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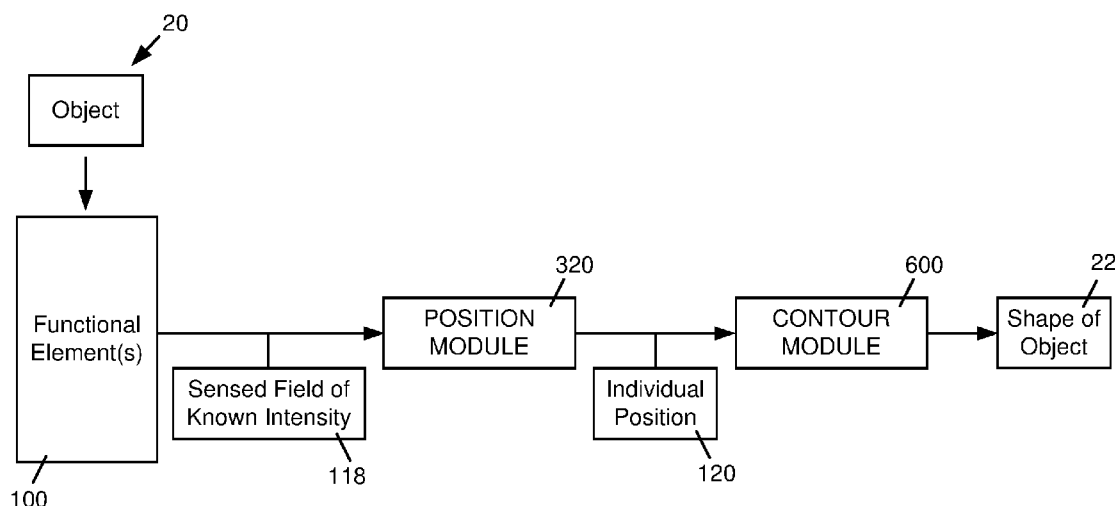


FIG. 9

(57) **Abstract:** A system for three-dimensional scanning of an object includes a set of functional elements, with each of the functional elements including a housing and a processor, memory, power supply, sensor, and wireless communication module each within the housing, a position module to determine an individual position of each of the functional elements after the object is in the set of functional elements, and a contour module to determine a shape of the object based on the individual position of each of the functional elements and a void of functional elements created by the object in the set of functional elements.

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THREE-DIMENSIONAL SCANNING WITH FUNCTIONAL ELEMENTS

Background

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The Internet of Things (IoT) may include smart objects with embedded technology to sense, communicate and/or interact with their internal states, each other, and/or their external environment.

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Brief Description of the Drawings

Figure 1 is a block diagram illustrating an example of a functional element.

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Figure 2 is a schematic illustration of an example of a plurality of functional elements.

Figure 3 is a block diagram illustrating an example of determining a pose of a functional element.

Figures 4A, 4B, 4C schematically illustrate an example of determining a position of a functional element.

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Figures 5A, 5B, 5C schematically illustrate another example of determining a position of a functional element.

Figures 6A, 6B schematically illustrate an example of determining an orientation of a functional element.

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Figures 7A, 7B schematically illustrate another example of determining an orientation of a functional element.

Figures 8A and 8B are flow diagrams illustrating an example of a method of determining a pose of a functional element.

Figure 9 is a block diagram illustrating an example of three-dimensional scanning of an object.

Figures 10A and 10B schematically illustrate an example of three-dimensional scanning of an object.

5 Figure 11 is a flow diagram illustrating an example of a method of three-dimensional scanning of an object.

Detailed Description

10 Figure 1 is a block diagram illustrating an example of a functional element 100. In one implementation, functional element 100 includes a shell or housing 102 with components, such as a processor 104, memory 106, power supply 108, sensor 110, and wireless communication module 112, provided within housing 102.

15 Processor 104 transfers, communicates, and/or processes signals, commands, conditions, states, and/or parameters for and/or between components of functional element 100, and may include analog and/or digital elements and/or circuits. In examples, processor 104 implements and/or executes computer-readable, computer-executable instructions for data
20 processing functions and/or functionality of functional element 100. In examples, such instructions are stored in memory, such as memory 106. Memory 106 may include volatile and non-volatile memory, and includes a non-transitory computer-readable storage medium suitable for tangibly embodying program instructions and data. Power supply 108 provides energy for operating
25 components of functional element 100. In one implementation, power supply 108 is a rechargeable battery.

30 Sensor 110 provides information about one or more than one operating and/or environmental condition and/or state of functional element 100. In examples, sensor 110 includes one or more than one instrument or device for reading, detecting, measuring, indicating, and/or responding to a condition and/or state of functional element 100, including, for example, position,

orientation, gravitational force, magnetic force, and/or ambient or environmental conditions such as temperature, humidity, and/or pressure.

Wireless communication module 112 facilitates the exchange and/or transmission of information and/or data between functional element 100 and
5 another device or system, including an external device such as, for example, computing device 10. Such information and/or data may include, for example, control and/or logic instructions or commands, condition or state information, as well as other information and/or data to be exchanged with and/or transmitted to and/or from functional element 100.

10 In some examples, functional element 100 includes an actuator 114. Actuator 114 includes, operates, and/or controls one or more than one mechanism or mechanical element, component, or system of functional element 100.

Figure 2 is a schematic illustration of an example of a plurality of
15 functional elements 100. In one implementation, functional elements 100 are individually addressable such that information and/or data of and/or for each functional element 100 of the plurality of functional elements 100 may be serialized or individualized. As such, information and/or data exchanged with and/or transmitted to and/or from an individual functional element 100, for
20 example, via wireless communication module 112, may be recognized and/or identified as being from a specific functional element 100. For example, as described below, a pose (position/location and/or orientation) of a functional element 100 (of a plurality of functional elements 100) may be individually determined and serialized such that transmission of the determined pose may
25 be recognized and/or identified as being of a specific functional element 100.

As illustrated in the example of Figure 2, a collection, set, accumulation, or grouping of functional elements 100 is provided or established. In one implementation, functional elements 100 are spherical in shape. Functional elements 100, however, may be of other shapes, including, for example,
30 polyhedral shapes, such as dodecahedral. In addition, functional elements 100 may be irregularly shaped, and may be of different shapes and/or different sizes relative to each other.

In the illustrated example, functional elements 100 are held or contained by or within an enclosure or container 200. Although illustrated as being a rectangular prism, container 200 may be of other shapes and/or sizes. In other examples, functional elements 100 are accumulated, grouped, and/or maintained in a pile or mound without an enclosure or container.

It is to be understood that Figure 2 is a schematic representation of a collection, set, accumulation, or grouping of functional elements 100 within container 200. Although illustrated with a void between a top of the functional elements 100 and a top of container 200, the void may be filled with additional functional elements and/or a fill material. In addition, the number of functional elements 100 within container 200 may vary such that the number of functional elements 100 within container 200 may be more or less than that illustrated.

In one example, the collection, set, accumulation, or grouping of functional elements 100 is random such that an initial pose of each functional element 100, for example, within container 200, is unknown. In one implementation, each functional element 100 includes six degrees of freedom, namely translation in three perpendicular axes and rotation about the three perpendicular axes. As such, a pose of each functional element 100 includes three degrees of position (location) and three degrees of orientation. For example, the three degrees of position include x, y, and z coordinates, and the three degrees of orientation include degrees of rotation about x, y, and z axes. More specifically, the three degrees of position include, for example, surge (movement forward and backward along an x-axis), sway (movement left and right along a y-axis), and heave (movement up and down along a z-axis), and the three degrees of orientation include, for example, roll (tilting side to side about the x-axis), pitch (tilting forward and backward about the y-axis), and yaw (left and right turning about the z-axis). With a collection, set, accumulation, or grouping of functional elements 100, the pose of each functional element 100 may be established relative to each other and/or relative to an environment or surrounding, such as container 200.

Figure 3 is a block diagram illustrating an example of determining a pose of a functional element. In examples, as described below, a pose determination

unit or module 300 determines a pose of a functional element 100, including an individual position and an individual orientation of a respective functional element 100, based on a condition or conditions sensed by a respective functional element 100.

5 In one implementation, as schematically illustrated in Figure 3, pose determination module 300 includes a position unit or module 320, and an orientation unit or module 340. As described below, position module 320 determines an individual position 120 of a respective functional element 100, and orientation module 340 determines an individual orientation 140 of a
10 respective functional element 100, such that an individual pose 160 of the respective functional element 100 may be established from individual position 120 and individual orientation 140.

 Pose determination module 300 includes hardware, software, firmware, or a combination of these. In one implementation, pose determination module
15 300 is included in a computer, computer server, or other microprocessor-based system capable of performing a sequence of logic operations. Components of pose determination module 300, including position module 320, and/or orientation module 340, can be implemented in hardware via a microprocessor, programmable logic device, or state machine, in firmware, or in software within
20 a given device. Position module 320, and/or orientation module 340 may be implemented, for example, as a subroutine of a computer program. Pose determination module 300, including position module 320, and/or orientation module 340, can be implemented, wholly or in part, on a respective functional element 100 or on an external device, such as computing device 10 (Figure 1).

