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Miller et al.

(10) Patent No.: US 12,482,125 B1
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(54) **SYSTEM AND METHOD FOR BOX SEGMENTATION AND MEASUREMENT**

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(73) Assignee: **4DMobile, LLC**, Hiawatha, IA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 238 days.

(21) Appl. No.: **18/139,248**

(22) Filed: **Apr. 25, 2023**

Related U.S. Application Data

(63) Continuation-in-part of application No. 17/114,066, filed on Dec. 7, 2020, now Pat. No. 11,669,988, (Continued)

(51) **Int. Cl.**

G06T 7/62	(2017.01)
G06F 3/01	(2006.01)
G06F 3/04815	(2022.01)
G06F 3/04845	(2022.01)
G06F 3/0488	(2022.01)
G06F 3/16	(2006.01)
G06K 7/14	(2006.01)
G06T 7/593	(2017.01)

(Continued)

(52) **U.S. Cl.**
CPC ***G06T 7/62*** (2017.01); ***G06F 3/017*** (2013.01); ***G06F 3/04815*** (2013.01); ***G06F 3/04845*** (2013.01); ***G06F 3/0488*** (2013.01); ***G06F 3/167*** (2013.01); ***G06K 7/1408*** (2013.01); ***G06T 7/593*** (2017.01); ***G06T 19/006*** (2013.01); ***H04N 5/44504*** (2013.01); ***H04N 23/45*** (2023.01); *G06T 2200/04* (2013.01); *G06T 2200/08* (2013.01)

(58) **Field of Classification Search**
CPC G06T 7/62; G06T 7/593; G06T 19/006; G06T 2200/04; G06T 2200/08; G06F 3/017; G06F 3/04815; G06F 3/04845; G06F 3/0488; G06F 3/167; H04N 5/44504; H04N 23/45
See application file for complete search history.

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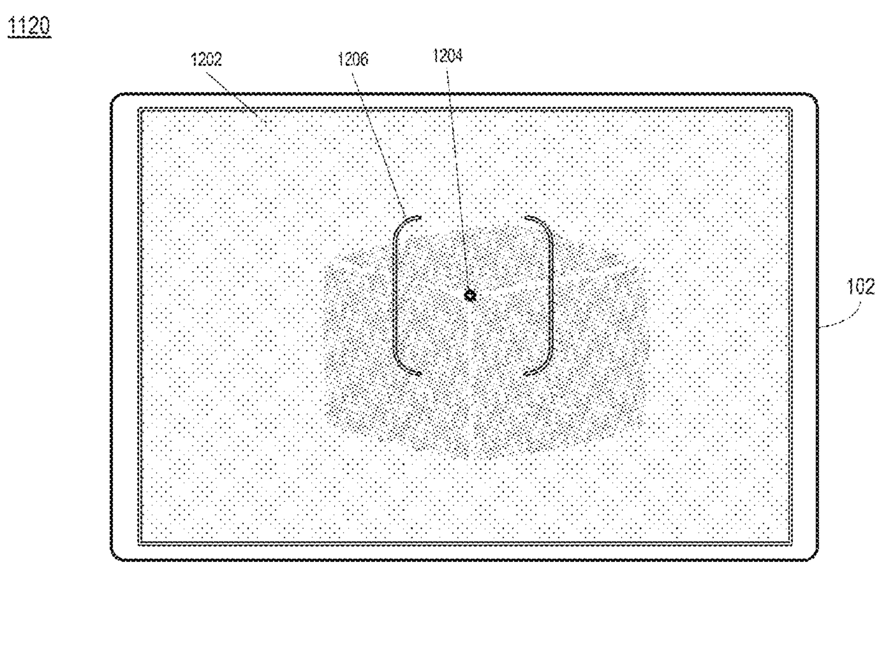
Primary Examiner — Jin Cheng Wang
(74) *Attorney, Agent, or Firm* — Suiter Swantz IP

(57) **ABSTRACT**

A mobile device is capable of being carried by a user and directed at a target object. The mobile device may implement a system to dimension the target object. The system, by way of the mobile device, may image the target object to and receive a 3D image stream, including one or more frames. Each frame may include a plurality of points, where each point has an associated depth value. Based on the depth value of the plurality of points, the system, by way of the mobile device, may determine one or more dimensions of the target object.

18 Claims, 64 Drawing Sheets



Related U.S. Application Data

which is a continuation-in-part of application No. 16/786,268, filed on Feb. 10, 2020, now abandoned, which is a continuation of application No. 16/390,562, filed on Apr. 22, 2019, now Pat. No. 10,559,086, which is a continuation-in-part of application No. 15/156,149, filed on May 16, 2016, now Pat. No. 10,268,892.

(60) Provisional application No. 63/113,658, filed on Nov. 13, 2020, provisional application No. 62/694,764, filed on Jul. 6, 2018, provisional application No. 62/162,480, filed on May 15, 2015.

(51) **Int. Cl.**

G06T 19/00	(2011.01)
H04N 5/445	(2011.01)
H04N 23/45	(2023.01)

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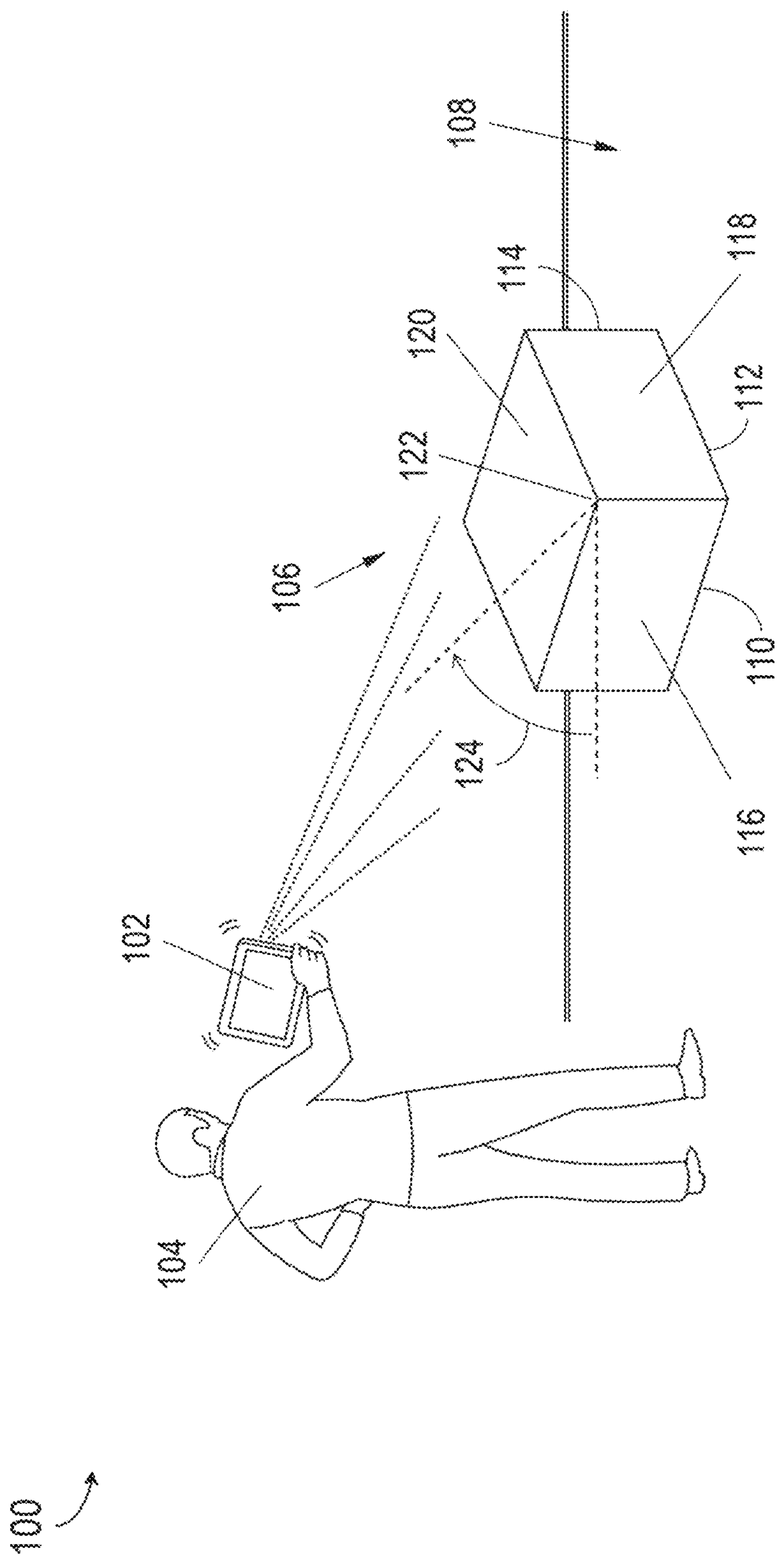


FIG. 1

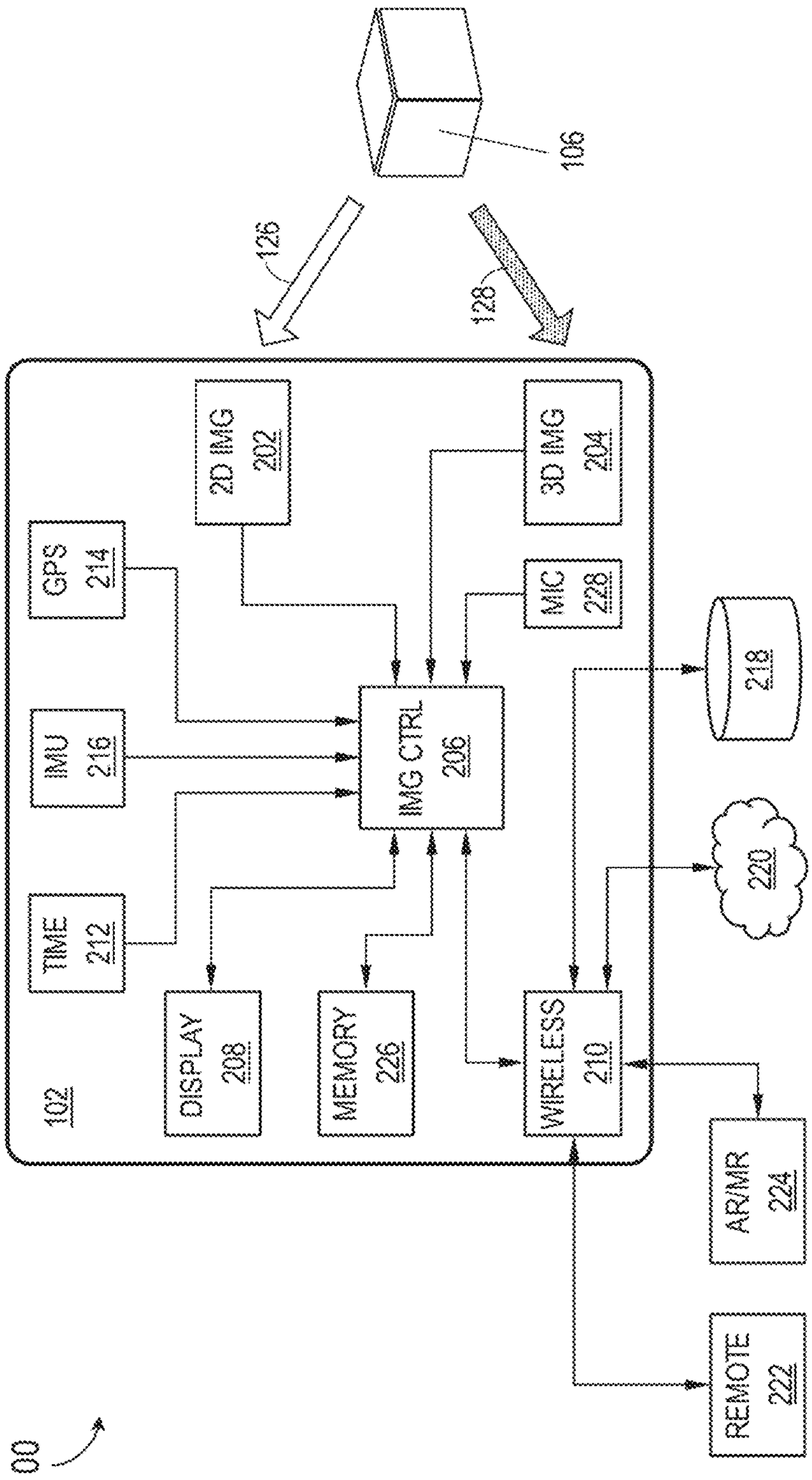

106
126
128
102
2D IMG 202
3D IMG 204
GPS 214
MIC 228
IMU 216
IMG CTRL 206
218
TIME 212
220
DISPLAY 208
MEMORY 226
WIRELESS 210
AR/MR 224
REMOTE 222
100

