects in the overlapping sensor fields of view (507). This determination can be performed by determining a transformation of the speed and position data for the object as detected by the second electronic device to match the speed and position data for the object as detected by the first electronic device. This transformation indicates the relative position and orientation of the first and second devices.

If the time, speed, and position data for the detected objects does not correlate (NO, 504), the first electronic device can determine if the sensor data from the first electronic device and the second electronic device indicates time shifted observations with correlated motion vectors (506). Time shifted observations would indicate that the same object may have been detected, though not at the same time, as the object moves across the separate fields of view of the electronic devices. If the data does not indicate time shifted observations (NO, 506), then the first electronic device and the second electronic device can each continue gathering sensor observations (508). Over time, it may be possible to determine relative positions based on commonly observed objects. If, after a period of time, the first electronic device cannot determine a position relative to any other detected electronic devices, the first electronic device can determine that it may be located a significant distance from any other sensor equipped devices.

If the first electronic device determines that the sensor data indicates time shifted observations with correlated motion vectors (YES, 506), the first electronic device can create a motion model for the objects (510). The first electronic device can then determine relative positions of the first electronic device and the second electronic device based on the motion model (512). The motion model can enable the prediction of a past and future position for an object detected in sensor data gathered by the first electronic device to model the movement of the object for the period before and after the object is within the field of view of the sensor of the first electronic device. The motion model can also enable the prediction of a past and future position for an object detected in sensor data gathered by the second electronic device to model the movement of the object for the period before and after the object is within the field of view of the sensors of the second electronic device. When the prediction for an object based on sensor data gathered by the first electronic device correlates with the sensor data observed by the second electronic device, the speed of the object and the time to move between sensor fields of view can be used to predict, at the least, a distance between the first electronic device and the second electronic device. Based on the degree of correlation, a difference in orientation between the devices (or the fields of view of the devices) can also be determined.

FIG. 6 illustrates a method 600 for a sensor equipped electronic device to differentiate between multiple objects within sensor data. The differentiation includes differentia-

tion between two concurrently detected objects, as well as determining that separate observations correspond to the same object.

The method **600** includes for an electronic device (e.g., the first or second electronic device) to analyze sensor data gathered by sensors of the first electronic device and the second electronic device (**602**). The electronic device can detect multiple objects within the sensor data (**604**) and disambiguate the multiple objects based on differences in rhythmic movement pattern, biometric data, or wireless signals that are detected concurrently with the multiple objects (**606**). The multiple objects may be multiple objects detected in a single scene by one or more of the electronic devices. The multiple objects may also be multiple objects that are separately detected by both of the electronic devices. When multiple objects are detected in a single scene, the objects may be differentiated based on a rhythmic movement pattern (e.g., stride, gait) associated with walking individuals. Where the data includes separately detected objects, the disambiguation logic can confirm that the movement patterns and/or biometrics of the separately detected objects correlate, such that the objects likely correspond to observation of the same individual. If an object is consistently detected currently with a specific wireless radio signal or data characteristic (e.g., wireless radio advertisement address, device identifier, etc.), that is distinct from those detected concurrently with other observations, then that characteristic may be informative as to the individual associated with the object detected within the sensor data.

The method **600** includes for an electronic device to filter an object from the multiple objects based on the differences in rhythmic movement patterns or biometric data (**608**). To filter an object can include to remove data associated with the object to create filtered sensor data. Alternatively, to filter an object can include to focus exclusively on data having the rhythmic movement patterns or biometric data detected for that object. Relative positions of the first electronic device and the second electronic device can then be determined based on the filtered list of objects (**610**).

FIG. 7A-7B illustrate methods **700**, **720** to refine determined relative positions over a period of time. FIG. 7A illustrates a method **700** of refining stored relative positions based on subsequent updates. FIG. 7B illustrates a method **720** updating relative positions in response to detecting movement at an electronic device. The methods **700**, **720** can be performed by one or more of the electronic devices in a mesh of multiple electronic devices equipped with electromagnetic spatial sensors.

As shown in FIG. 7A, method **700** includes operations to enable a sensor equipped electronic device to determine a position of the device relative to other nearby sensor equipped electronic devices based on a first common observation (**702**). The sensor electronic device can then store the relative positions of the device and the other nearby sensor equipped electronic devices (**704**). The sensor equipped electronic device can then re-determine the position of a sensor equipped electronic device relative to other nearby sensor equipped electronic devices based on a second common observation (**706**).

The device can then refine the stored relative positions based on the second common observation (**708**). This refinement can be performed, in one embodiment, by performing an average operation or a weighted average operation of multiple determinations. Where a weighted average is performed, the weight for a position determination can be based on the confidence of the accuracy of the position determination. The accuracy determination can be based on the

quality of the observation that is used to determine the relative position. The accuracy determination can then be based on the number of position data points that are present within the sensor data. One or more sensor-based metrics or parameters can also be used to determine an accuracy metric. For example, some sensors (e.g., radar) may have reduced angular resolution at longer range. Accordingly, longer range observations can be assigned a lower accuracy value.