25 In one implementation, position module 320 determines individual position 120 based on a field with a known intensity sensed by a respective functional element 100, as described below. As such, position module 320 receives, as input, a measure of a sensed field of known intensity 118 from a respective functional element 100. The field of known intensity may be sensed,
30 for example, by an implementation of sensor 110 (Figure 1) of a respective functional element 100. In one implementation, the measure of the sensed field of known intensity 118 is transmitted or communicated to pose determination

module 300, including, more specifically, position module 320, via wireless communication module 112 (Figure 1) of the respective functional element 100.

In one implementation, orientation module 340 determines individual orientation 140 based on a field with a known structure sensed by a respective functional element 100, as described below. As such, orientation module 340 receives, as input, a measure of a sensed field of known structure 138 from a respective functional element 100. The field of known structure may be sensed, for example, by an implementation of sensor 110 (Figure 1) of a respective functional element 100. In one implementation, the measure of the sensed field of known structure 138 is transmitted or communicated to pose determination module 300, including, more specifically, orientation module 340, via wireless communication module 112 (Figure 1) of the respective functional element 100.

Figures 4A, 4B, 4C schematically illustrate an example of determining a position of a functional element, such as individual position 120 of a respective functional element 100. In one example, as described above, determination of individual position 120 is based on a field with a known intensity, including, more specifically, a field with a known intensity profile, intensity gradient, or three-dimensional intensity. In one implementation, the field of known intensity is ambient pressure, including, more specifically, atmospheric pressure (i.e., air pressure or gas pressure). As such, the field of known intensity may be sensed, for example, by an altimeter, as an example of sensor 110 of a respective functional element 100.

As illustrated in the example of Figure 4A, container 200, with functional elements 100 therein, is positioned in or has a first orientation. With the first orientation, atmospheric pressure at a respective functional element 100 is measured such that a "depth" or position of the respective functional element 100 relative to a first surface, face, or boundary of container 200, such as boundary 201, is resolved, as represented, for example, by arrow 401. As such, a first positional coordinate, such as an x-coordinate, of the respective functional element 100 is determined. In one implementation, container 200 includes a transmitter or sensor 210 at one or more known locations such that a sensed

measurement by a respective functional element 100 is compared with a sensed measurement by sensor 210.

As illustrated in the example of Figure 4B, container 200, with functional elements 100 therein, is positioned in or has a second orientation. With the
5 second orientation, atmospheric pressure at the respective functional element 100 is measured such that a "depth" or position of the respective functional element 100 relative to a second surface, face, or boundary of container 200, such as boundary 202, is resolved, as represented, for example, by arrow 402. As such, a second positional coordinate, such as a y-coordinate, of the
10 respective functional element 100 is determined.

As illustrated in the example of Figure 4C, container 200, with functional elements 100 therein, is positioned in or has a third orientation. With the third orientation, atmospheric pressure at the respective functional element 100 is measured such that a "depth" or position of the respective functional element
15 100 relative to a third surface, face, or boundary of container 200, such as boundary 203, is resolved, as represented, for example, by arrow 403. As such, a third positional coordinate, such as a z-coordinate, of the respective functional element 100 is determined.

In one example, container 200, with functional elements 100 fixed
20 therein, is re-oriented or rotated, as represented by arrow 221, between the first orientation of Figure 4A and the second orientation of Figure 4B, and re-oriented or rotated, as represented by arrow 222, between the second orientation of Figure 4B and the third orientation of Figure 4C. In one implementation, container 200 is rotated ninety degrees between the first
25 orientation and the second orientation, and rotated ninety degrees between the second orientation and the third orientation such that the second orientation of Figure 4B is orthogonal to the first orientation of Figure 4A, and the third orientation of Figure 4C is orthogonal to both the first orientation of Figure 4A and the second orientation of Figure 4B. Although illustrated as being rotated
30 ninety degrees between the first orientation and the second orientation, and rotated ninety degrees between the second orientation and the third orientation, container 200, with functional elements 100 fixed therein, may be rotated a

different amount (or amounts) between the first orientation and the second orientation, and/or between the second orientation and the third orientation such that the rotation (or rotations) include a non-zero orthogonal vector component (e.g., 30 degrees, 120 degrees).

5 Figures 5A, 5B, 5C schematically illustrate another example of determining a position of a functional element, such as individual position 120 of a respective functional element 100. In one example, as described above, determination of individual position 120 is based on a field with a known intensity, including, more specifically, a field with a known intensity profile,
10 intensity gradient, or three-dimensional intensity. In one implementation, the field of known intensity is ambient pressure, including, more specifically, liquid pressure (e.g., water pressure). As such, the field of known intensity may be sensed, for example, by a liquid pressure sensor or transducer or hydrostatic depth sensor, as an example of sensor 110 of a respective functional element
15 100.

As illustrated in the example of Figure 5A, container 200, with functional elements 100 therein, is positioned in or has a first orientation, and is filled with a liquid 230, such as water, oil, alcohol, acetone, mercury or other liquid or liquid mixture, such that functional elements 100 are submerged in liquid 230. With
20 the first orientation, liquid pressure at a respective functional element 100 is measured such that a "depth" or position of the respective functional element 100 relative to a first surface, face, or boundary of container 200, such as boundary 201, is resolved, as represented, for example, by arrow 401. As such, a first positional coordinate, such as an x-coordinate, of the respective functional
25 element number 100 is determined. In one implementation, container 200 includes a transmitter or sensor 210 at one or more known locations such that a sensed measurement by a respective functional element 100 is compared with a sensed measurement by sensor 210.

As illustrated in the example of Figure 5B, container 200, with functional
30 elements 100 submerged in liquid 230 therein, is positioned in or has a second orientation. With the second orientation, liquid pressure at the respective functional element 100 is measured such that a "depth" or position of the

respective functional element 100 relative to a second surface, face, or boundary of container 200, such as boundary 202, is resolved, as represented, for example, by arrow 402. As such, a second positional coordinate, such as a y-coordinate, of the respective functional element 100 is determined.

5 As illustrated in the example of Figure 5C, container 200, with functional elements 100 submerged in liquid 230 therein, is positioned in or has a third orientation. With the third orientation, liquid pressure at the respective functional element 100 is measured such that a "depth" or position of the respective functional element 100 relative to a third surface, face, or boundary
10 of container 200, such as boundary 203, is resolved, as represented, for example, by arrow 403. As such, a third positional coordinate, such as a z-coordinate, of the respective functional element 100 is determined.

 Similar to the example of Figures 4A, 4B, 4C, container 200, with functional elements 100 fixed and submerged in liquid 230 therein, is re-
15 oriented or rotated, as represented by arrow 221, between the first orientation of Figure 5A and the second orientation of Figure 5B, and re-oriented or rotated, as represented by arrow 222, between the second orientation of Figure 5B and the third orientation of Figure 5C. Although illustrated as being rotated ninety degrees between the first orientation and the second orientation, and rotated
20 ninety degrees between the second orientation and the third orientation, container 200, with functional elements 100 fixed and submerged in liquid 230 therein, may be rotated a different amount (or amounts) between the first orientation and the second orientation, and/or between the second orientation and the third orientation such that the rotation (or rotations) include a non-zero
25 orthogonal vector component (e.g., 30 degrees, 120 degrees).

 In the examples described above, the field of known intensity is ambient pressure, including, more specifically, atmospheric pressure (i.e., air pressure or gas pressure) and liquid pressure (e.g., water pressure). In other examples, the field of known intensity may include light or radio signals directed from or
30 generated by a respective source. As such, and similar to the examples of Figures 4A, 4B, 4C, and Figures 5A, 5B, 5C, container 200, with functional elements 100 fixed therein, may be re-oriented or rotated between a first

orientation, a second orientation, and a third orientation, and the field of known intensity (e.g., light intensity or radio signal strength) may be sensed by a respective functional element 100 such that a position of the respective functional element 100 may be determined.

5 Figures 6A, 6B schematically illustrate an example of determining an orientation of a functional element, such as individual orientation 140 of a respective functional element 100. In one example, as described above, determination of individual orientation 140 is based on a field with a known structure. In one implementation, the field of known structure is a gravitational
10 field. As such, the field of known structure may be sensed, for example, by an accelerometer or tilt sensor, as an example of sensor 110 of a respective functional element 100.

 As illustrated in the example of Figure 6A, container 200, with functional elements 100 therein, is positioned in or has a first orientation. With the first
15 orientation, a direction of the gravitational field (i.e., a direction of gravitational force), as represented, for example, by arrow 410 (i.e., "down"), is sensed by a respective functional element 100. As such, a first orientation parameter relative to the sensed direction of the gravitational field, such as roll, and a second orientation parameter relative to the sensed direction of the gravitational
20 field, such as pitch, of the respective functional element 100 is determined.