FIG. 2

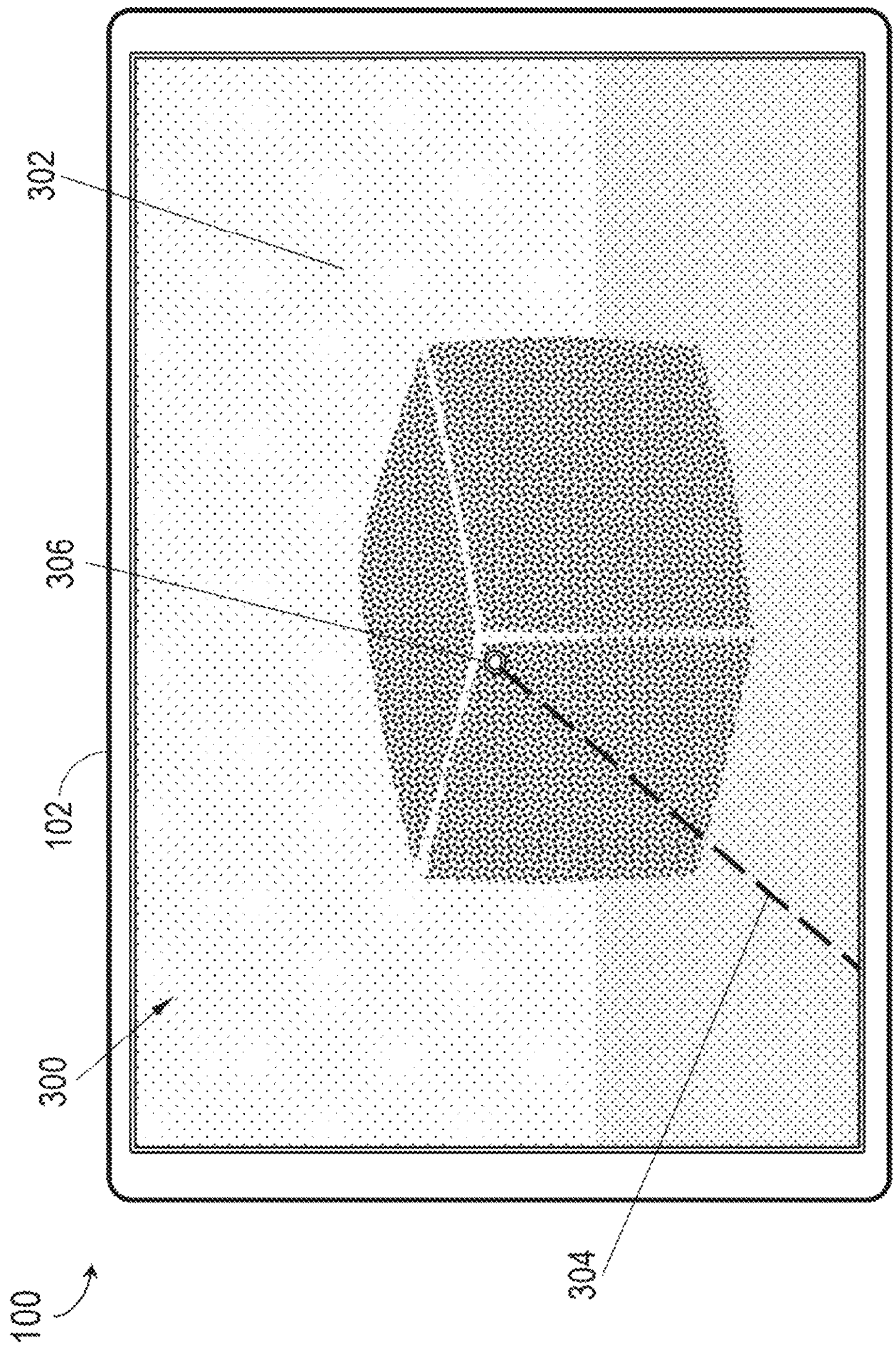


FIG. 3A

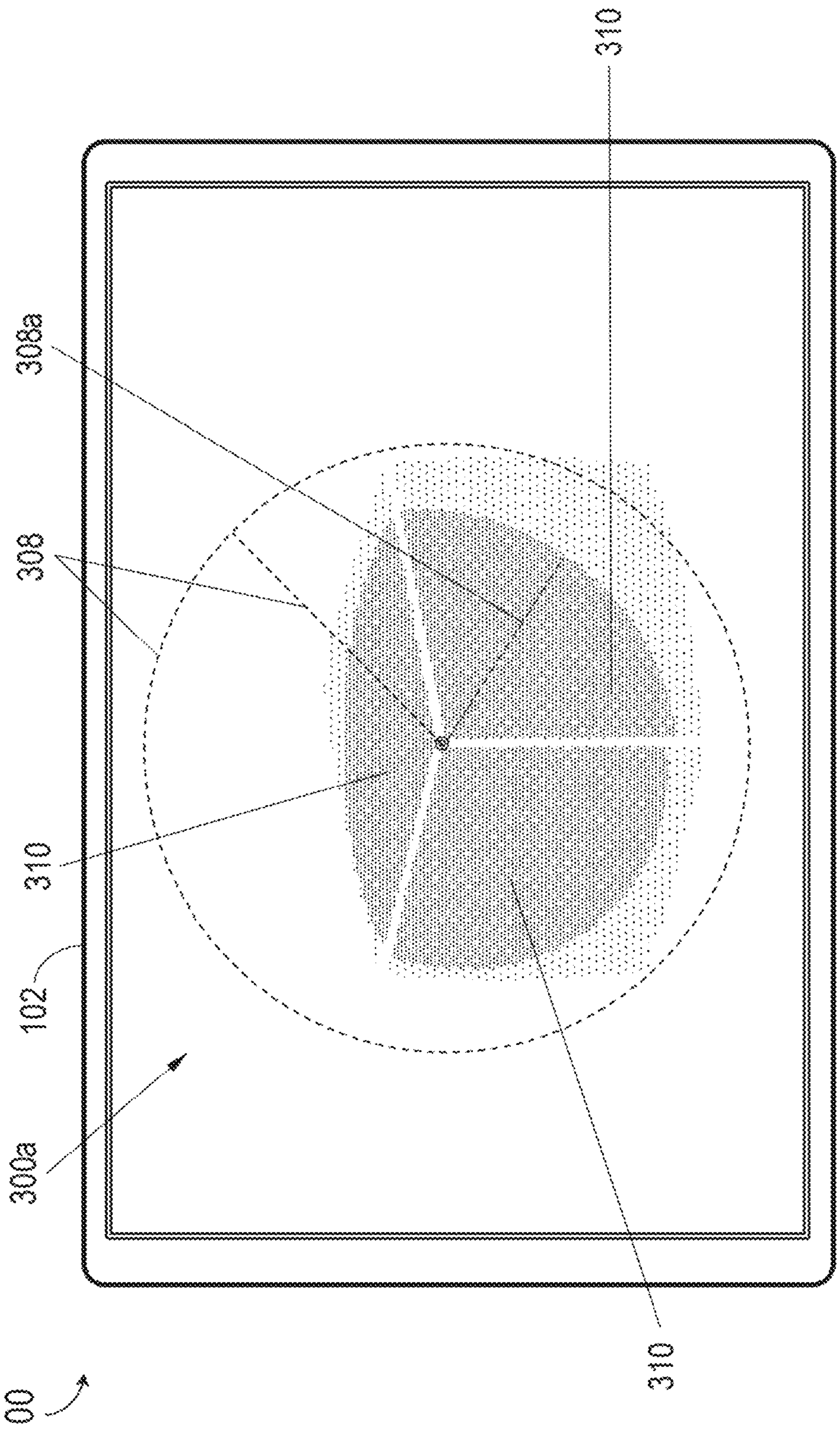


FIG. 3B

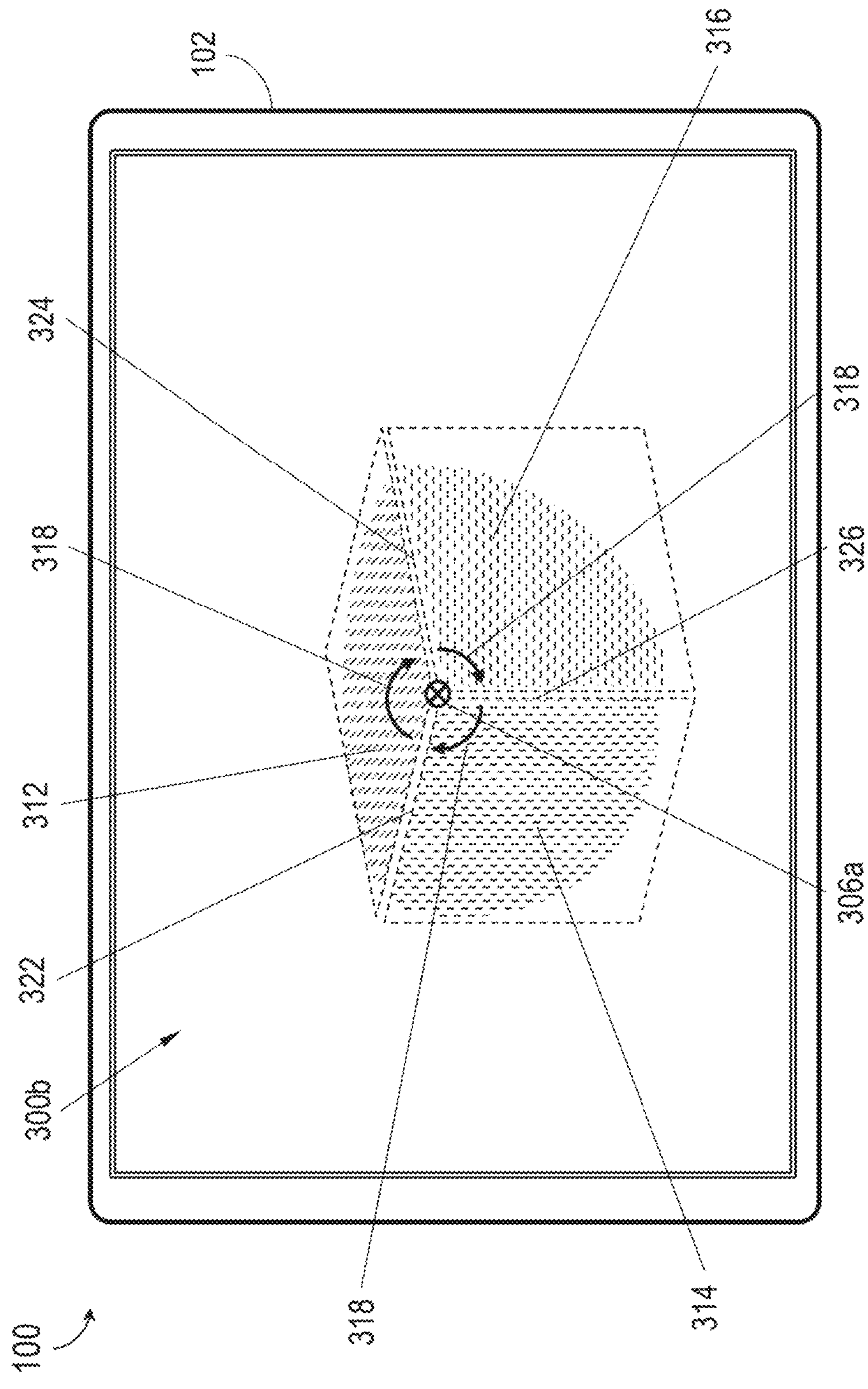


FIG. 3C

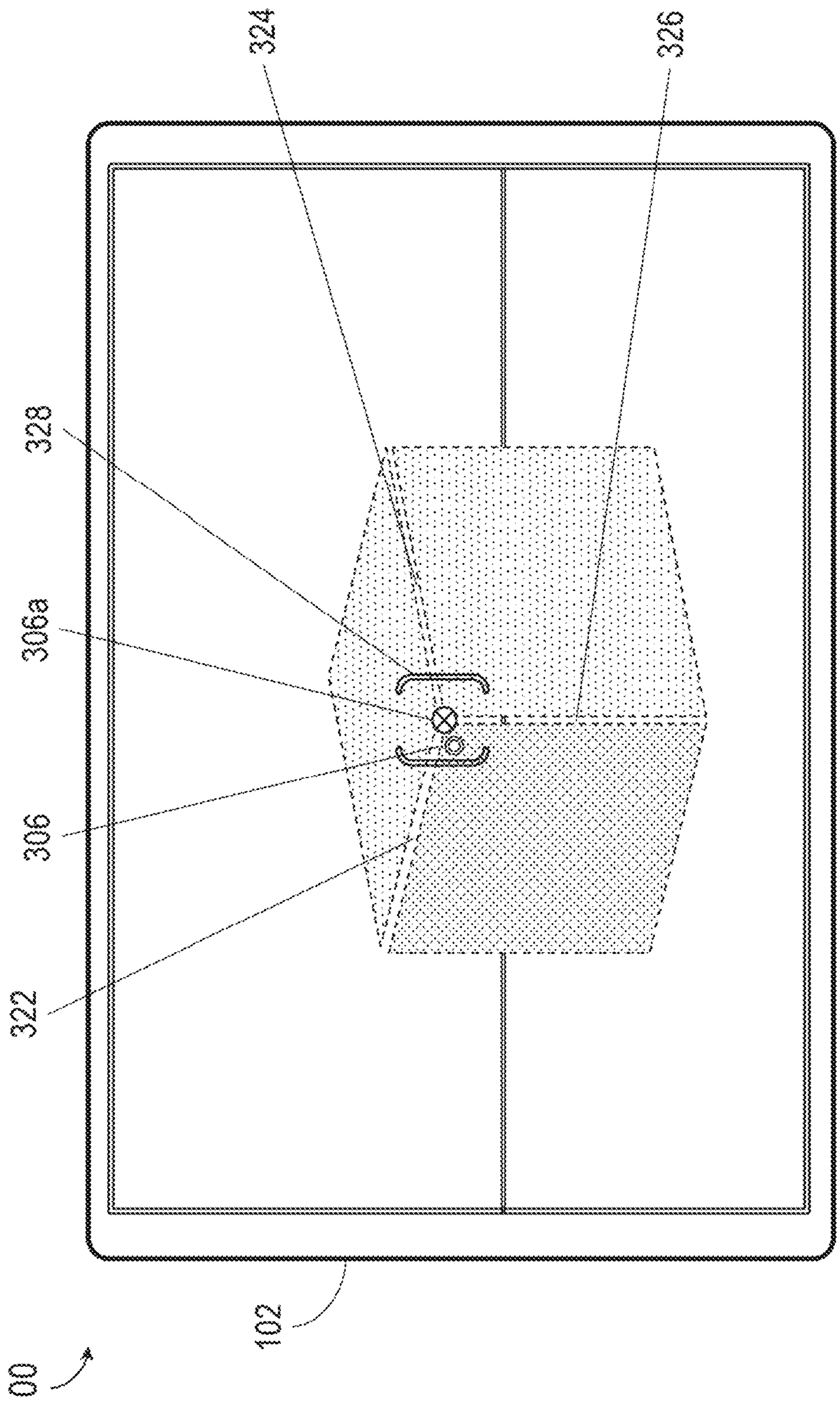


FIG. 3D

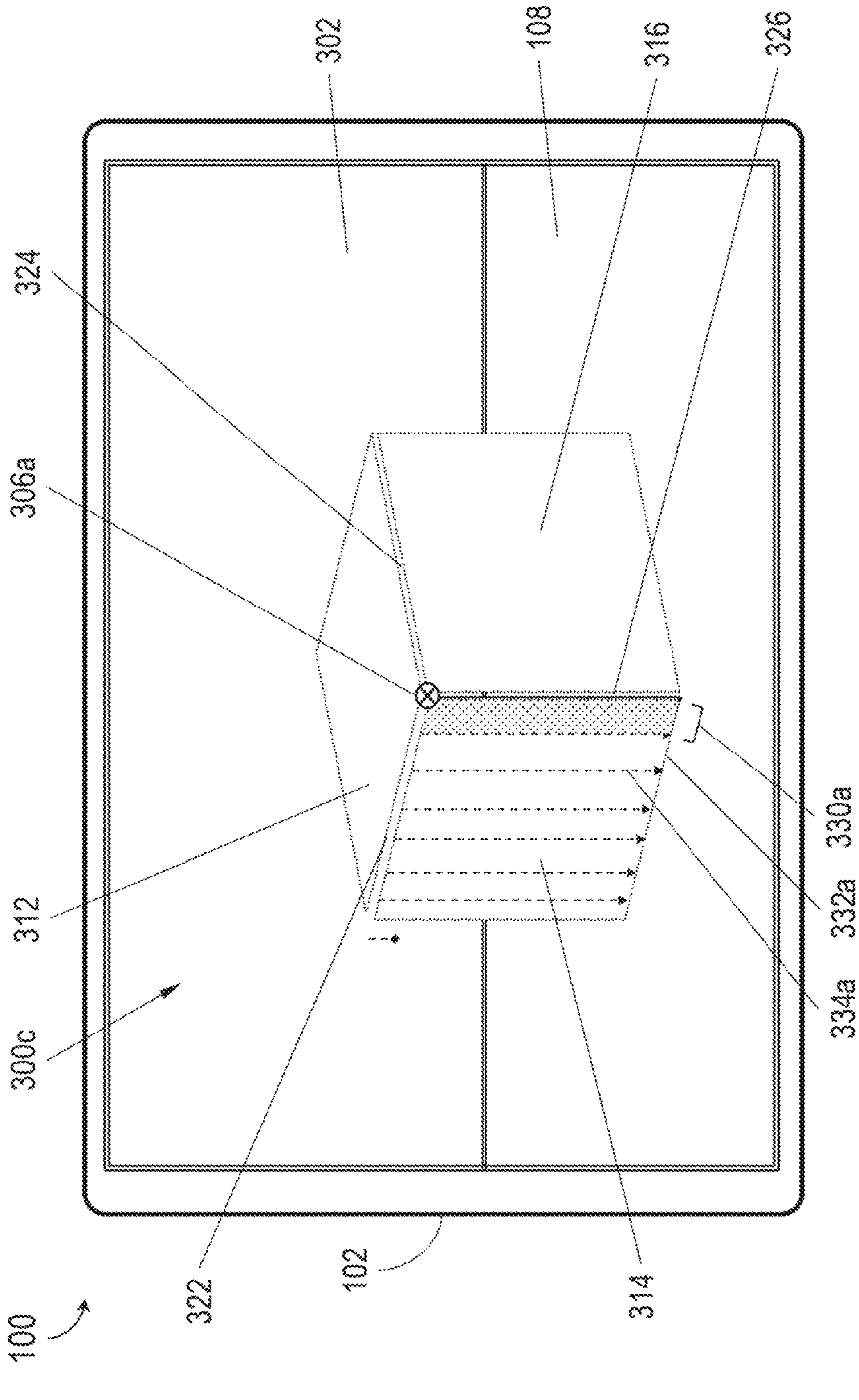