The electronic device can additionally refine stored relative positions based on relative positions determined by one or more of the nearby sensor equipped electronic devices (**710**). As each sensor equipped electronic device will independently perform relative position calculations based on commonly observed objects, position determinations performed by the various devices can be refined at each device based on the collective set of measurements.

As shown in FIG. 7B, **720** includes operations to enable a sensor equipped electronic device to determine, via a motion a sensor of an electronic device, that the electronic device has experienced movement (**722**). In one embodiment, this determination is performed at least in part by a sensor processor on the electronic device, which can signal software logic executed by an application processor that movement has been detected. The electronic device can then determine, based on motion sensor data captured by the motion sensor, whether the amount of movement is over a threshold (**723**). Motion under the threshold may indicate that the device has been bumped or slightly repositioned, but has not experienced significant movement. Motion over the threshold may indicate that the device was significantly repositioned.

In one embodiment, when movement is not over the threshold (NO, **723**), the electronic device may be able to update the relative position determination based on accelerometer data. In the event that the electronic device is able to accurately determine the amount and direction of movement based on detected acceleration and deceleration, the electronic device will update the stored set of relative positions to other sensor equipped electronic devices based on accelerometer data (**726**). The electronic device can then broadcast a relative position update to nearby devices (**728**). The relative position update may indicate that the update has occurred due to detected device movement. The electronic device can then confirm or tune the relative positions via subsequent data on objects that are commonly observed by multiple sensor equipped electronic devices (**730**).

In one embodiment, when movement is over the threshold (YES, **723**), the electronic device can mark stored relative positions as potentially invalid (**725**) and broadcast a movement notification to nearby sensor equipped electronic devices (**727**). The movement notification indicates to the nearby sensor equipped electronic devices that the relative position of the broadcasting device has changed. The electronic device, and the nearby devices, can then update their relative positions via subsequent common observations (**729**).

It will be understood that some specific details described herein may vary based on the type of spatial sensor used to detect objects around the sensor equipped electronic device, with different types of sensors having different performance characteristics. For example, where a radar sensor is used, objects may be detected as a point cloud of detected radar reflections that are centered on the detected object. Sensor processing logic can then be used to filter out artifacts an anomalies in the returned signal. The radar sensor may operate using a polar coordinate system. Determination of

positions relative to other radar equipped electronic devices can enable transformation from the polar coordinates associated with a first device to the polar coordinates with a second device. When a radar sensor is in use, raw radar data may be streamed between connected devices. Point clouds within the data can be used to resolve detected objects. For a radar sensor, the position element for an object is an easier transform relative to velocity, which is a radial vector to the system. Enabling transforms between sensors of multiple devices provide the sensor system a greater number of points to represent each detected object. The greater number of points increases the likelihood of success for point cloud clustering algorithms that are used to resolve details of a detected object. Initially, devices are not aware of the transform. Observing the motion of commonly detected objects is used to determine the transform that is used to fuse the sensor data.

FIG. 8 illustrates a sensor system 800 that includes multiple devices having fused radar sensors. The sensor system 800 includes instances of electronic devices 102A-102B described herein, where the spatial sensors are radar sensors. The radar sensors of the electronic devices 102A-102B have respective sweep directions 802A-802B, such that a radar beam sweeps a 360 degree field of view centered at each electronic devices 102A-102B. Alternatively, the radar sensors of the electronic devices 102A-102B may be MIMO radars with multiple antennas and capable of sensing the fields of view 210A-210B without scanning or sweeping. In either scenario, the angular resolution of the radar sensor may decrease with range. Thus, radar fields of view 210A-210B have a radius based on the effective range of the radar sensor. The effective range of the radar sensor is defined by the maximum range at which useful data may be resolved based on beam reflections. Once relative positions for the electronic devices 102A-102B are determined and a transform is computed to enable sensor data to be transformed between the electronic devices 102A-102B. While an individual sensor on an individual device may be able to detect a point cloud 804 for an object, a tighter cluster 806 of points can be resolved from fused sensor data from both of the electronic devices 102A-102B. The fused sensor data enables a higher combined resolution than possible with each individual device.

Once sensor equipped devices within an area have been able to synchronize their relative locations and establish a sensor network that expands the sensor capabilities of each device, further functionality can be enabled. For example, a collection of sensor equipped devices may collaborate to build a picture of a floor plan of the structure in which the devices are positioned. By identifying and tracking individuals as they move from one scene to another, the adjacency of rooms may be inferred, as well as the relative orientation of those rooms.