 As illustrated in the example of Figure 6B, container 200, with functional elements 100 therein, is positioned in or has a second orientation. With the second orientation, a direction of the gravitational field (i.e., a direction of gravitational force), as represented, for example, by arrow 411 (i.e., "down"), is
25 sensed by the respective functional element 100. As such, a third orientation parameter relative to the sensed direction of the gravitational field, such as yaw, of the respective functional element 100 is determined.

 In one example, container 200, with functional elements 100 fixed therein, is re-oriented or rotated, as represented by arrow 223, between the first
30 orientation of Figure 6A and the second orientation of Figure 6B. In one implementation, the second orientation of Figure 6B is orthogonal to the first

orientation of Figure 6A such that container 200 is rotated ninety degrees between the first orientation and the second orientation.

Figures 7A, 7B schematically illustrate another example of determining an orientation of a functional element, such as individual orientation 140 of a
5 respective functional element 100. In one example, as described above, determination of individual orientation 140 is based on a field with a known structure. In one implementation, the field of known structure is a magnetic field. As such, the field of known structure may be sensed, for example, by a magnetometer, as an example of sensor 110 of a respective functional element
10 100.

As illustrated in the example of Figure 7A, container 200, with functional elements 100 therein, is positioned in a magnetic field 241 having a first orientation. With the first orientation of magnetic field 241, an orientation of the magnetic field is sensed by a respective functional element 100 such that a first
15 orientation parameter, such as roll, and a second orientation parameter, such as pitch, of the respective functional element 100 is determined.

As illustrated in the example of Figure 7B, container 200, with functional elements 100 therein, is positioned in a magnetic field 242 having a second orientation. With the second orientation of magnetic field 242, an orientation of
20 the magnetic field is sensed by the respective functional element 100 such that a third orientation parameter, such as yaw, of the respective functional element 100 is determined.

In one implementation, the orientation of magnetic field 242 of Figure 7B is orthogonal to the orientation of magnetic field 241 of Figure 7A, and is
25 established by re-orienting or rotating a magnetic field ninety degrees relative to functional elements 100, for example, relative to container 200, with functional elements 100 therein. As such, the first orientation includes a first orientation of the field of known structure (i.e., magnetic field), and the second orientation includes a second orientation of the field of known structure (i.e., magnetic field)
30 rotated relative to the first orientation of the field of known structure. In another implementation, container 200, with functional elements 100 fixed therein, is re-oriented or rotated ninety degrees relative to a magnetic field to establish a first

orientation of the magnetic field and a second orientation of the magnetic field relative to container 200 and functional elements 100.

Figures 8A and 8B are flow diagrams illustrating an example of a method 500 of determining a pose of a functional element, such as functional element 100, as schematically illustrated, for example, in Figure 1.

In one example, as illustrated in Figure 8A, at 502, method 500 includes grouping a plurality of functional elements, such as functional elements 100, with each of the functional elements including a housing, such as housing 102, and a processor, such as processor 104, memory, such as memory 106, power supply, such as power supply 108, sensor, such as sensor 110, and wireless communication module, such as wireless communication module 112, each within the housing, as schematically illustrated, for example, in Figure 1.

As such, in one example, at 504, method 500 includes determining an individual position of a respective one of the functional elements, such as individual position 120 of a respective functional element 100. In one example, determining an individual position of a respective one of the functional elements includes sensing a field of known intensity by the respective one of the functional elements in each a first orientation, a second orientation rotated relative to the first orientation, and a third orientation rotated relative to the second orientation, as schematically illustrated, for example, in Figures 4A, 4B, 4C, and Figures 5A, 5B, 5C.

In one implementation, sensing the field of known intensity, for example, at 504, includes sensing atmospheric pressure by the respective one of the functional elements in each the first orientation, the second orientation, and the third orientation, as schematically illustrated, for example, in Figures 4A, 4B, 4C.

In another implementation, method 500 includes submerging the functional elements in liquid, such that sensing the field of known intensity, for example, at 504, includes sensing liquid pressure by the respective one of the functional elements in each the first orientation, the second orientation, and the third orientation, as schematically illustrated, for example, in Figures 5A, 5B, 5C.

In one example, as illustrated in Figure 8B, at 506, method 500 further includes determining an individual orientation of the respective one of the

functional elements, such as individual orientation 140 of a respective functional element 100. In one example, determining an individual orientation of the respective one of the functional elements includes sensing a field of known structure by the respective one of the functional elements in both the first
5 orientation and the second orientation, as schematically illustrated, for example, in Figures 6A, 6B, and Figures 7A, 7B.

In one implementation, sensing the field of known structure, for example, at 506, includes sensing a direction of a gravitational field by the respective one of the functional elements in both the first orientation and the second
10 orientation, as schematically illustrated, for example, in Figures 6A, 6B.

In another implementation, sensing the field of known structure, for example, at 506, includes sensing an orientation of a magnetic field by the respective one of the functional elements in both the first orientation and the second orientation, as schematically illustrated, for example, in Figures 7A, 7B.

15 Although illustrated and described as separate and/or sequential steps, the method may include a different order or sequence of steps, and may combine one or more steps or perform one or more steps concurrently, partially or wholly.

Figure 9 is a block diagram illustrating an example of three-dimensional
20 scanning of an object. In one example, as described below, a contour module 600 determines a shape or contour of an object, such as object 20, based on a position of functional elements 100 after object 20 is in or positioned in, including inserted into (at least partially or wholly) or placed within (at least partially or wholly), a collection, set, accumulation, or grouping of functional
25 elements 100.

In one implementation, as schematically illustrated in Figure 9, contour module 600 determines a shape 22 of object 20, including a boundary or contour of object 20, based on individual position 120 of functional elements 100 as determined, for example, by position module 320. More specifically, with
30 object 20 in (at least partially or wholly) functional elements 100, a number of functional elements 100 contact, are contacted by, or are in contact with object 20, such that a respective position of the contacted or contacting (i.e., in-

contact) functional elements 100, identify, indicate, and/or establish shape 22 of object 20. Thus, a multi-dimensional scan, namely, a three-dimensional scan of object 20 is obtained with functional elements 100.

5 In examples, position module 320 determines individual position 120 of functional elements 100 based on a measure of a sensed field of known intensity 118 received from a respective functional element 100, as described above. Thus, by sensing a respective position within the collection, set, accumulation, or grouping of functional elements 100, functional elements 100 identify, indicate, and/or establish shape 22 of object 20.

10 In one example, with object 20 positioned in (at least partially or wholly) functional elements 100, a void is created within the collection, set, accumulation, or grouping of functional elements 100. More specifically, position information is absent or a lack of position information exists amongst the collection, set, accumulation, or grouping of functional elements 100 where
15 object 20 is located. As such, in one example, contour module 600 determines shape 22 of object 20, including a boundary or contour of object 20, based on the void within the collection, set, accumulation, or grouping of functional elements 100.

In some examples, in addition to determining shape 22 of object 20
20 based on an individual position of functional elements 100, contour module 600 determines shape 22 of object 20 based on an individual orientation of functional elements 100. More specifically, orientation module 340, as described above, determines individual orientation 140 of functional elements 100 after object 20 is in functional elements 100. As such, contour module 600
25 further determines shape 22 of object 20, including a boundary or contour of object 20, based on individual orientation 140 of functional elements 100.

Figures 10A and 10B schematically illustrate an example of three-dimensional scanning of an object, such as object 20. In one example, object 20 is positioned in (at least partially or wholly) a collection, set, accumulation, or
30 grouping of functional elements 100. As such, with object 20 in functional elements 100, an individual position 120 of functional elements 100 is determined, for example, by position module 320. Accordingly, based on

individual position 120 of functional elements 100, contour module 600 determines shape 22 of object 20, including a boundary or contour of object 20.

In one example, positioning object 20 in the collection, set, accumulation, or grouping of functional elements 100 displaces a number of functional
5 elements such that the individual position of a number of functional elements 100 after object 20 is in the collection, set, accumulation, or grouping of functional elements 100 includes a displaced position of functional elements 100. In addition, in one example, with object 20 in the collection, set, accumulation, or grouping of functional elements 100, a volume free of
10 functional elements (i.e., a non-functional-element volume) is created within the collection, set, accumulation, or grouping of functional elements 100. Accordingly, such non-functional-element volume corresponds to a volume of object 20.

In one implementation, as schematically illustrated in the example of
15 Figure 10B, one or multiple functional elements 100 include a probe 116, as an example of actuator 114 (Figure 1), which may extend from or be extended from a respective functional element 100 for contact with object 20. As such, additional position information of a respective functional element 100 in the collection, set, accumulation, or grouping of functional elements 100, including
20 information on point contact with object 20, may be obtained and used in determining shape 22 of object 20, including a boundary or contour of object 20.