302
108
316
326
324
306a
312
300c
330a
332a
334a
322
102
314
100

FIG. 3E

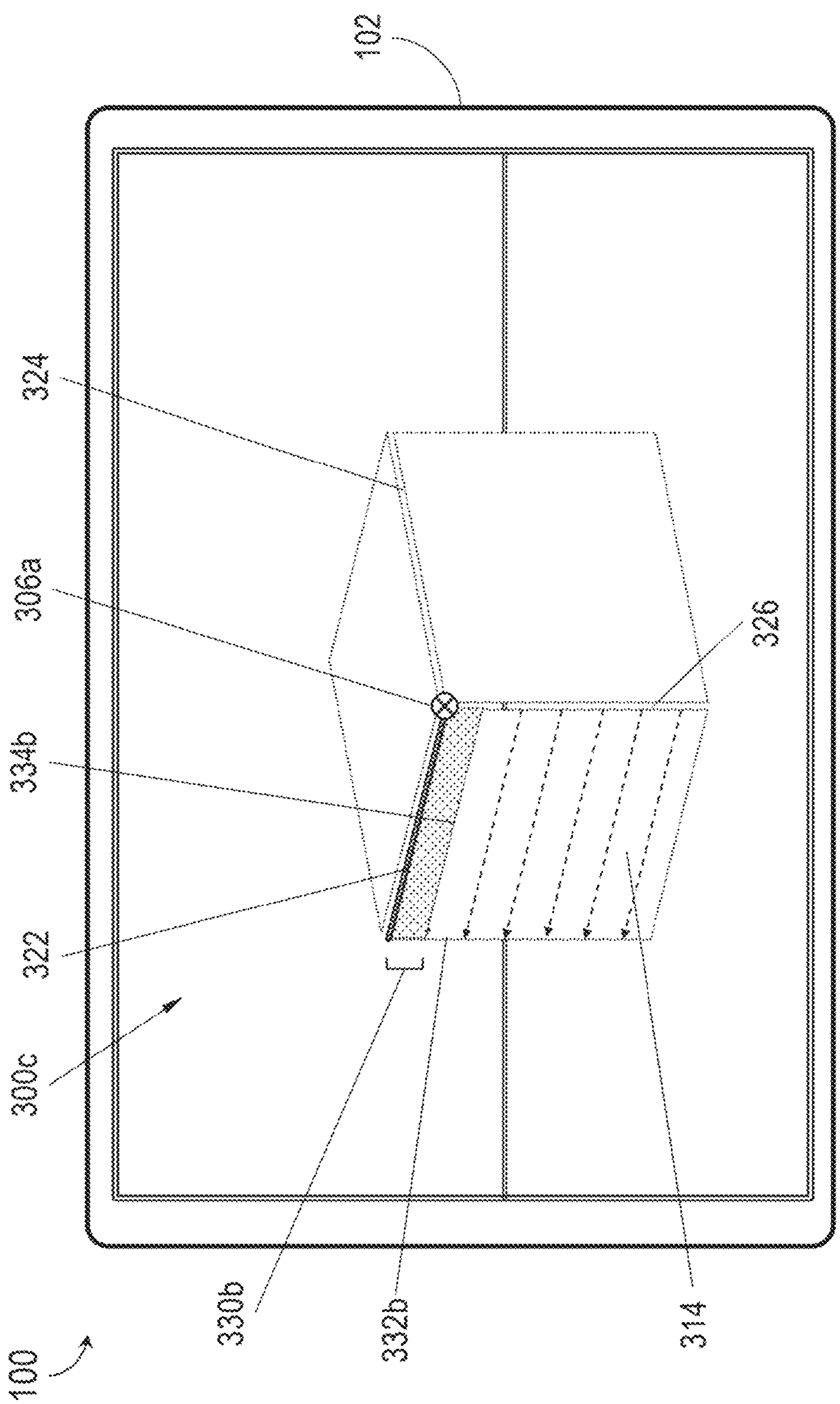


FIG. 3F

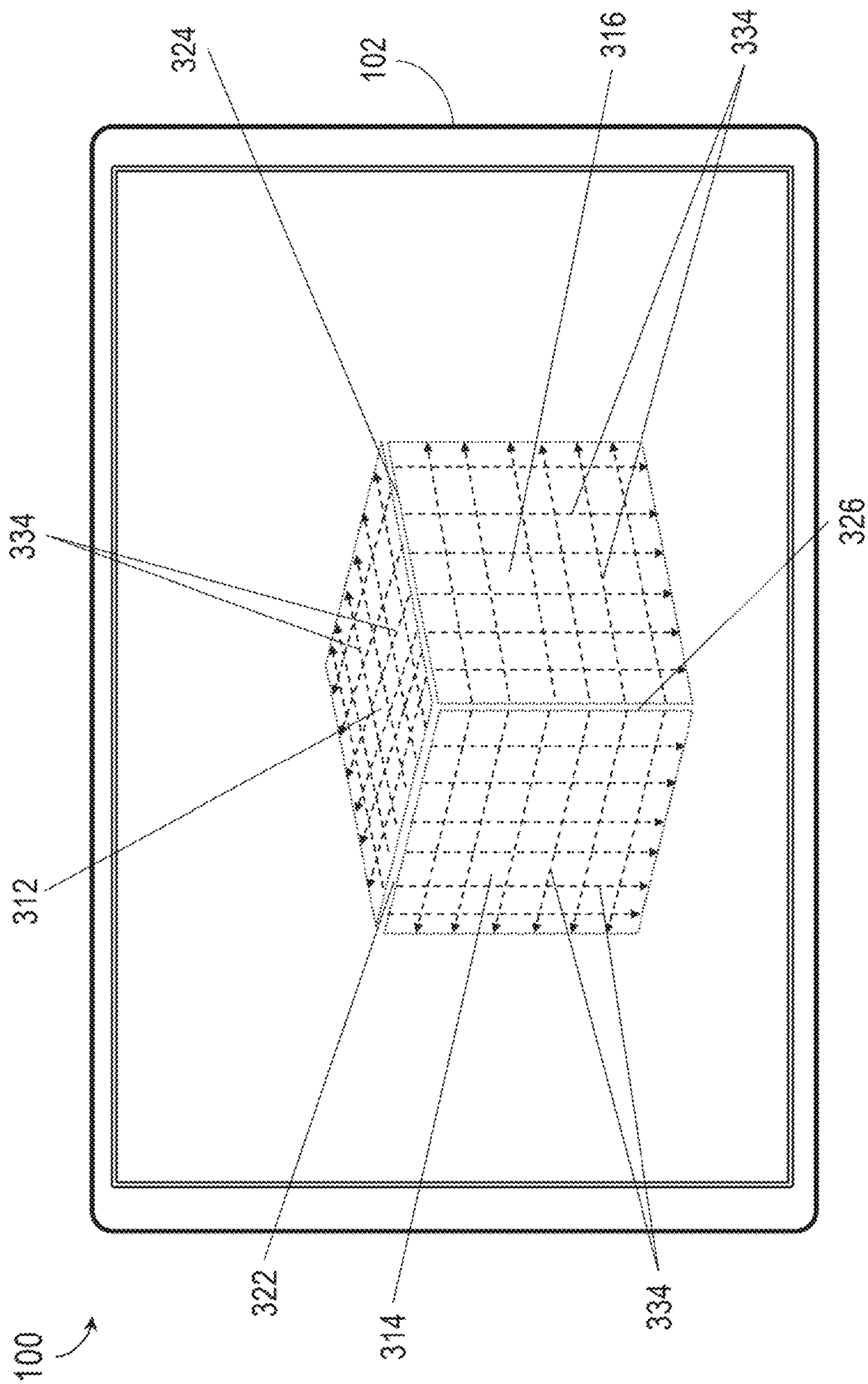


FIG. 3G

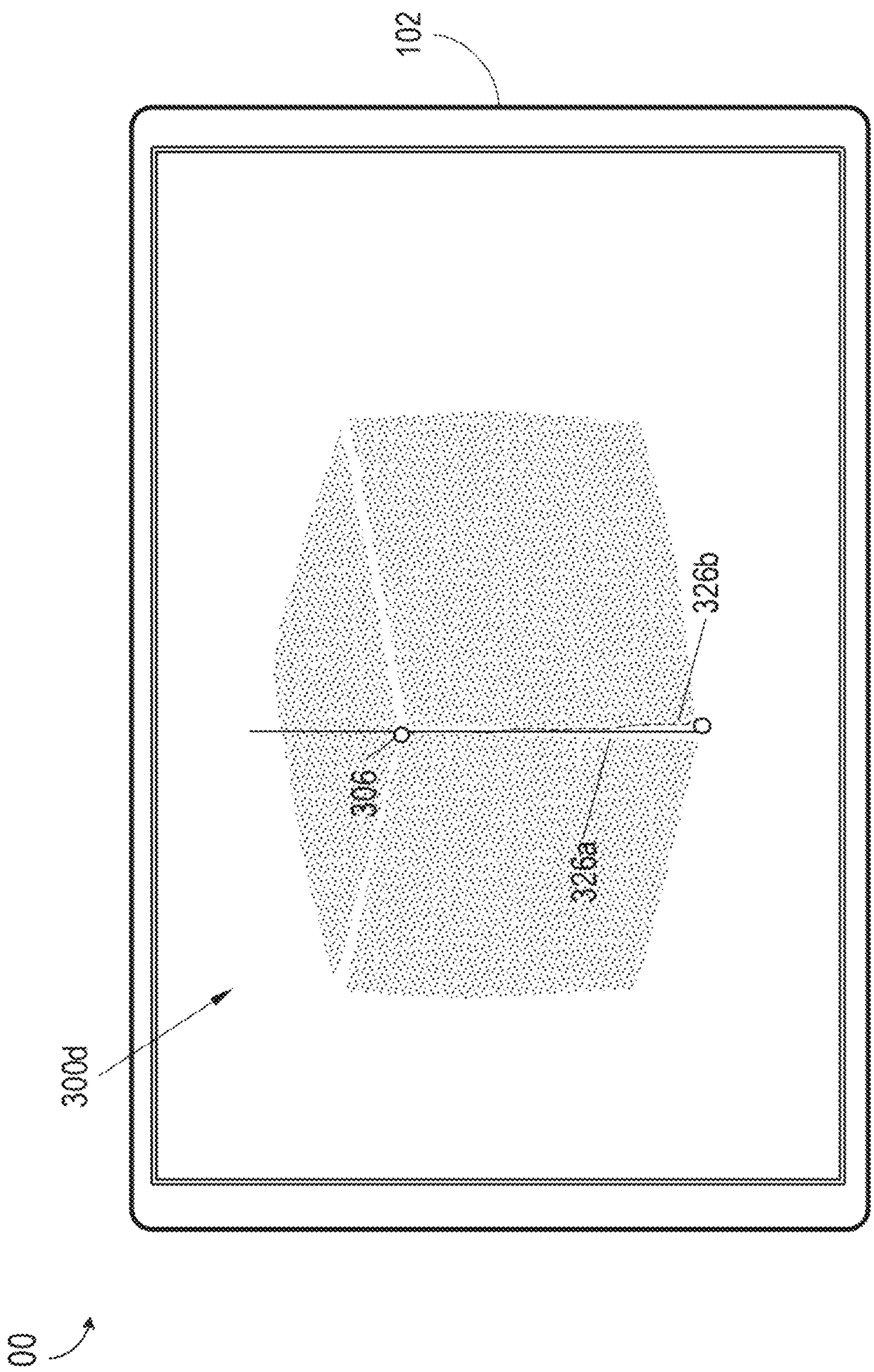