#### Machine Learning Based Object Identification

Traditional machine learning techniques for object detection within sensor data are trained to recognize objects using the entirety of the sensor data. Such models may become large and computationally complex. Described herein is a machine learning based object identification technique that uses a limited and focused number of features to classify transformed sensor data. A specific combination of transforms and features can be used to recognize certain motions or actions within sensor data or differentiate between specific types or classes of objects. Heuristic techniques are used to determine a specific subset of features that are dispositive as to whether the detected object is, for example, human or non-human and/or living or non-living. The spe-

cific subset of features are used to classify objects or motions detected within transformed sensor data. Using a limited number of features on transformed sensor data can significantly reduce the computational complexity of the machine learning model, allowing continuous low power classification based on received sensor data. While embodiments are not limited to a specific sensor type, specific sensor data representations, specific features, or specific transforms, exemplary sensors, features, and transforms are described herein that are capable of distinguishing between specific movements or specific objects detected within the sensor data.

FIG. 9 illustrates an object identification system 900 to enable the identification of object types using within sensor data using a reduced set of features. The object identification system 900 includes sensor data source(s) 902 that provides sensor data to a sensor processor/filter 904 to generate point cloud data 906. The sensor processor/filter 904 can also output signal metrics for the signal used to generate the point cloud data 906. In one embodiment the sensor data source(s) 902 include a local sensor transceiver 106 as in FIG. 1, which may be a radar transceiver. The sensor data source(s) 902 can also include sensor data from nearby sensor-equipped electronic devices. The sensor data source(s) 902 can provide raw or pre-processed sensor data. The sensor processor/filter 904 can perform operations such as processing raw sensor data to filter out low signal to noise ratio (SNR) data. The sensor processor/filter 904 can also process and enhance the sensor data received from a local transceiver using sensor data received from other electronic devices using coordinate space transformations computed for those other electronic devices. The sensor processor/filter 904 can be embodied within software logic that executes on processor (e.g., processor 104), firmware logic associated with the processor, or dedicated hardware logic. The point cloud data 906 that is generated by the sensor processor/filter 904 may be a three-dimensional (3D) point cloud based at least in part on a polar coordinate system. In one embodiment the point cloud data 906 uses a range, azimuth, and velocity model.

The point cloud data 906 can be processed by a reduced feature classifier 910 to generate a classification 920. The reduced feature classifier 910 provides an object identification pipeline including cluster logic 912, area of interest (AOI) setup logic 914, and feature extraction logic 916. A classifier 917 can be used to make the final determination of a type or class of a detected object based on data provided by the object identification pipeline.

The point cloud data 906 can be transformed into one or more transformations 908 by transformation logic 911. Where the point cloud data 906 represents a 3D point cloud, the transformation logic 911 can transform the point cloud data 906 into one or more two-dimensional (2D) representations of the point cloud. The transformation(s) 908 can include, for example, coordinate space transformations from a polar coordinate system to a Cartesian coordinate system. The transformation(s) 908 can also include transforming a time series of 3D data into a 2D representation of that data.

Different transformations may be used at different stages of analysis. For example, the cluster logic 912 may use clustering of positions within a cartesian coordinate system to detect clusters within the point cloud data that are associated with a detected object. The area of interest setup logic 914 can narrow the analysis space to the points within the detected clusters. The feature extraction logic 916 can then extract features from the point cloud data 906 (e.g., velocity, position variance) and associated signal metrics

(e.g., SNR). The feature extraction logic **916** can provide the extracted features to the classifier **917**. The classifier **917** can then analyze the provided features using one or more models that are trained to perform object identification based on the supplied features.

In one embodiment, the transformation(s) **908** include image space transformations of the point cloud data **906**. The transformation logic **911** can include image space transformation logic that can transform numerical data into image data. For example, numerical point cloud data in the form of 3D tensors can be transformed into 2D tensors. A plot of the points within the 2D tensor data can then be rendered as an image using the image space transformation logic. Feature extraction and classification can then be performed based on the image space (e.g., pixel) data. Exemplary plots can include, for example, a position plot of a detected object within a coordinate space, a velocity plot over time, a magnitude of variance in position of points associated with an object within in one or more coordinate systems. In one embodiment, the feature extraction logic **916** is configured to extract features from image space plots of the point cloud data **906**. In various embodiments, operations performed by cluster logic **912** and/or AOI setup logic **914** may be performed on image space plots or other types of 2D transformations of the point cloud data **906**.

For some sensors, transformations based on signal characteristics within the sensor data, or plots thereof, can be generated and used by feature extraction logic **916** for object classification or differentiation. For example, feature extraction may be performed using a plot of mean normalized SNR against a magnitude of position variance with a coordinate system. For radar sensors, the energy reflection pattern of the object may be as informative as the manner in which the detected object moves within space. For example, the amount of radar energy that is reflected by humans may differ significantly from objects that are more or less reflective at the radio frequency associated with the radar. Objects of a certain size that fall within certain ranges of reflectivity are more likely to be human. Smaller objects falling within similar ranges of reflectivity are more likely to be human children or animals. Other ranges of reflectivity, in concert with velocity data, can be used to detect objects that are clearly non-human.