Figure 11 is a flow diagram illustrating an example of a method 700 of three-dimensional scanning of an object, such as object 20, as schematically illustrated, for example, in Figure 9 and Figures 10A, 10B.

25 In one example, as illustrated in Figure 11, at 702, method 700 includes grouping a plurality of functional elements, such as functional elements 100, with each of the functional elements including a housing, such as housing 102, and a processor, such as processor 104, memory, such as memory 106, power supply, such as power supply 108, sensor, such as sensor 110, and wireless
30 communication module, such as wireless communication module 112, each within the housing, as schematically illustrated, for example, in Figure 1.

As such, at 704, method 700 includes positioning the object in the grouping of functional elements, such as positioning object 20 in functional elements 100 as schematically illustrated, for example, in Figure 9 and Figures 10A, 10B. In one example, positioning the object in the grouping of functional elements includes contacting the object with a number of the functional elements, such as contacting object 20 with a number of functional elements 100, as schematically illustrated, for example, in Figure 10B.

As such, at 706, method 700 includes determining an individual position of each of the functional elements after positioning the object in the grouping of functional elements, such as determining individual position 120 of each functional element 100 after positioning object 20 in functional elements 100, as schematically illustrated, for example, in Figure 9 and Figures 10A, 10B. In one example, determining an individual position of each of the functional elements, such as determining individual position 120 of each functional element 100, includes sensing a field of known intensity by a respective one of the functional elements, such as sensing a field of known intensity by a respective functional element 100, as schematically illustrated, for example, in Figures 4A, 4B, 4C, and Figures 5A, 5B, 5C.

As such, at 708, method 700 includes determining a shape of the object based on the individual position of the number of functional elements contacting the object, such as determining shape 22 of object 20 based on individual position 120 of functional elements 100 contacting object 20, as schematically illustrated, for example, in Figure 9 and Figures 10A, 10B. In one example, positioning the object in the grouping of functional elements, such as positioning object 20 in functional elements 100, includes creating a void of functional elements in the grouping of functional elements, such that determining the shape of the object, such as determining shape 22 of object 20, further includes determining the shape of the object based on the void of functional elements.

In one implementation, determining the shape of the object, such as determining shape 22 of object 20, further includes contacting the object with a probe extended from a number of the functional elements, such as probe 116

extended from functional element 100, as schematically illustrated, for example, in Figure 10B.

Although illustrated and described as separate and/or sequential steps, the method may include a different order or sequence of steps, and may
5 combine one or more steps or perform one or more steps concurrently, partially or wholly.

Although specific examples have been illustrated and described herein, a variety of alternate and/or equivalent implementations may be substituted for the specific examples shown and described without departing from the scope of the
10 present disclosure. This application is intended to cover any adaptations or variations of the specific examples discussed herein.

CLAIMS

1. A system for three-dimensional scanning of an object, comprising:
a set of functional elements, each of the functional elements including a housing and a processor, memory, power supply, sensor, and wireless communication module each within the housing;
a position module to determine an individual position of each of the functional elements after the object is in the set of functional elements; and
a contour module to determine a shape of the object based on the individual position of each of the functional elements and a void of functional elements created by the object in the set of functional elements.
2. The system of claim 1, wherein the position module is to determine the individual position of a respective one of the functional elements based on a field of known intensity sensed by the respective one of the functional elements.
3. The system of claim 2, wherein the field of known intensity comprises atmospheric pressure, and each of the functional elements is to sense a magnitude of the atmospheric pressure after the object is in the set of functional elements.
4. The system of claim 2, wherein the functional elements are submerged in liquid, wherein the field of known intensity comprises liquid pressure, and each of the functional elements is to sense a magnitude of the liquid pressure after the object is in the set of functional elements.
5. The system of claim 1, wherein the individual position of each of the functional elements after the object is in the set of functional elements includes a displaced position of a number of the functional elements.

6. The system of claim 1, wherein a number of the functional elements includes a probe to be extended therefrom to contact the object.
7. The system of claim 1, wherein the functional elements are spherical in shape.
8. A system for three-dimensional scanning of an object, comprising:
 - an accumulation of functional elements, each of the functional elements including a housing and a processor, memory, power supply, sensor, and wireless communication module each within the housing, and each of the functional elements having a respective position after the object is in the accumulation of functional elements,
 - wherein, after the object is in the accumulation of functional elements, a non-functional-element volume in the accumulation of functional elements corresponds to a volume of the object.
9. The system of claim 8, wherein each of the functional elements sense the respective position thereof.
10. The system of claim 8, wherein a number of the functional elements are in contact with the object after the object is in the accumulation of functional elements, wherein the respective position of the number of the functional elements identifies a boundary of a shape of the object.
11. A method of three-dimensional scanning of an object, comprising:
 - grouping a plurality of functional elements, each of the functional elements including a housing and a processor, memory, power supply, sensor, and wireless communication module each within the housing;
 - positioning the object in the grouping of functional elements, including contacting the object with a number of the functional elements;
 - determining an individual position of each of the functional elements after the positioning the object in the grouping of functional elements; and

determining a shape of the object based on the individual position of the number of the functional elements contacting the object.

12. The method of claim 11, wherein determining the individual position of each of the functional elements includes sensing a field of known intensity by a respective one of the functional elements.

13. The method of claim 11, wherein positioning the object in the grouping of functional elements includes creating a void of functional elements in the grouping of functional elements, wherein determining the shape of the object further includes determining the shape of the object based on the void of functional elements.

14. The method of claim 11, wherein determining the shape of the object further includes contacting the object with a probe extended from a number of the functional elements.