FIG. 3H

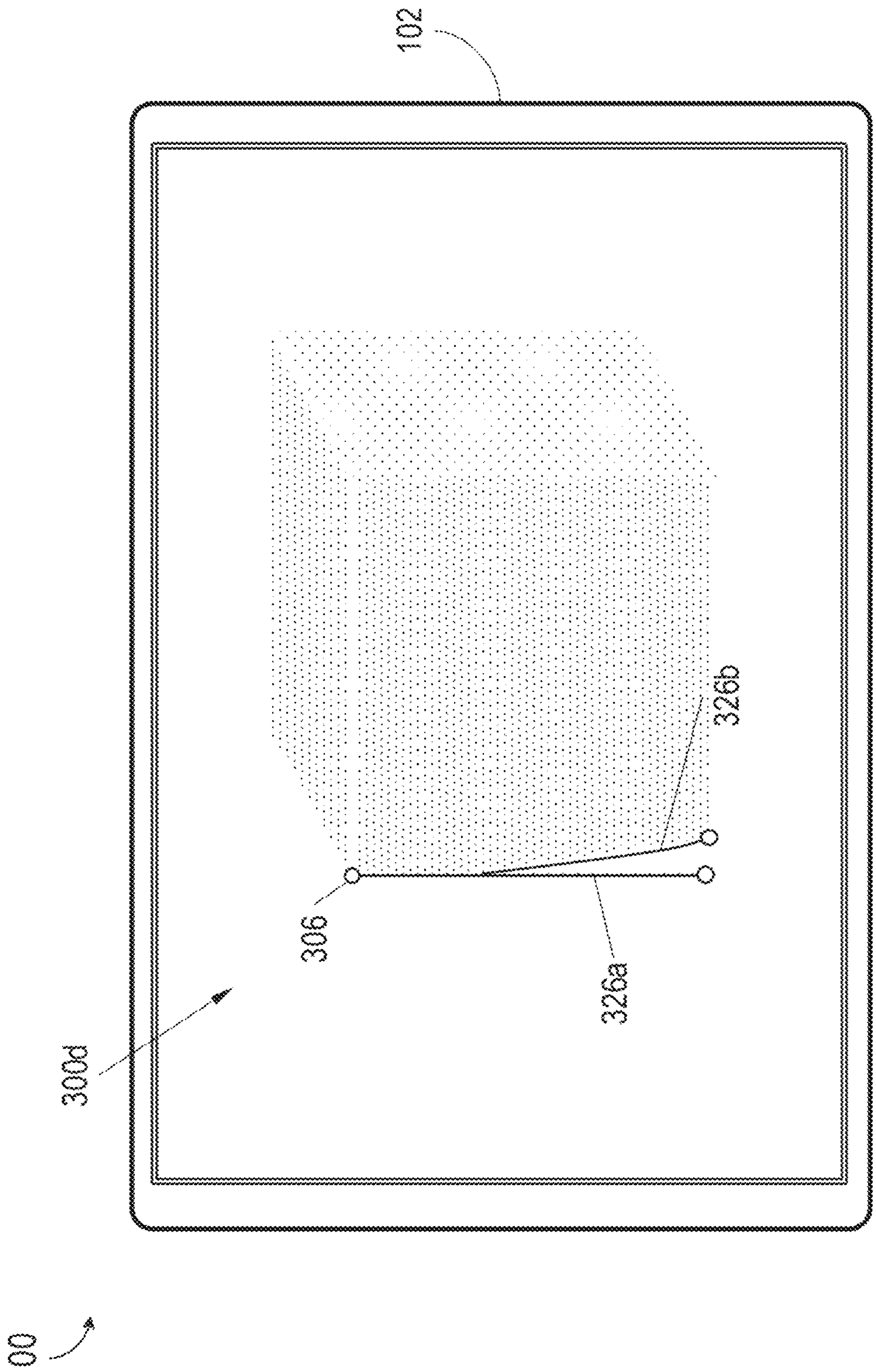


FIG. 3I

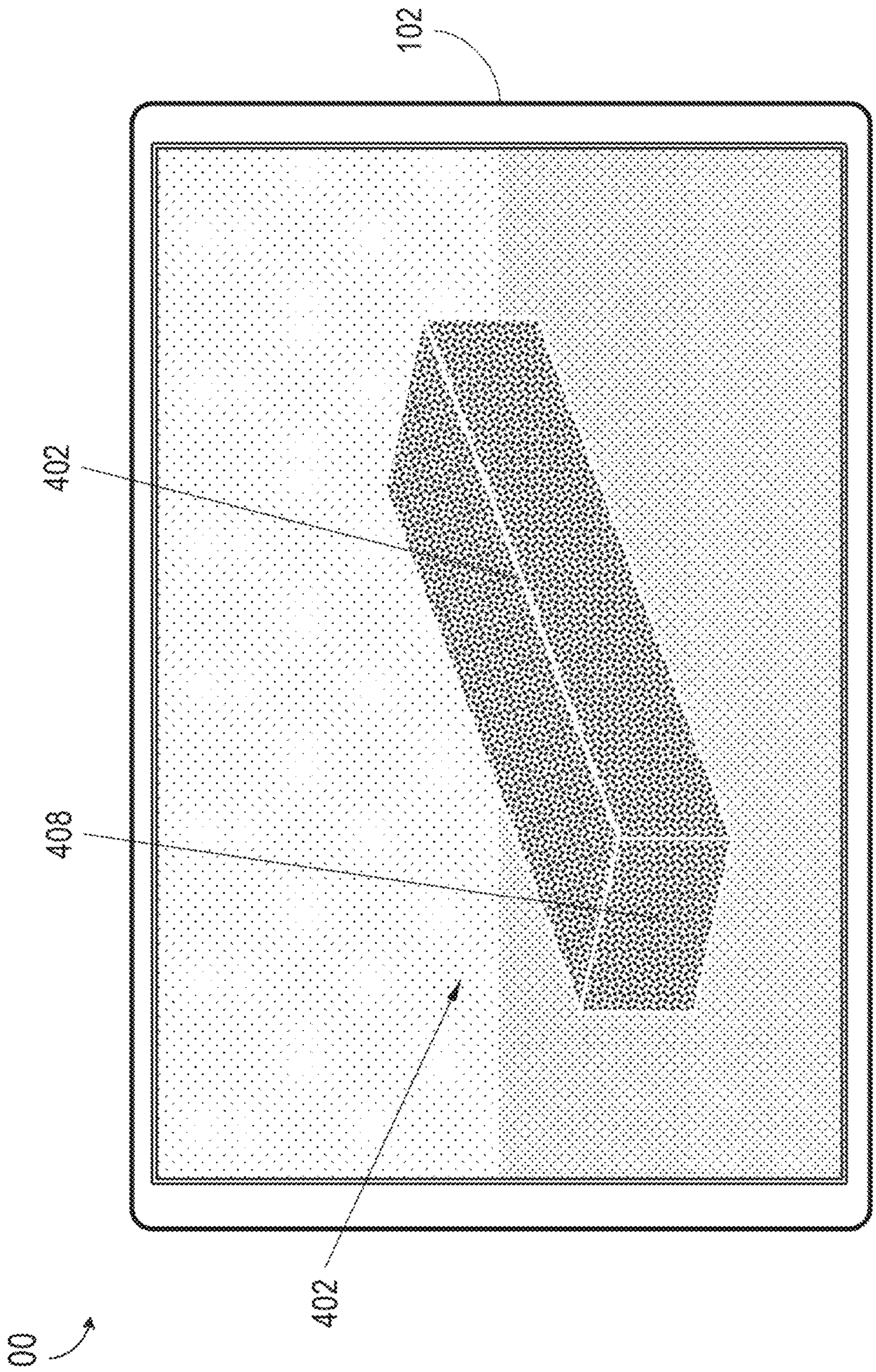


FIG. 4A

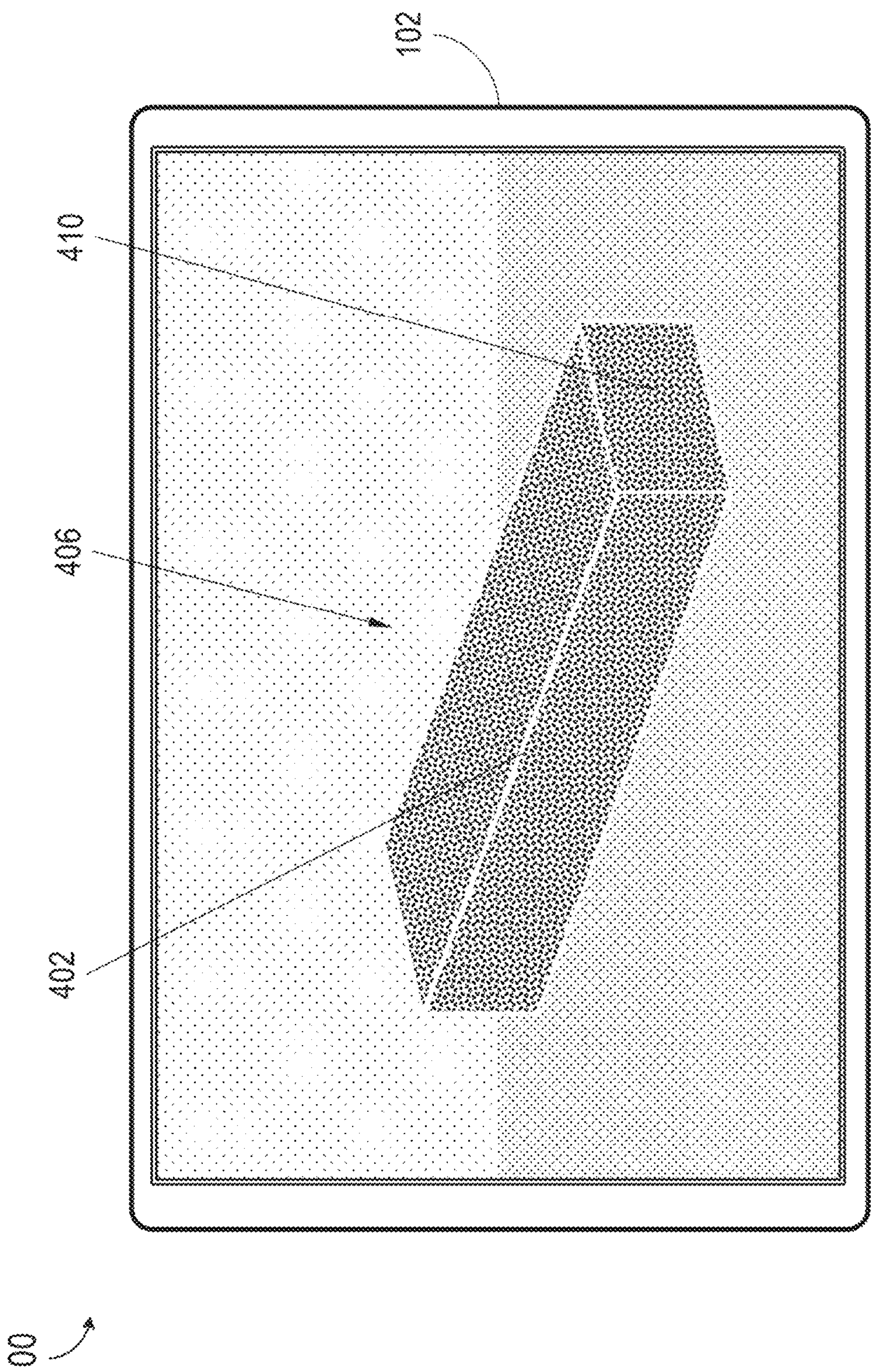


FIG. 4B

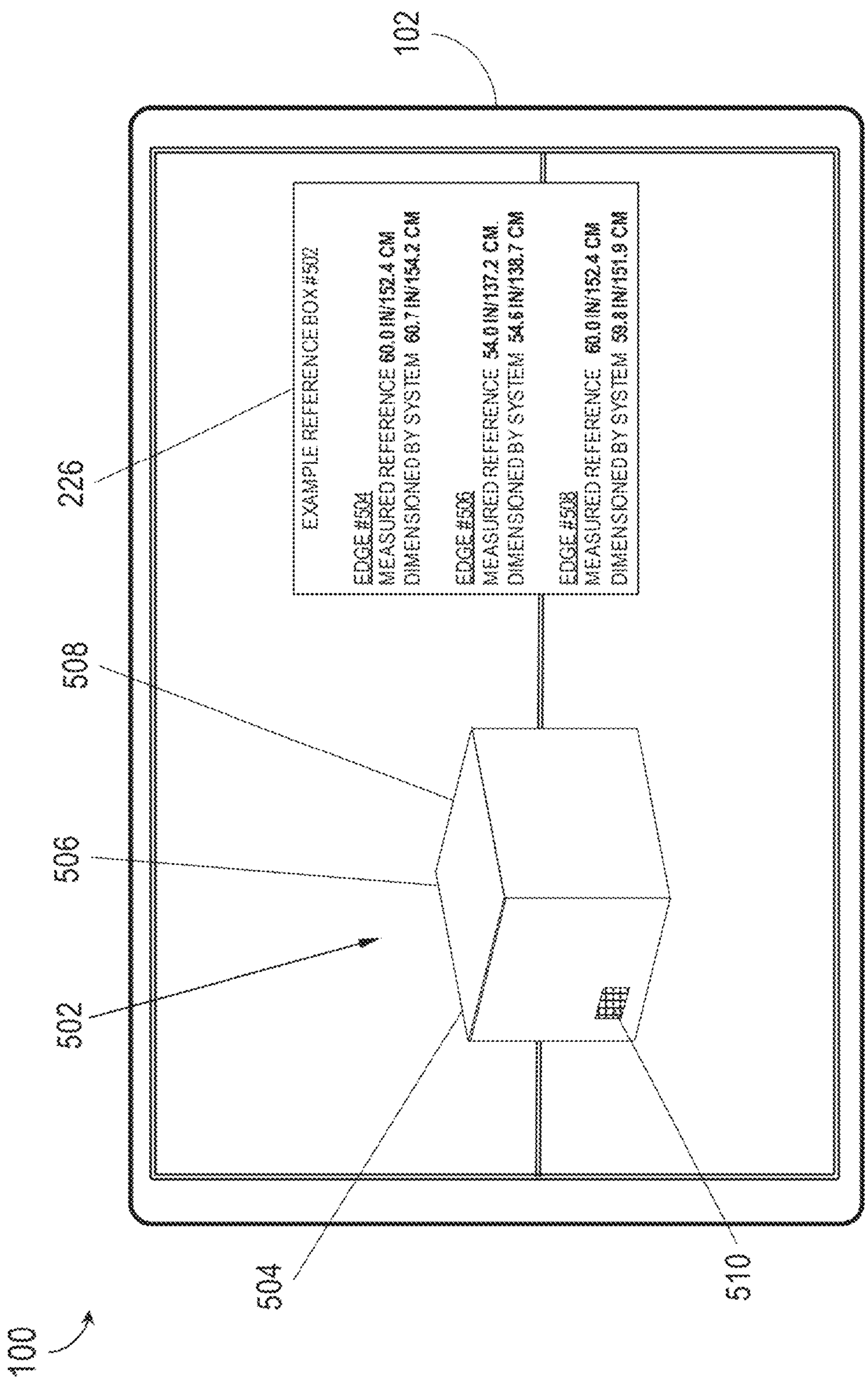
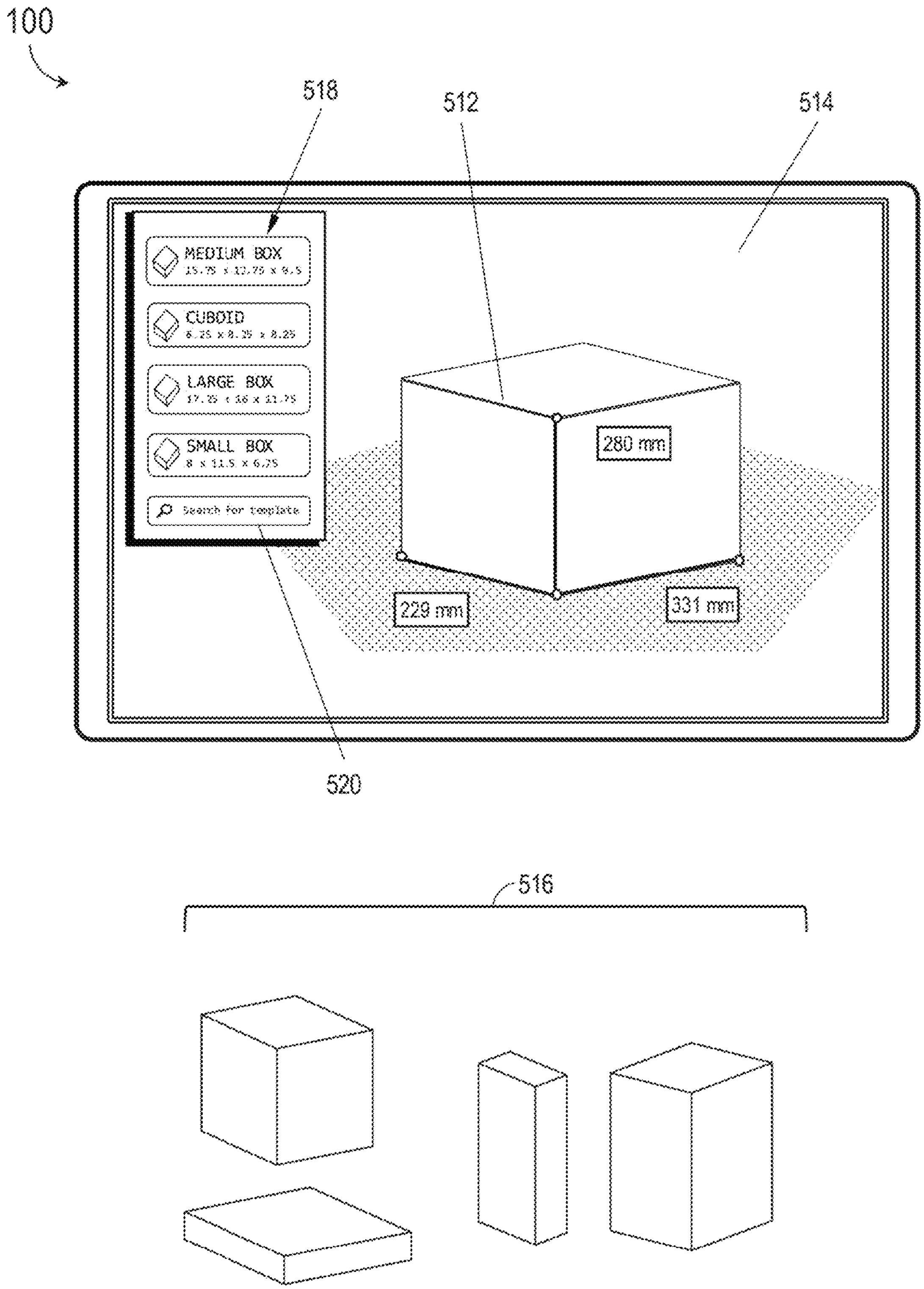

102
226
EXAMPLE REFERENCE BOX #502
EDGE #504
MEASURED REFERENCE 60.0 IN/152.4 CM
DIMENSIONED BY SYSTEM 60.7 IN/154.2 CM
EDGE #506
MEASURED REFERENCE 54.0 IN/137.2 CM
DIMENSIONED BY SYSTEM 54.6 IN/138.7 CM
EDGE #508
MEASURED REFERENCE 60.0 IN/152.4 CM
DIMENSIONED BY SYSTEM 59.8 IN/151.9 CM
508
506
502
504
510
100

FIG. 5A



100
518
512
514
MEDIUM BOX
CUBOID
LARGE BOX
17.25 x 16 x 11.75
SMALL BOX
8 x 11.5 x 6.75
Search for template
280 mm
229 mm
331 mm
520
516