FIG. **10A-10D** illustrates transformed sensor point cloud data that facilitates differentiation between specific movements and object types using a reduced set of features. FIG. **10A** illustrates transformed sensor data **1000** used for a clustering stage of an object detection pipeline. FIG. **10B** illustrates transformed sensor data **1030** used for area of interest setup. FIG. **10C** illustrates a first feature space **1050** for transformed sensor data that can be used for object differentiation. FIG. **10D** illustrates a second feature space **1060** for transformed sensor data that can be used for object differentiation.

With additional reference to FIG. **9**, the transformed sensor data **1000** of FIG. **10A** may be, for example, a 3D to 2D transformation of point cloud data **906**. The transformed sensor data **1000** may also be an image space transformation of a graphic of point cloud data. Both spatial and temporal locality of the plotted points can be analyzed to detect clusters within the transformed point cloud data. In one embodiment, the transformed sensor data **1000** is a 2D image that represents the amount of reflected energy associated with an object and a velocity metric for the object (e.g., magnitude, variance, etc.). A new image may be created multiple times per second based on sensor data and

provided to cluster logic **912** for clustering. The clusters may be generated using a unsupervised machine learning approach.

As illustrated, the transformed sensor data **1000** includes at least a first cluster **1010** and a second cluster **1020**. The first cluster **1010** and second cluster **1020** can be used by AOI setup logic **914** to determine areas of interest for analysis. In one embodiment, an area of interest can be set up for each detected cluster. In one embodiment, a single area of interest is set up for closely spaced clusters. In one embodiment, signal characteristics associated with one or more detected clusters can be used to select or disregard a detected cluster for AOI setup.

Transformed sensor data **1030** used to select an area of interest **1033** is shown in FIG. **10B**. The transformed sensor data **1030** can be the same or similar to transformed sensor data **1000** of FIG. **10A** or a different transformation may be used. The transformed sensor data **1030** used to select an area of interest **1033** may also be an image space transformation.

Once clustering is used to detect objects within point cloud data and an AOI for analysis is configured, image space transformations in the form of 2D images of various plots or graphs of the signal and movement characteristics of objects are generated. Classification can be performed using multiple transformed representations of point cloud data using multiple features spaces associated with those multiple transformations. In one embodiment a histogram can be generated, for example, based on velocity data of points in the point cloud. Features within those 2D images can be extracted by feature extraction logic **916** and provided to the classifier **917**. A first feature space **1050** showing features that may be extracted by feature extraction logic **916** is shown in FIG. **10C**. The first feature space **1050** that is used for object differentiation can vary across embodiments and may depend on the type of differentiation being performed. As illustrated, a 2D image plot of the mean of the normalized SNR relative to the variance of object locations in X and Y coordinates can present the feature space used to differentiate between features **1052** that correspond with the movement or activities of a human (e.g., sit, stand, walk) and features **1051** that correspond with the activities of a non-human (e.g., a fan in operation).

A second feature space **1060** showing features that may be extracted by feature extraction logic **916** is shown in FIG. **10C**. The second feature space **1060**, as illustrated, is based on a transformation of point cloud data into a 2D image representation of a histogram of the probability density for a given velocity for points within a detected object. The features of the second feature space **1060** correspond with a histogram of velocity probability density for a walking human. Different features would be found, for example, in the 2D image representation of a histogram of velocity probability density for a highly reflective but stationary inanimate object or a moving inanimate object such as an oscillating fan.

FIG. **11** illustrates a method **1100** of sensor point cloud transformation that enables differentiation between specific object types using a reduced set of features. The method **1100** can be performed, for example, by logic associated with the reduced feature classifier **910** of FIG. **9**. The logic to perform method **1100** can be integrated within a data processing system of an electronic device, such as sensor equipped smart home device or appliance as described herein.

In one embodiment, method **1100** includes operations to enable a sensor equipped electronic device to receive point

cloud data and source signal metrics derived from a sensor data stream (1102). The sensor data stream can be a stream of radar sensor data that is output by sensor processor/filter 904 as in FIG. 9. The signal metrics can include a signal strength and SNR for the sensor data that is used to derive the point cloud. The point cloud data can be a range, azimuth, and velocity point cloud. Points from sensor data having a low SNR can be filtered from the point cloud. According to method 1100, the sensor equipped electronic device can then cluster points within the point cloud data to detect the presence of objects within the point cloud data (1104). Clustering can be performed by cluster logic 912 using various clustering algorithms or techniques. The sensor equipped electronic device can then determine (e.g., via AOI setup logic 914) an area of interest based on the location and the number of objects (1106).