15. The method of claim 11, wherein the functional elements are spherical in shape.

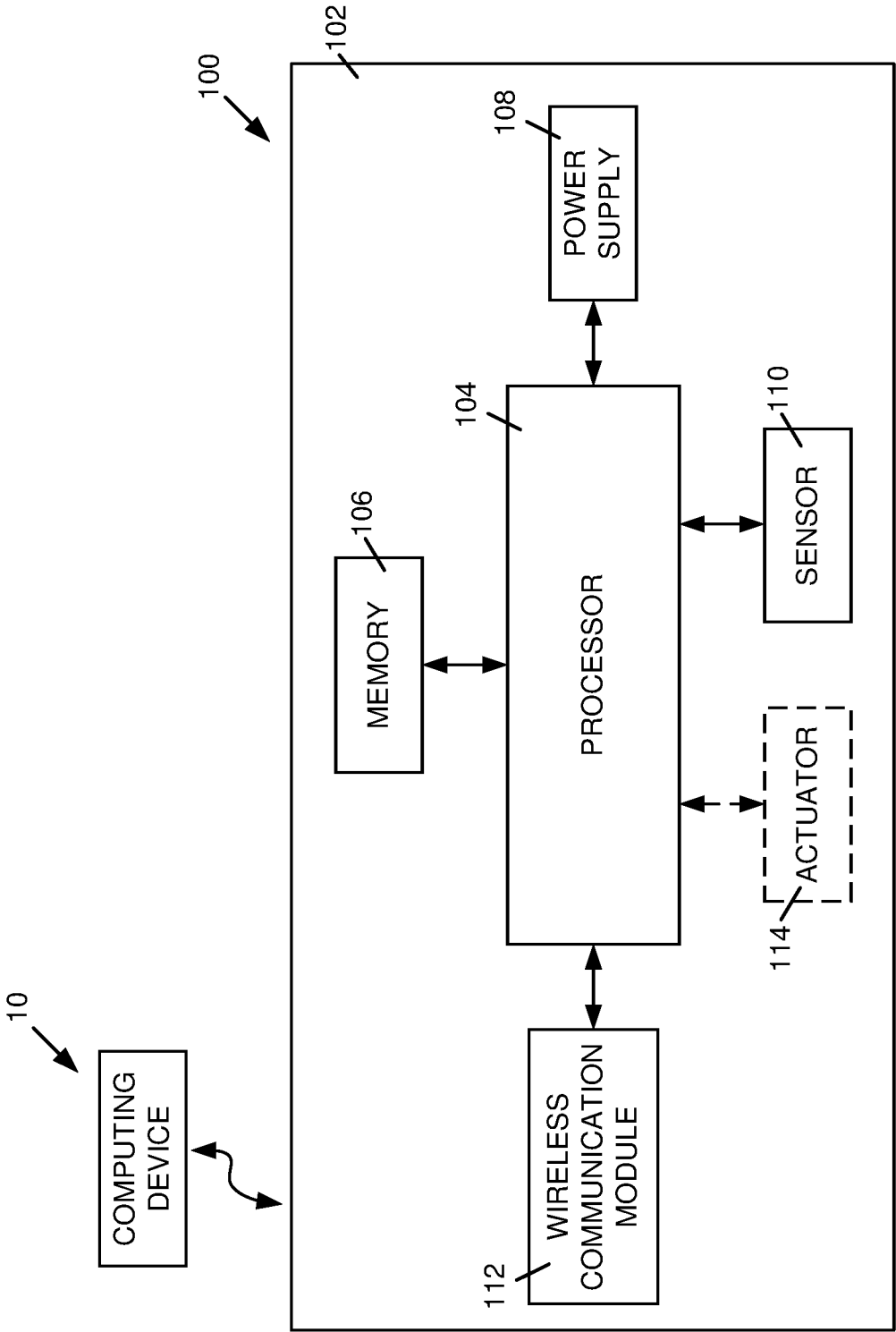


FIG. 1

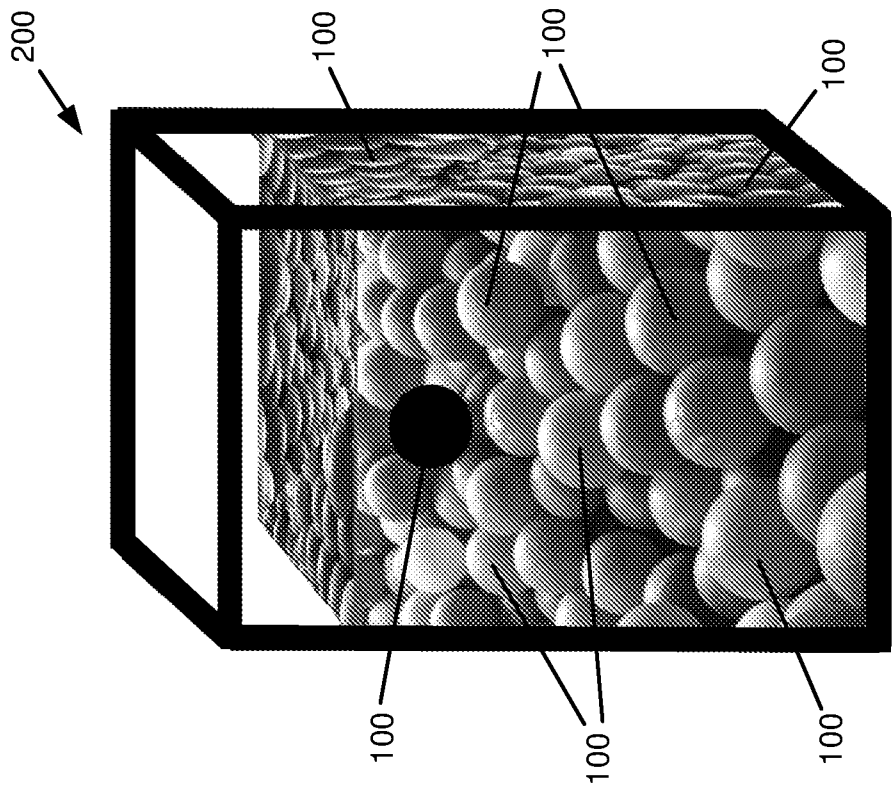


FIG. 2

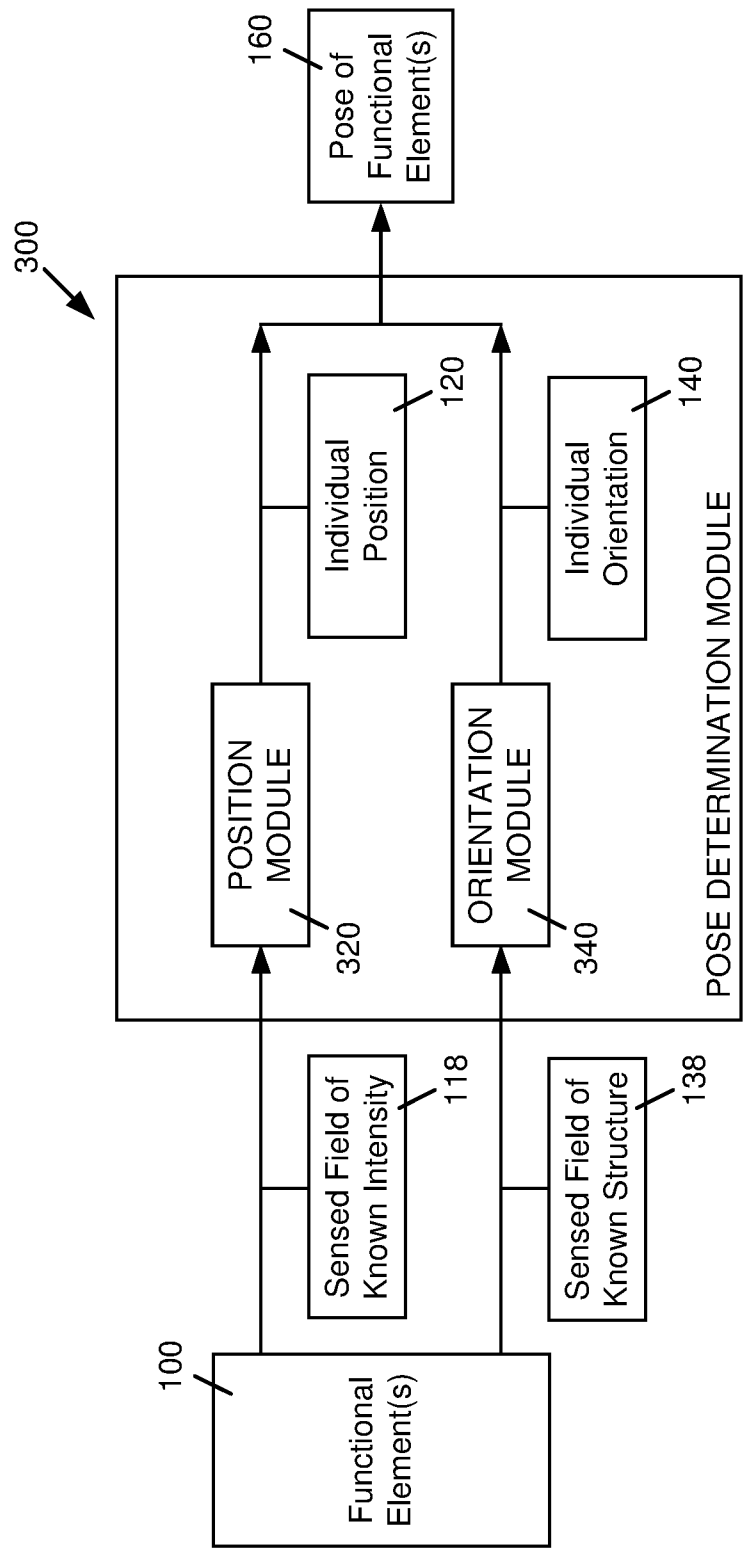


FIG. 3

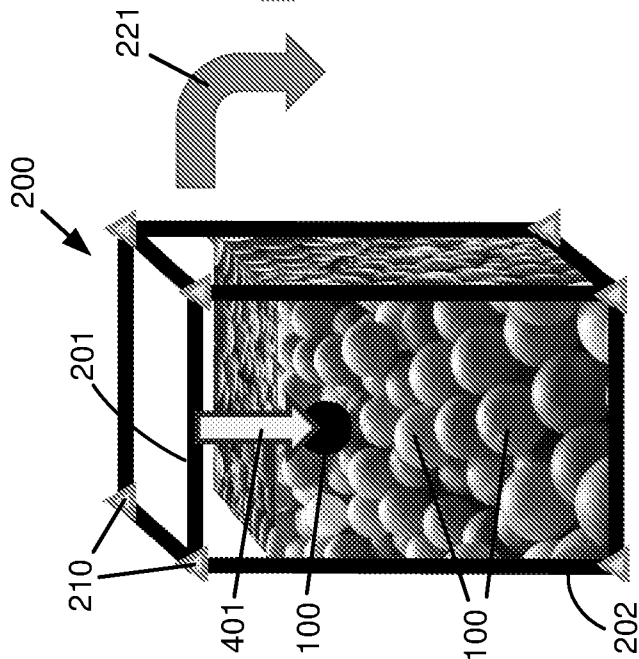