FIG. 5B

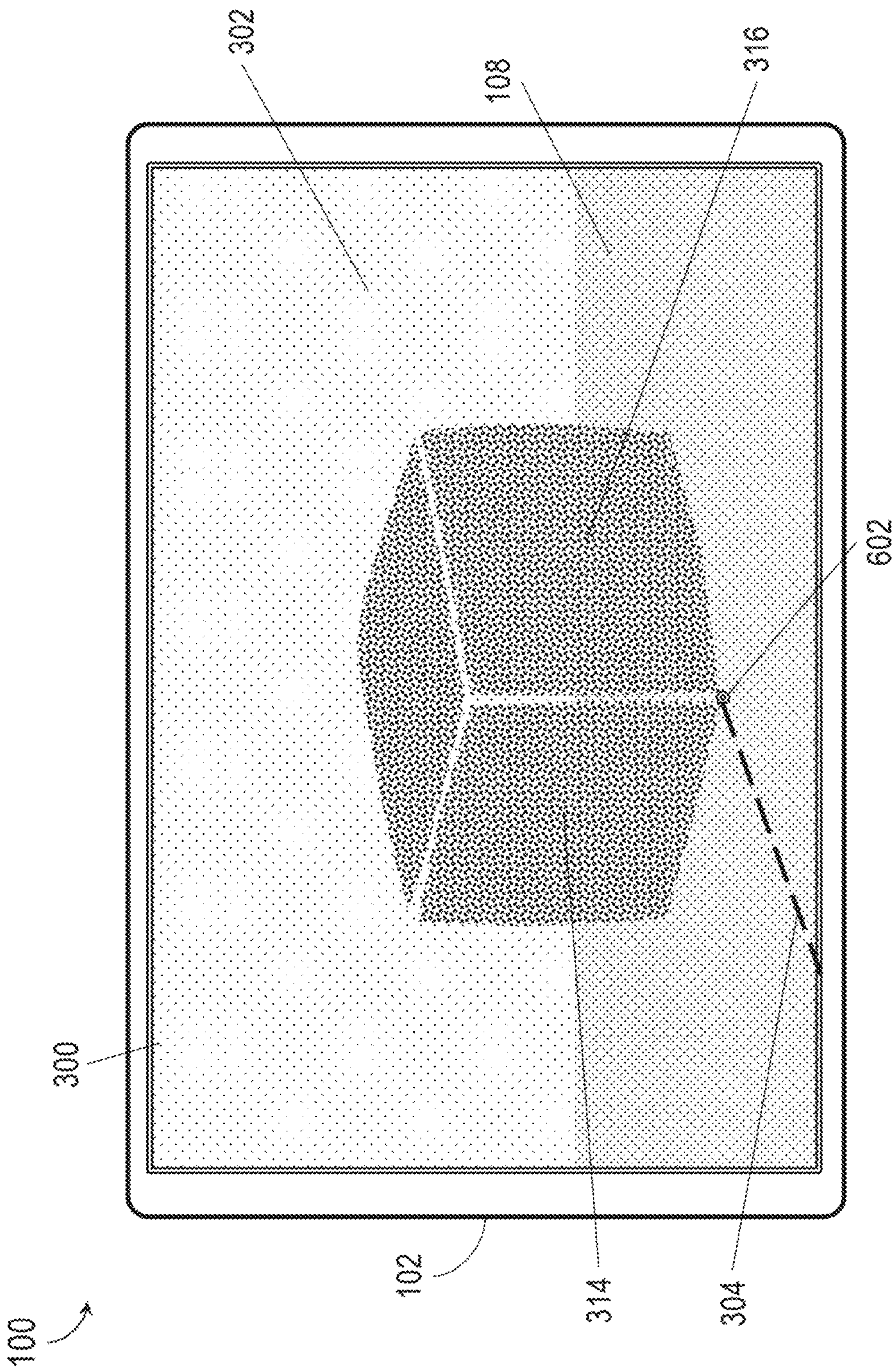


FIG. 6A

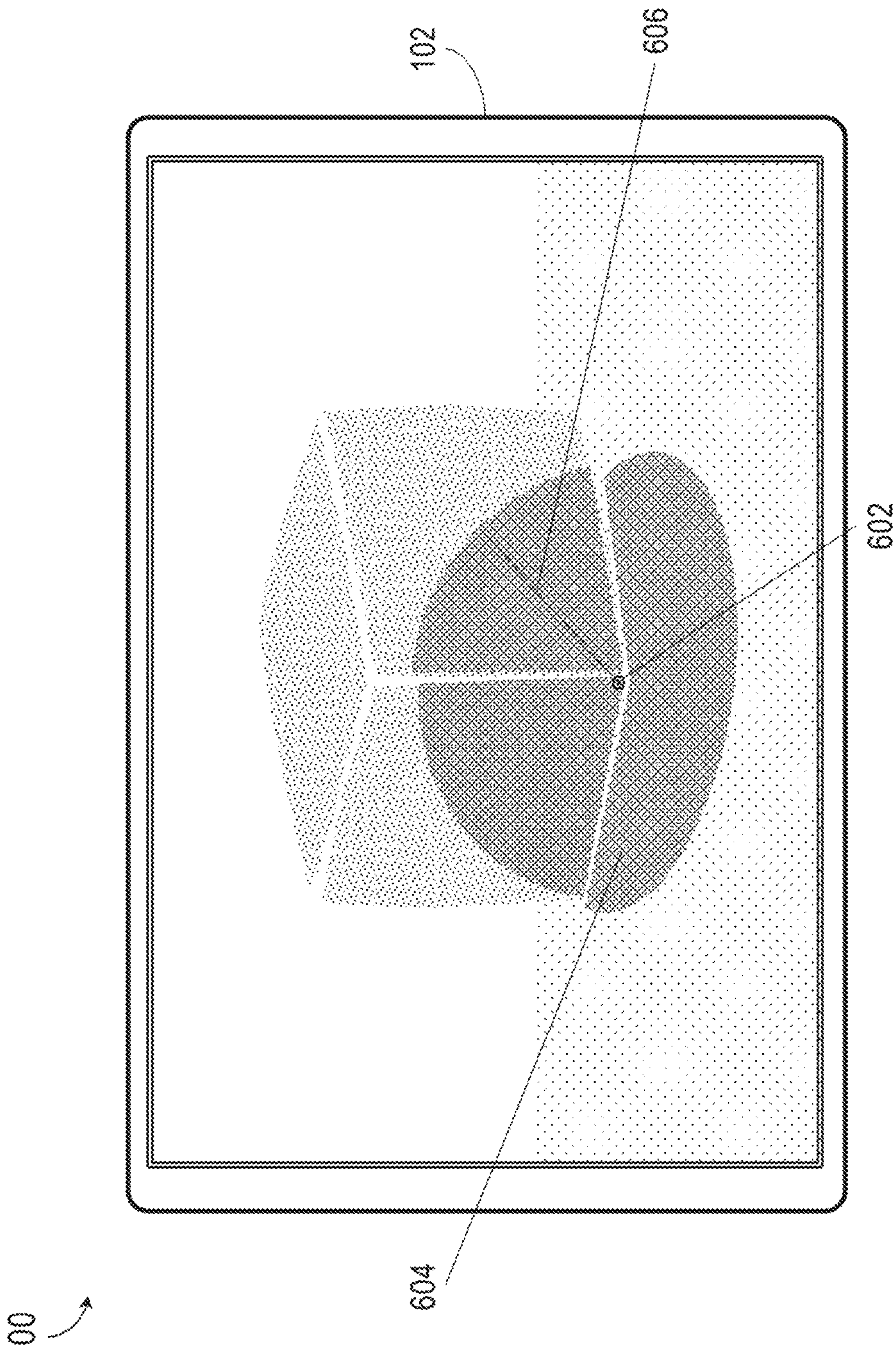


FIG. 6B

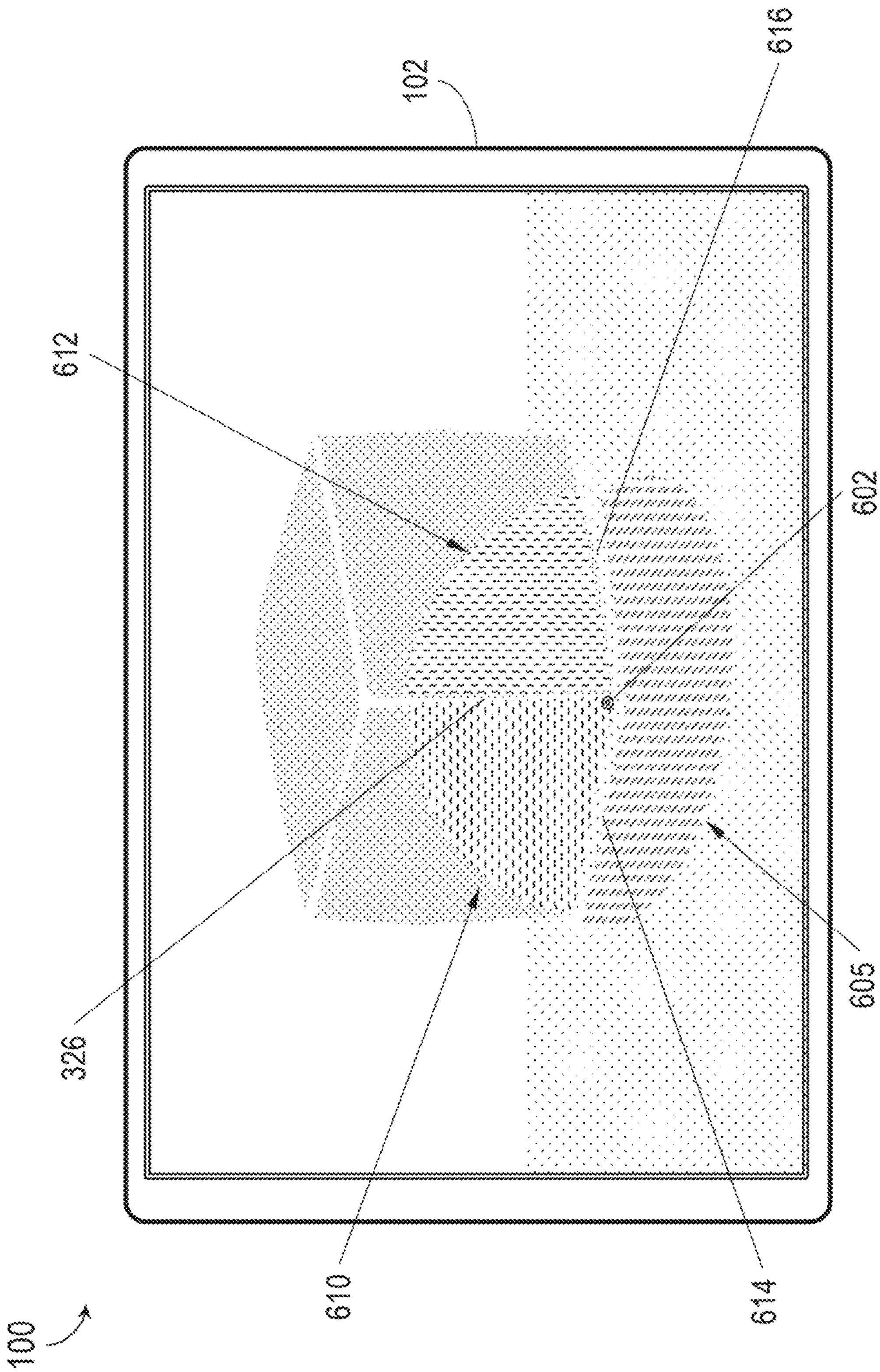


FIG. 6C