The sensor equipped electronic device can then (e.g., via transformation logic 911), transform the filtered set of sensor data to generate first transformed data for objects within the area of interest (1108). The transformation can be from a 3D point cloud to a 2D point cloud. The transformation can also be an image space transformation in which 2D point cloud data is rendered as a 2D image. Graphs, histograms, or other representations of characteristics of the 2D point cloud data can be generated or rendered as a 2D image. In one embodiment, clustering and AOI setup may also be performed using 2D image space transformations. For example, clustering may be performed by clustering pixels of a 2D image that represents point cloud data or signal metrics.

In one embodiment, the sensor equipped electronic device can then extract a first set of features from the transformed data for each object in the area of interest (1110). For example, point cloud data can be transformed into an image of a histogram of velocity data for points associated with a detected object within the area of interest. Features may then be extracted from the histogram image that are useful for identifying the detected object. The sensor equipped electronic device can then transform the filtered set of data to generate second transformed data (1112). The second transformed data can be a 2D image of a representation of a graph of point cloud data or signal metrics, such as a graph of range, azimuth, and/or velocity metrics for points of an object, or a graph of mean normalized SNR relative to location variance. The sensor equipped electronic device can then extract a second set of features from the transformed data for each object in the area of interest (1114). The sensor equipped electronic device can then classify at least one object in the area of interest based on the first set of features and the second set of features (1116). To classify the at least one object can include to determine whether the at least one object is a human or non-human. The classification can also include to determine whether the at least one object is a living or non-living object. The features on which the classifications are performed include both motion characteristics and signal characteristics for reflected data.

FIG. 12 is a block diagram of a device architecture 1200 for a mobile or embedded device, according to an embodiment. The device architecture 1200 includes a memory interface 1202, a processing system 1204 including one or more data processors, image processors and/or graphics processing units, and a peripherals interface 1206. The various components can be coupled by one or more communication buses or signal lines. The various components can be separate logical components or devices or can be integrated in one or more integrated circuits, such as in a system on a chip integrated circuit.

The memory interface 1202 can be coupled to memory 1250, which can include high-speed random-access memory such as static random-access memory (SRAM) or dynamic random-access memory (DRAM) and/or non-volatile memory, such as but not limited to flash memory (e.g., NAND flash, NOR flash, etc.).

Sensors, devices, and subsystems can be coupled to the peripherals interface 1206 to facilitate multiple functionalities. For example, a motion sensor 1210, a light sensor 1212, and a proximity sensor 1214 can be coupled to the peripherals interface 1206 to facilitate the mobile device functionality. One or more biometric sensor(s) 1215 may also be present, such as a fingerprint scanner for fingerprint recognition or an image sensor for facial recognition. Other sensors 1216 can also be connected to the peripherals interface 1206, such as a positioning system (e.g., GPS receiver), a temperature sensor, or other sensing device, to facilitate related functionalities. A camera subsystem 1220 and an optical sensor 1222, e.g., a charged coupled device (CCD) or a complementary metal-oxide semiconductor (CMOS) optical sensor, can be utilized to facilitate camera functions, such as recording photographs and video clips.

Communication functions can be facilitated through one or more wireless communication subsystems 1224, which can include radio frequency receivers and transmitters and/or optical (e.g., infrared) receivers and transmitters. The specific design and implementation of the wireless communication subsystems 1224 can depend on the communication network(s) over which a mobile device is intended to operate. For example, a mobile device including the illustrated device architecture 1200 can include wireless communication subsystems 1224 designed to operate over a GSM network, a CDMA network, an LTE network, a Wi-Fi network, a Bluetooth network, or any other wireless network. In particular, the wireless communication subsystems 1224 can provide a communications mechanism over which a media playback application can retrieve resources from a remote media server or scheduled events from a remote calendar or event server.

An audio subsystem 1226 can be coupled to a speaker 1228 and a microphone 1230 to facilitate voice-enabled functions, such as voice recognition, voice replication, digital recording, and telephony functions. In smart media devices described herein, the audio subsystem 1226 can be a high-quality audio system including support for virtual surround sound.

The I/O subsystem 1240 can include a touch screen controller 1242 and/or other input controller(s) 1245. For computing devices including a display device, the touch screen controller 1242 can be coupled to a touch sensitive display system 1246 (e.g., touch-screen). The touch sensitive display system 1246 and touch screen controller 1242 can, for example, detect contact and movement and/or pressure using any of a plurality of touch and pressure sensing technologies, including but not limited to capacitive, resistive, infrared, and surface acoustic wave technologies, as well as other proximity sensor arrays or other elements for determining one or more points of contact with a touch sensitive display system 1246. Display output for the touch sensitive display system 1246 can be generated by a display controller 1243. In one embodiment, the display controller 1243 can provide frame data to the touch sensitive display system 1246 at a variable frame rate.