FIG. 4A

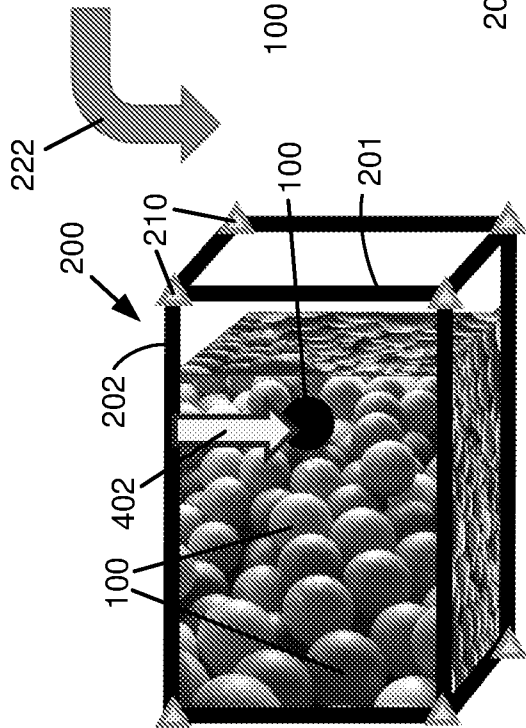


FIG. 4B

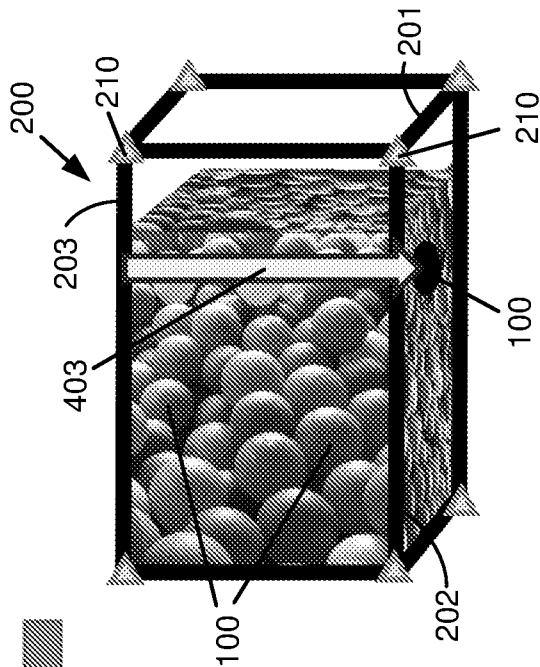


FIG. 4C

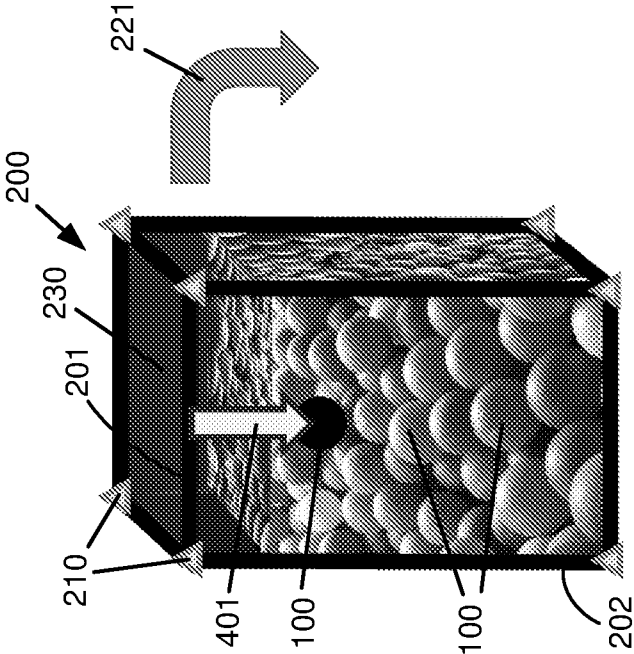


FIG. 5A

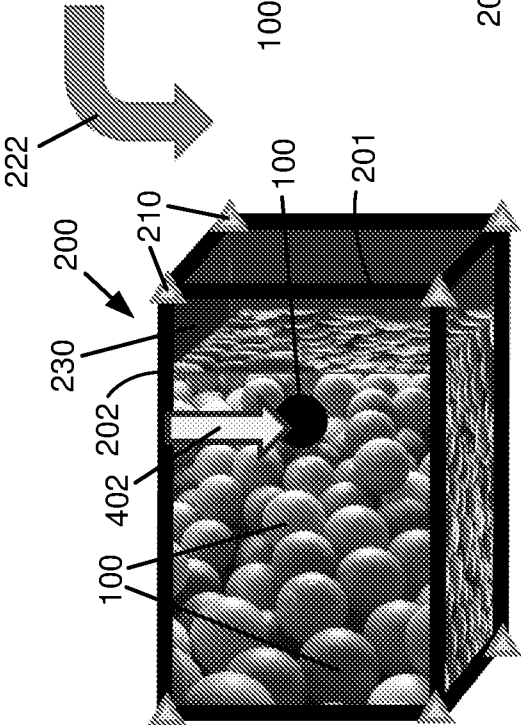


FIG. 5B

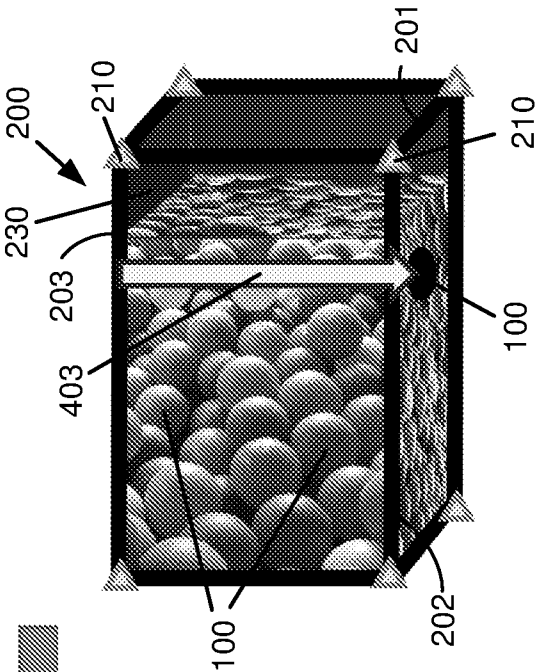


FIG. 5C

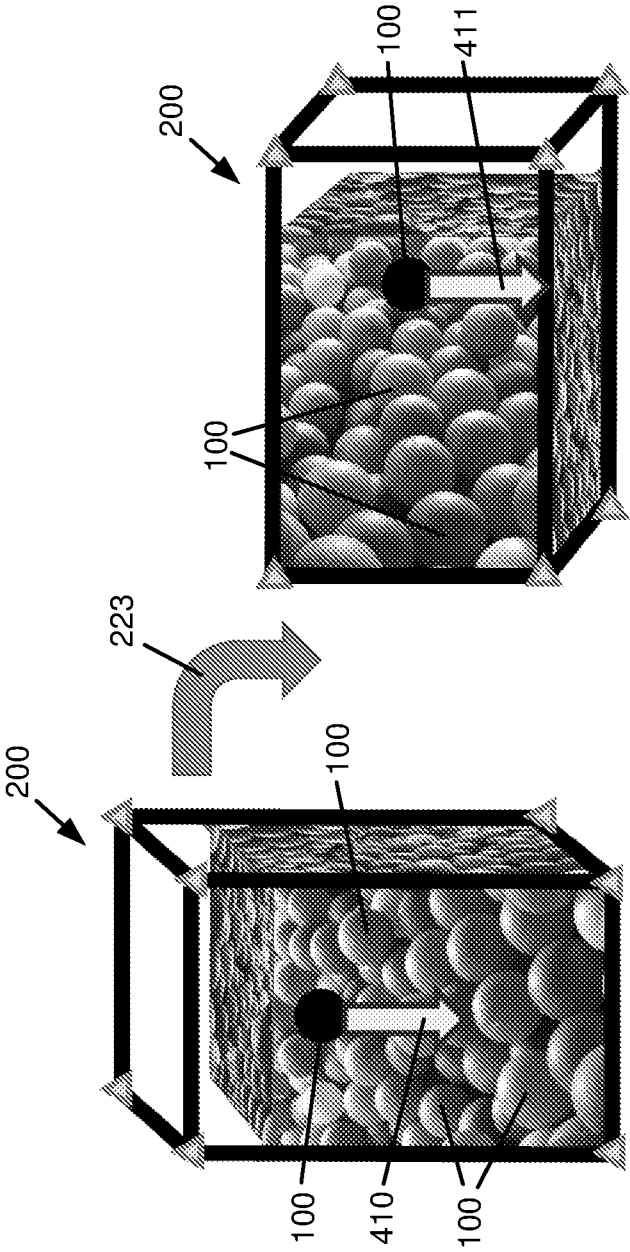


FIG. 6B

FIG. 6A

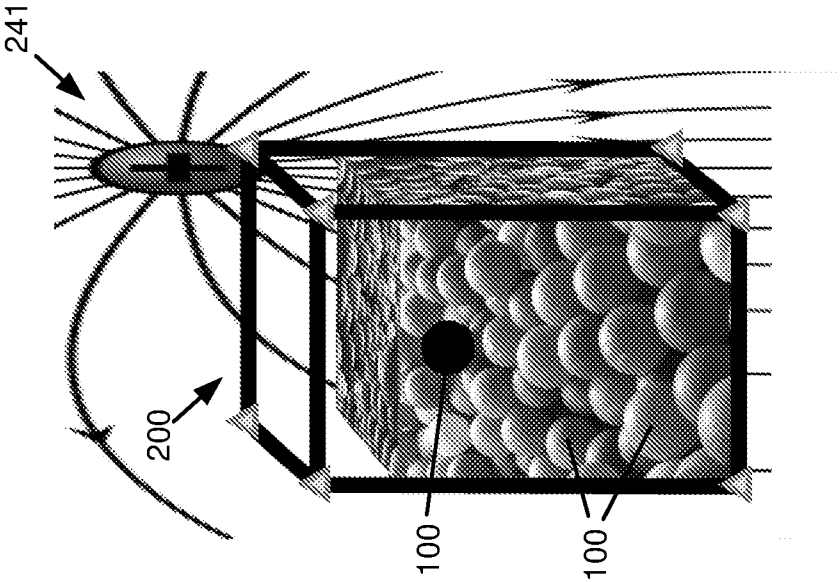


FIG. 7A

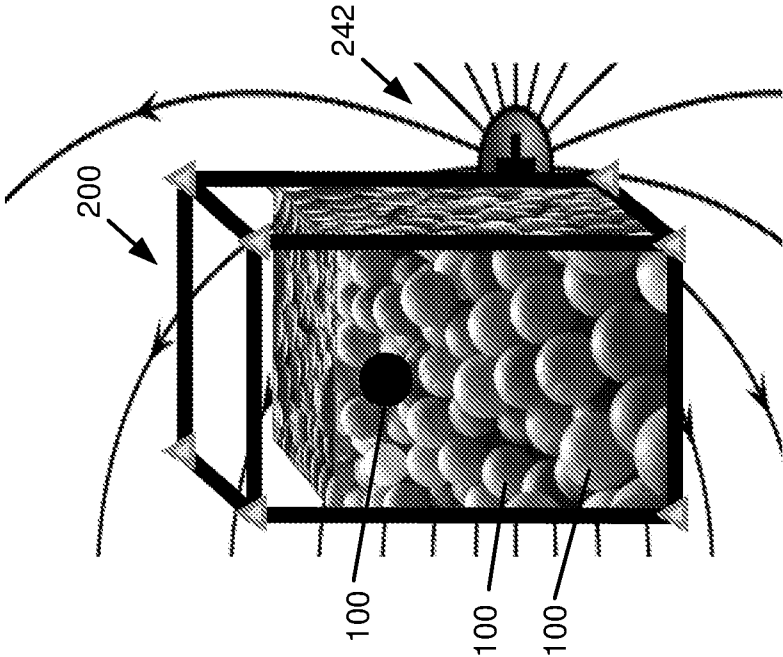
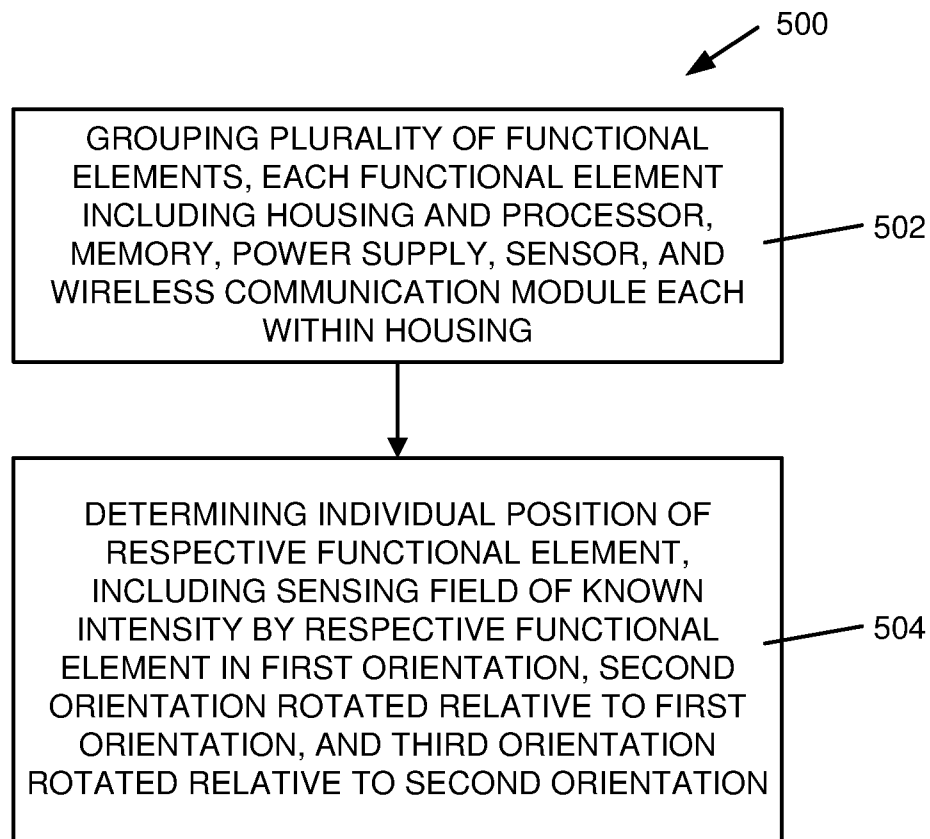
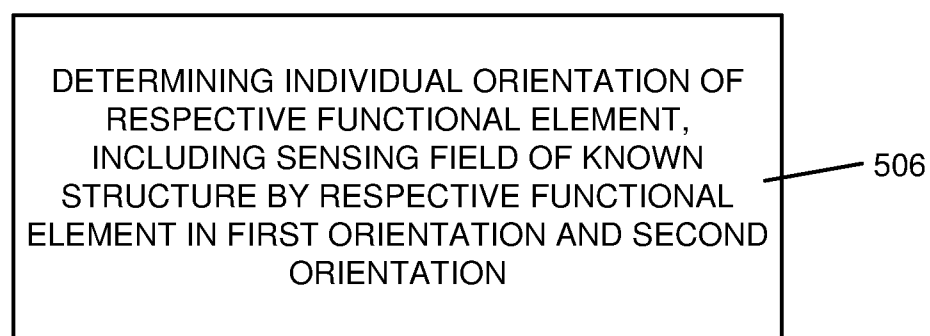