In one embodiment, a sensor controller 1244 is included to monitor, control, and/or processes data received from one or more of the motion sensor 1210, light sensor 1212, proximity sensor 1214, or other sensors 1216. The sensor

controller **1244** can include logic to interpret sensor data to determine the occurrence of one of more motion events or activities by analysis of the sensor data from the sensors.

In one embodiment, the I/O subsystem **1240** includes other input controller(s) **1245** that can be coupled to other input/control devices **1248**, such as one or more buttons, rocker switches, thumb-wheel, infrared port, USB port, and/or a pointer device such as a stylus, or control devices such as an up/down button for volume control of the speaker **1228** and/or the microphone **1230**.

In one embodiment, the memory **1250** coupled to the memory interface **1202** can store instructions for an operating system **1252**, including portable operating system interface (POSIX) compliant and non-compliant operating system or an embedded operating system. The operating system **1252** may include instructions for handling basic system services and for performing hardware dependent tasks. In some implementations, the operating system **1252** can be a kernel.

The memory **1250** can also store communication instructions **1254** to facilitate communicating with one or more additional devices, one or more computers and/or one or more servers, for example, to retrieve web resources from remote web servers. The memory **1250** can also include user interface instructions **1256**, including graphical user interface instructions to facilitate graphic user interface processing.

Additionally, the memory **1250** can store sensor processing instructions **1258** to facilitate sensor-related processing and functions; telephony instructions **1260** to facilitate telephone-related processes and functions; messaging instructions **1262** to facilitate electronic-messaging related processes and functions; web browser instructions **1264** to facilitate web browsing-related processes and functions; media processing instructions **1266** to facilitate media processing-related processes and functions; location services instructions including GPS and/or navigation instructions **1268** and Wi-Fi based location instructions to facilitate location based functionality; camera instructions **1270** to facilitate camera-related processes and functions; and/or other software instructions **1272** to facilitate other processes and functions, e.g., security processes and functions, and processes and functions related to the systems. The memory **1250** may also store other software instructions such as web video instructions to facilitate web video-related processes and functions; and/or web shopping instructions to facilitate web shopping-related processes and functions. In some implementations, the media processing instructions **1266** are divided into audio processing instructions and video processing instructions to facilitate audio processing-related processes and functions and video processing-related processes and functions, respectively. A mobile equipment identifier, such as an International Mobile Equipment Identifier (IMEI) **1274** or a similar hardware identifier can also be stored in memory **1250**.

Each of the above identified instructions and applications can correspond to a set of instructions for performing one or more functions described above. These instructions need not be implemented as separate software programs, procedures, or modules. The memory **1250** can include additional instructions or fewer instructions. Furthermore, various functions may be implemented in hardware and/or in software, including in one or more signal processing and/or application specific integrated circuits.

FIG. **13** is a block diagram of a computing system **1300**, according to an embodiment. The illustrated computing system **1300** is intended to represent a range of computing

systems (either wired or wireless) including, for example, desktop computer systems, laptop computer systems, tablet computer systems, cellular telephones, personal digital assistants (PDAs) including cellular-enabled PDAs, set top boxes, entertainment systems or other consumer electronic devices, smart appliance devices, or one or more implementations of a smart media playback device. Alternative computing systems may include more, fewer and/or different components. The computing system **1300** can be used to provide the computing device and/or a server device to which the computing device may connect.

The computing system **1300** includes bus **1335** or other communication device to communicate information, and processor(s) **1310** coupled to bus **1335** that may process information. While the computing system **1300** is illustrated with a single processor, the computing system **1300** may include multiple processors and/or co-processors. The computing system **1300** further may include memory **1320** configured as random access memory (RAM) or other dynamic storage device coupled to the bus **1335**. The memory **1320** may store information and instructions that may be executed by processor(s) **1310**. Memory **1320** may also be used to store temporary variables or other intermediate information during execution of instructions by the processor(s) **1310**.

The computing system **1300** may also include read only memory (ROM) **1330** and/or another data storage device **1340** coupled to the bus **1335** that may store information and instructions for the processor(s) **1310**. The data storage device **1340** can be or include a variety of storage devices, such as a flash memory device, a magnetic disk, or an optical disc and may be coupled to computing system **1300** via the bus **1335** or via a remote peripheral interface.

The computing system **1300** may also be coupled, via the bus **1335**, to a display device **1350** to display information to a user. The computing system **1300** can also include an alphanumeric input device **1360**, including alphanumeric and other keys, which may be coupled to bus **1335** to communicate information and command selections to processor(s) **1310**. Another type of user input device includes a cursor control **1370** device, such as a touchpad, a mouse, a trackball, or cursor direction keys to communicate direction information and command selections to processor(s) **1310** and to control cursor movement on the display device **1350**. The computing system **1300** may also receive user input from a remote device that is communicatively coupled via one or more network interface(s) **1380**.

The computing system **1300** further may include one or more network interface(s) **1380** to provide access to a network, such as a local area network. The network interface(s) **1380** may include, for example, a wireless network interface having antenna **1385**, which may represent one or more antenna(e). The computing system **1300** can include multiple wireless network interfaces such as a combination of Wi-Fi, Bluetooth®, near field communication (NFC), and/or cellular telephony interfaces. The network interface(s) **1380** may also include, for example, a wired network interface to communicate with remote devices via network cable **1387**, which may be, for example, an Ethernet cable, a coaxial cable, a fiber optic cable, a serial cable, or a parallel cable.

In one embodiment, the network interface(s) **1380** may provide access to a local area network, for example, by conforming to IEEE 802.13 standards, and/or the wireless network interface may provide access to a personal area network, for example, by conforming to Bluetooth standards. Other wireless network interfaces and/or protocols

can also be supported. In addition to, or instead of, communication via wireless LAN standards, network interface (s) **1380** may provide wireless communications using, for example, Time Division, Multiple Access (TDMA) protocols, Global System for Mobile Communications (GSM) protocols, Code Division, Multiple Access (CDMA) protocols, Long Term Evolution (LTE) protocols, and/or any other type of wireless communications protocol.

The computing system **1300** can further include one or more energy sources **1305** and one or more energy measurement systems **1345**. Energy sources **1305** can include an AC/DC adapter coupled to an external power source, one or more batteries, one or more charge storage devices, a USB charger, or other energy source. Energy measurement systems include at least one voltage or amperage measuring device that can measure energy consumed by the computing system **1300** during a predetermined period of time. Additionally, one or more energy measurement systems can be included that measure, e.g., energy consumed by a display device, cooling subsystem, Wi-Fi subsystem, or other frequently used or high-energy consumption subsystem.

As described above, some aspects of the subject matter of this specification include gathering and use of data available from various sources to improve services a mobile device can provide to a user. The present disclosure contemplates that in some instances, this gathered data may identify a particular location or an address based on device usage. Such personal information data can include location-based data, addresses, subscriber account identifiers, or other identifying information.

The present disclosure further contemplates that the entities responsible for the collection, analysis, disclosure, transfer, storage, or other use of such personal information data will comply with well-established privacy policies and/or privacy practices. In particular, such entities should implement and consistently use privacy policies and practices that are generally recognized as meeting or exceeding industry or governmental requirements for maintaining personal information data private and secure. For example, personal information from users should be collected for legitimate and reasonable uses of the entity and not shared or sold outside of those legitimate uses. Further, such collection should occur only after receiving the informed consent of the users. Additionally, such entities would take any needed steps for safeguarding and securing access to such personal information data and ensuring that others with access to the personal information data adhere to their privacy policies and procedures. Further, such entities can subject themselves to evaluation by third parties to certify their adherence to widely accepted privacy policies and practices.

In the case of advertisement delivery services, the present disclosure also contemplates embodiments in which users selectively block the use of, or access to, personal information data. That is, the present disclosure contemplates that hardware and/or software elements can be provided to prevent or block access to such personal information data. For example, in the case of advertisement delivery services, the present technology can be configured to allow users to select to “opt in” or “opt out” of participation in the collection of personal information data during registration for services.

Therefore, although the present disclosure broadly covers use of personal information data to implement one or more various disclosed embodiments, the present disclosure also contemplates that the various embodiments can also be implemented without the need for accessing such personal information data. That is, the various embodiments of the

present technology are not rendered inoperable due to the lack of all or a portion of such personal information data. For example, content can be selected and delivered to users by inferring preferences based on non-personal information data or a bare minimum amount of personal information, such as the content being requested by the device associated with a user, other non-personal information available to the content delivery services, or publicly available information.

In the foregoing description, example embodiments of the disclosure have been described. It will be evident that various modifications can be made thereto without departing from the broader spirit and scope of the disclosure. The specification and drawings are, accordingly, to be regarded in an illustrative sense rather than a restrictive sense. The specifics in the descriptions and examples provided may be used anywhere in one or more embodiments. The various features of the different embodiments or examples may be variously combined with some features included and others excluded to suit a variety of different applications. Examples may include subject matter such as a method, means for performing acts of the method, at least one machine-readable medium including instructions that, when performed by a machine cause the machine to perform acts of the method, or of an apparatus or system according to embodiments and examples described herein. Additionally, various components described herein can be a means for performing the operations or functions described herein.

Those skilled in the art will appreciate from the foregoing description that the broad techniques of the embodiments can be implemented in a variety of forms. Therefore, while the embodiments have been described in connection with particular examples thereof, the true scope of the embodiments should not be so limited since other modifications will become apparent to the skilled practitioner upon a study of the drawings, specification, and following claims.