FIG. 7B

**FIG. 8A****FIG. 8B**

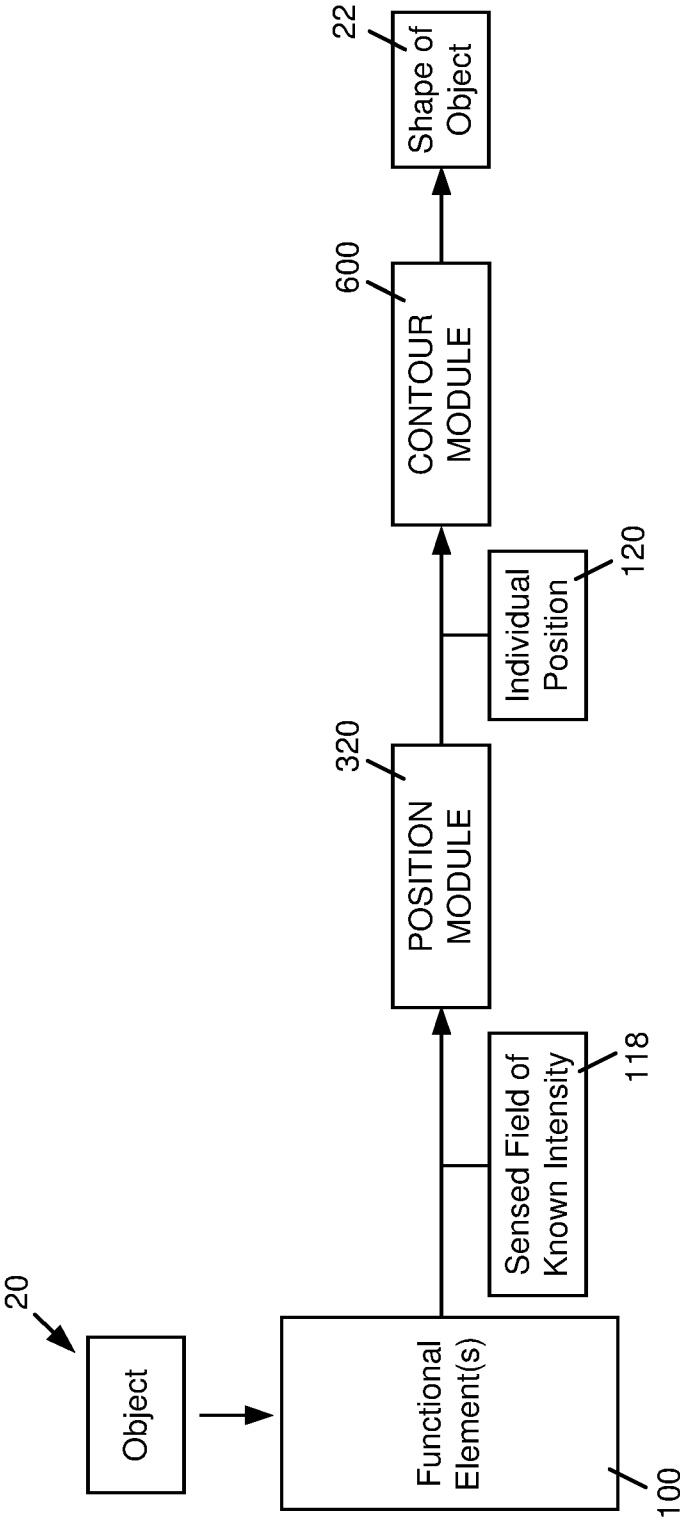


FIG. 9

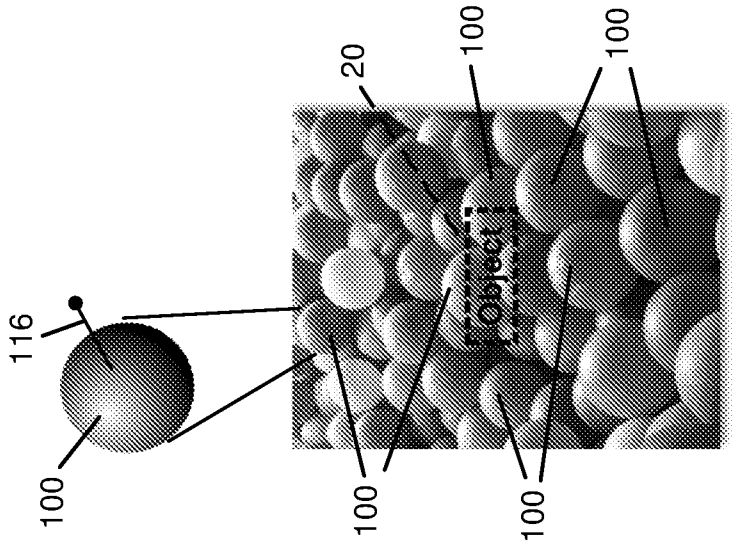


FIG. 10B

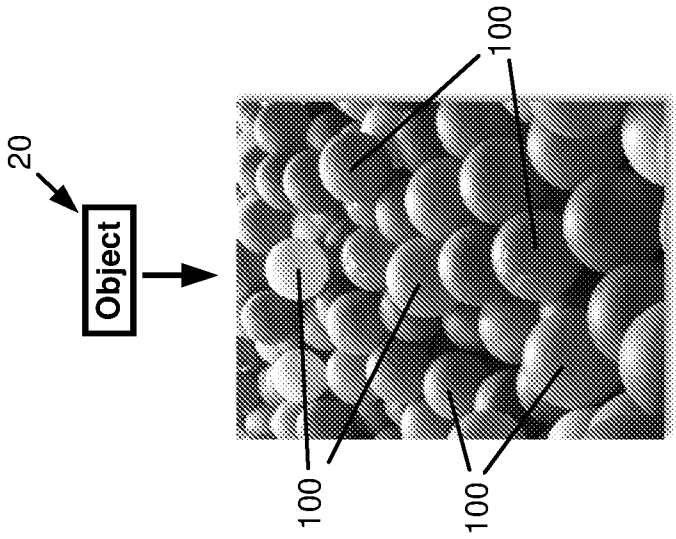
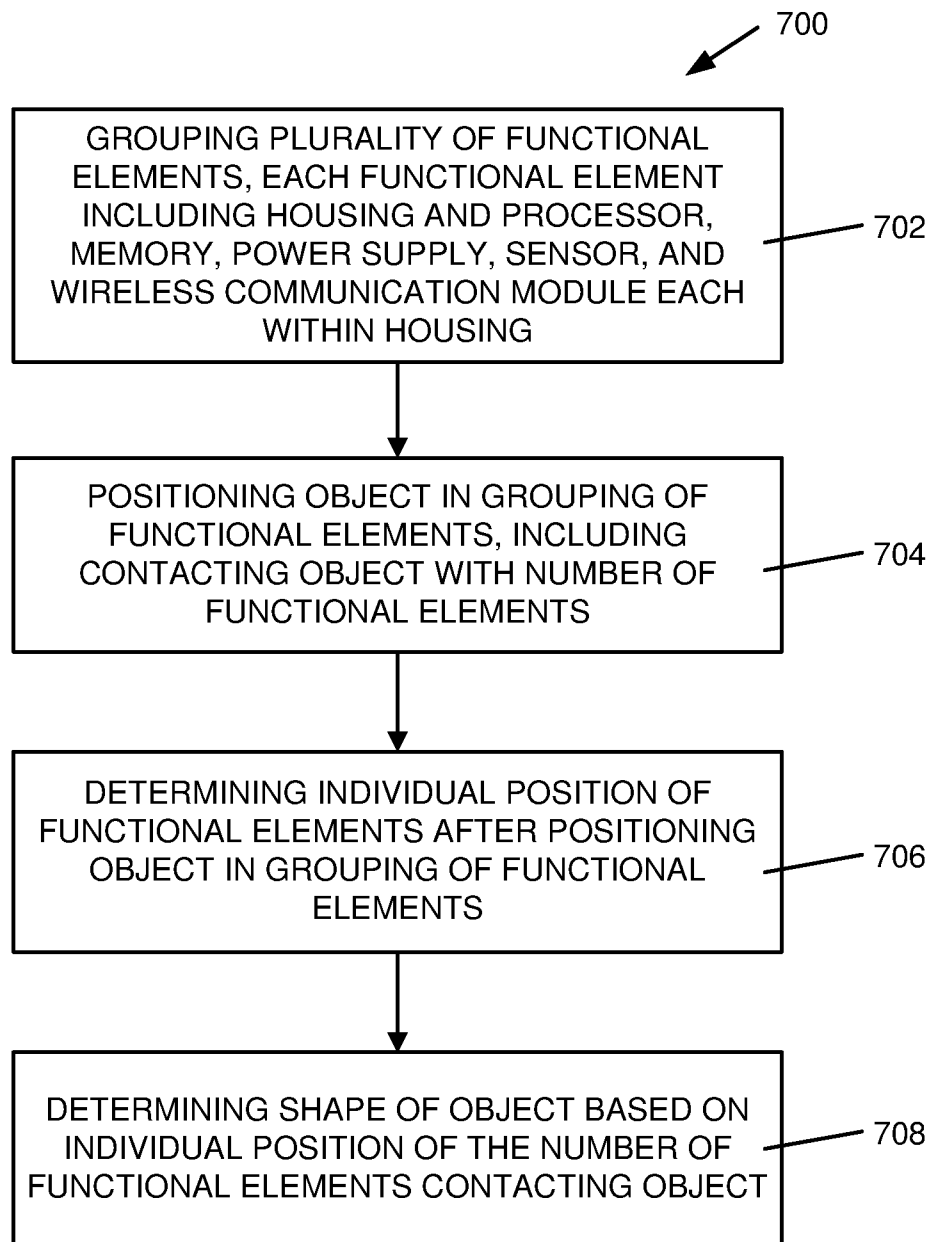


FIG. 10A

**FIG. 11**

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 2017/016260

A. CLASSIFICATION OF SUBJECT MATTER		
G01B 21/20 (2006.01)		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED		
Minimum documentation searched (classification system followed by classification symbols)		
G01B 5/00-5/30, 7/00-7/34, 21/00-21/32, G01D 5/00-5/54, G12B 1/00-1/04, H04N 1/00-1/52		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)		
PatSearch (RUPTO internal), USPTO, PAJ, Esp@cenet, DWPI, EAPATIS, PATENTSCOPE, Information Retrieval System of FIPS		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	RU 2474787 C1 (ФЕДЕРАЛЬНОЕ ГОСУДАРСТВЕННОЕ УНИТАРНОЕ ПРЕДПРИЯТИЕ "ВСЕРОССИЙСКИЙ НАУЧНО-ИССЛЕДОВАТЕЛЬСКИЙ ИНСТИТУТ ОПТИКО-ФИЗИЧЕСКИХ ИЗМЕРЕНИЙ") 10.02.2013	1-15
A	US 6701633 B2 (CANON KABUSHIKI KAISHA) 09.03.2004	1-15
A	US 2012/0025803 A1 (SONY CORPORATION) 02.02.2012	1-15
A	US 5822877 A1 (BROWN & SHARPE MANUFACTURING COMPANY) 20.10.1998	1-15
☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.		
* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention	
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone	
"E" earlier document but published on or after the international filing date	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art	
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"O" document referring to an oral disclosure, use, exhibition or other means		
"P" document published prior to the international filing date but later than the priority date claimed		
Date of the actual completion of the international search	Date of mailing of the international search report	
16 October 2017 (16.10.2017)	19 October 2017 (19.10.2017)	
Name and mailing address of the ISA/RU: Federal Institute of Industrial Property, Berezhkovskaya nab., 30-1, Moscow, G-59, GSP-3, Russia, 125993 Facsimile No: (8-495) 531-63-18, (8-499) 243-33-37	Authorized officer D. Melnikov Telephone No. (499) 240-25-91	