What is claimed is:

1. A system to perform object classification at a stationary electronic device, the system comprising:
  - a radar sensor;
  - one or more processors including a sensor processor and an application processor, wherein the one or more processors are to:
    - receive a set of processed and filtered radar sensor data including point cloud data and signal to noise metrics associated with the point cloud data, wherein the set of processed and filtered radar sensor data includes processed and filtered second sensor measurement data from a second electronic device;
    - determine a relative position of the second electronic device to the stationary electronic device based on a commonly detected object in first sensor measurement data from the stationary electronic device and the second sensor measurement data from the second electronic device, wherein to determine the relative position the one or more processors are to compare a locally detected path of the commonly detected object with a remotely detected path of the commonly detected object to determine the relative position of the second electronic device;
    - transform the processed and filtered set of radar sensor data using the relative position of the second electronic device to generate transformed data for objects within an area of interest;
    - and
    - classify at least one object in the area of interest based on a set of features from the transformed data,



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wherein to classify the at least one object includes to classify the at least one object as a human or non-human.

2. The system as in claim 1, wherein the point cloud data includes range, azimuth, and velocity data.

3. The system as in claim 2, wherein the signal to noise metrics include a signal to noise ratio (SNR) associated with a point in the point cloud data.

4. The system as in claim 3, wherein a first set of features from the set of features is based on probability density of velocity for an object in the area of interest.

5. The system as in claim 4, wherein a second set of features from the set of features is based on a mean of normalized SNR and a location variance for an object within the area of interest.

6. The system as in claim 1, wherein a second set of features from the set of features includes the amount of radar energy that is reflected.

7. A method to perform object classification at a stationary electronic device, the method comprising:

receiving a set of processed and filtered radar sensor data including point cloud data and signal to noise metrics associated with the point cloud data, wherein the set of processed and filtered radar sensor data includes processed and filtered second sensor measurement data from a second electronic device;

determining a relative position of the second electronic device to the stationary electronic device based on a commonly detected object in first sensor measurement data from the stationary electronic device and the second sensor measurement data from the second electronic device, wherein the determining comprises comparing a locally detected path of the commonly detected object with a remotely detected path of the commonly detected object to determine the relative position of the second electronic device;

transforming the processed and filtered set of radar sensor data using the relative position of the second electronic device to generate transformed data for objects within an area of interest; and

classifying at least one object in the area of interest based on a set of features from the transformed data, wherein to classify the at least one object includes to classify the at least one object as a human or non-human.

8. The method of claim 7, wherein the point cloud data includes range, azimuth, and velocity data.

9. The method of claim 7, wherein the signal to noise metrics include a signal to noise ratio (SNR) associated with a point in the point cloud data.

10. The method of claim 9, wherein a first set of features is based on probability density of velocity for an object in the area of interest.

11. The method of claim 10, wherein a second set of features is based on a mean of normalized SNR and a location variance for an object within the area of interest.

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12. The method of claim 7, wherein a second set of features includes the amount of radar energy that is reflected.

13. A non-transitory machine-readable medium having instructions stored thereon, wherein the instructions cause one or more processors of an electronic device to perform operations comprising:

receive a set of processed and filtered radar sensor data including point cloud data and signal to noise metrics associated with the point cloud data, wherein the set of processed and filtered radar sensor data includes processed and filtered second sensor measurement data from a second electronic device;

determine a relative position of the second electronic device to the electronic device based on a commonly detected object in first sensor measurement data from the electronic device and the second sensor measurement data from the second electronic device, wherein to determine the relative position the one or more processors further perform a comparison of a locally detected path of the commonly detected object with a remotely detected path of the commonly detected object to determine the relative position of the second electronic device;

transform the processed and filtered set of radar sensor data using the relative position of the second electronic device to generate first transformed data for objects within an area of interest; and

classify at least one object in the area of interest based on a set of features from the transformed data, wherein to classify the at least one object includes to classify the at least one object as a human or non-human.

14. The non-transitory machine-readable medium of claim 13, wherein the point cloud data includes range, azimuth, and velocity data.

15. The non-transitory machine-readable medium of claim 14, wherein the signal to noise metrics include a signal to noise ratio (SNR) associated with a point in the point cloud data.

16. The non-transitory machine-readable medium of claim 15, wherein a first set of features is based on probability density of velocity for an object in the area of interest.

17. The non-transitory machine-readable medium of claim 16, wherein a second set of features is based on a mean of normalized SNR and a location variance for an object within the area of interest.

18. The non-transitory machine-readable medium of claim 13, wherein a second set of features includes the amount of radar energy that is reflected.

19. The non-transitory machine-readable medium of claim 13, wherein a field of view of the electronic device does not overlap with the field of view of the second electronic device.

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