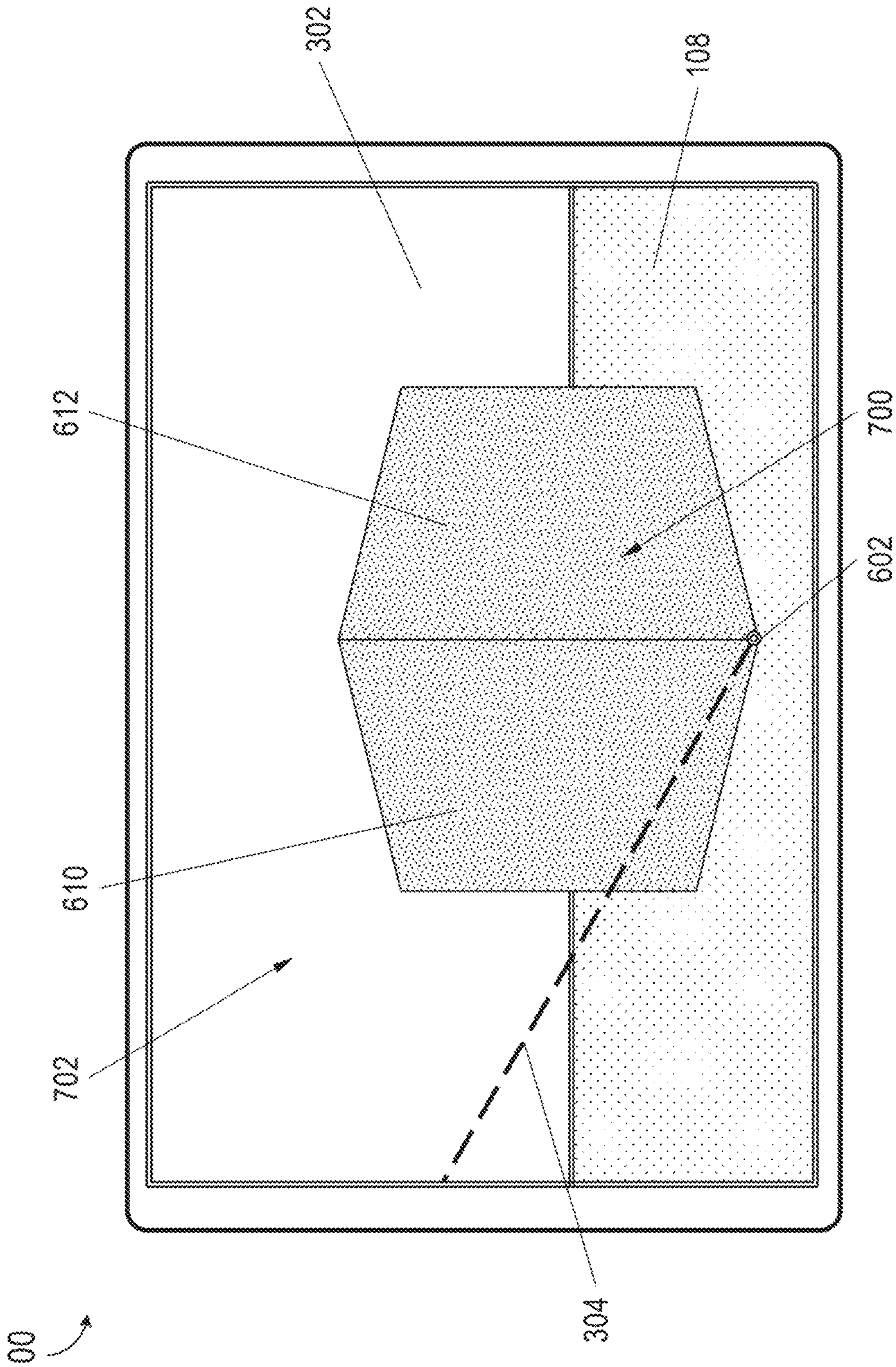


FIG. 7A

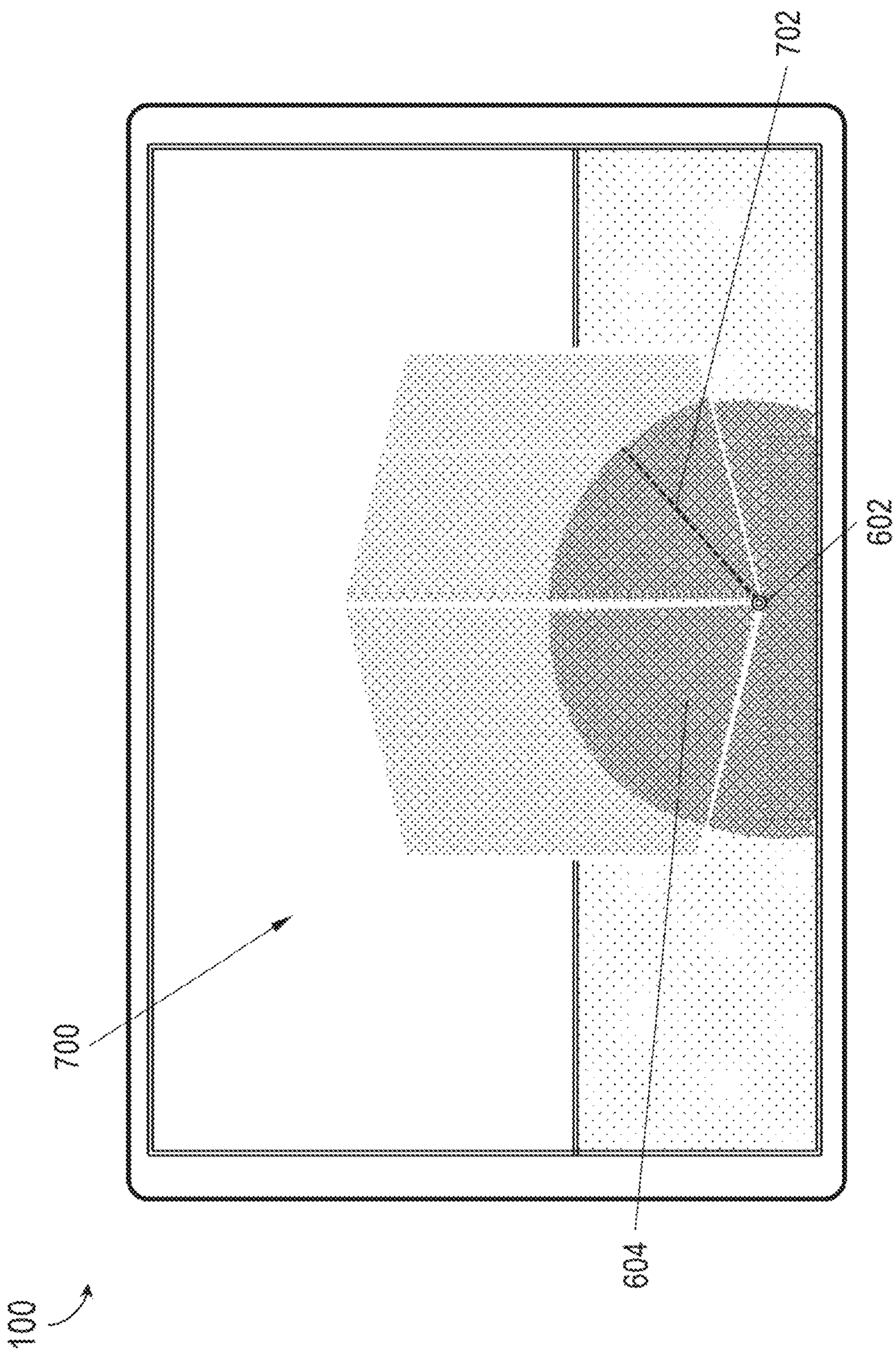


FIG. 7B

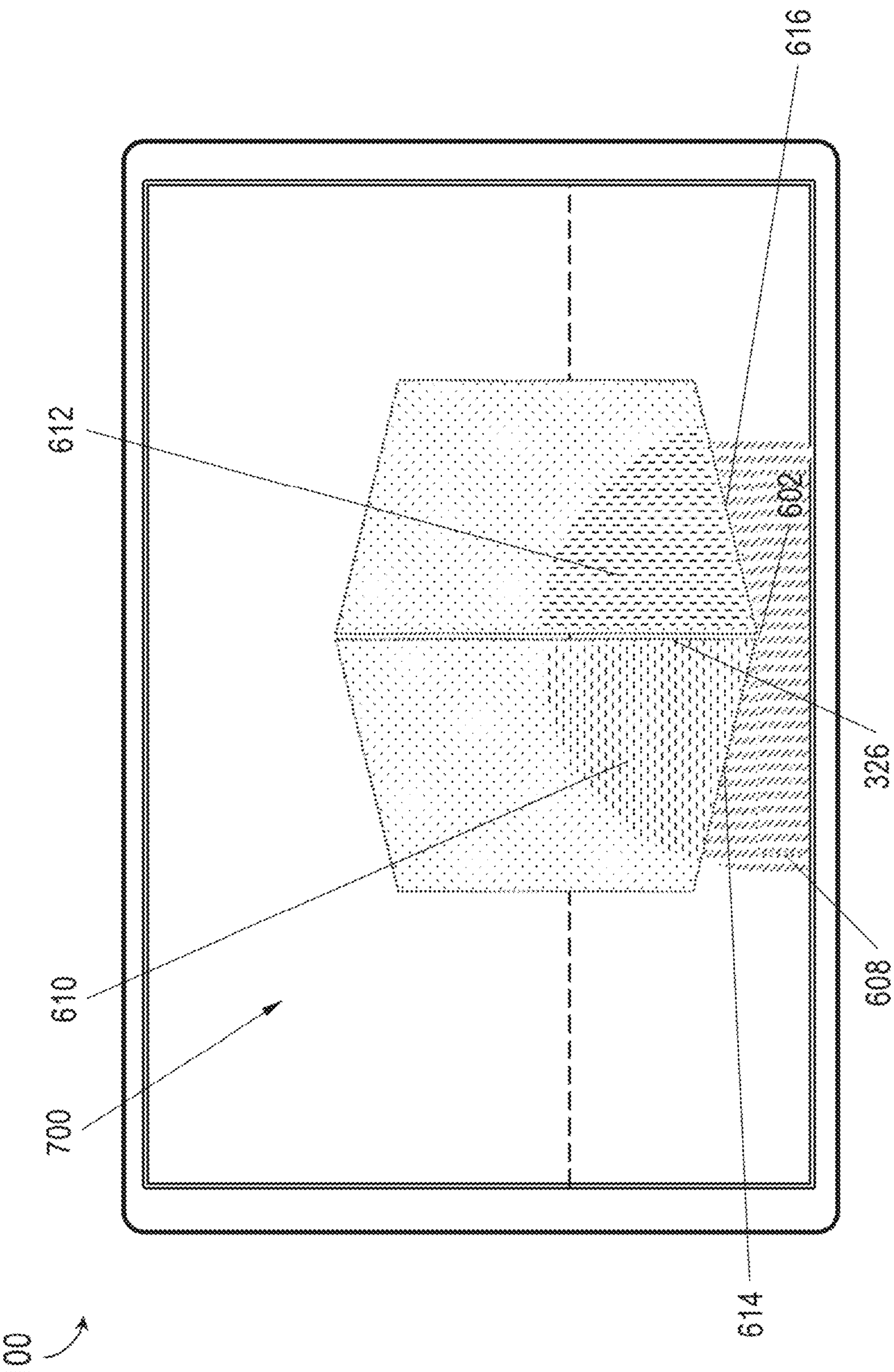


FIG. 7C

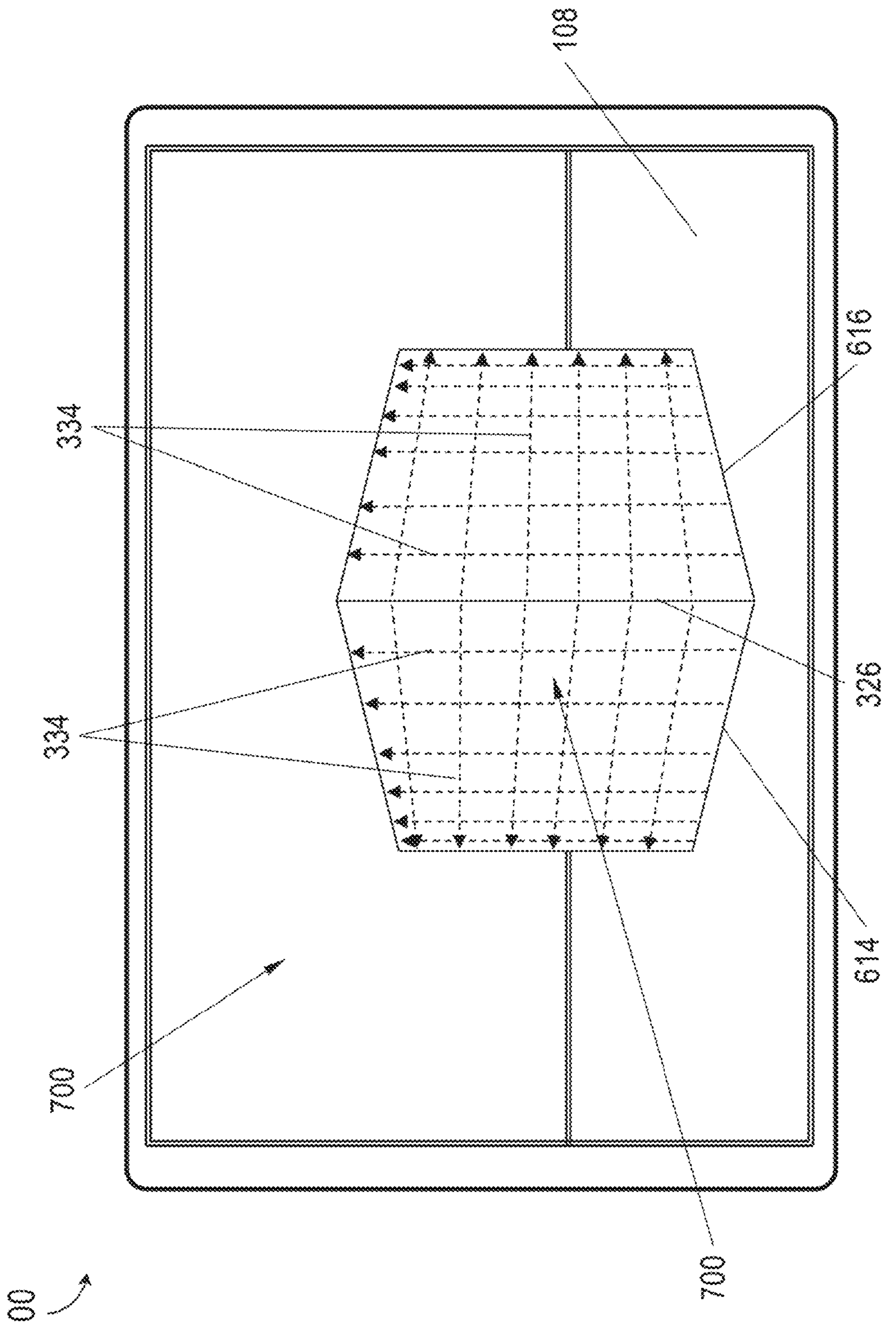


FIG. 7D

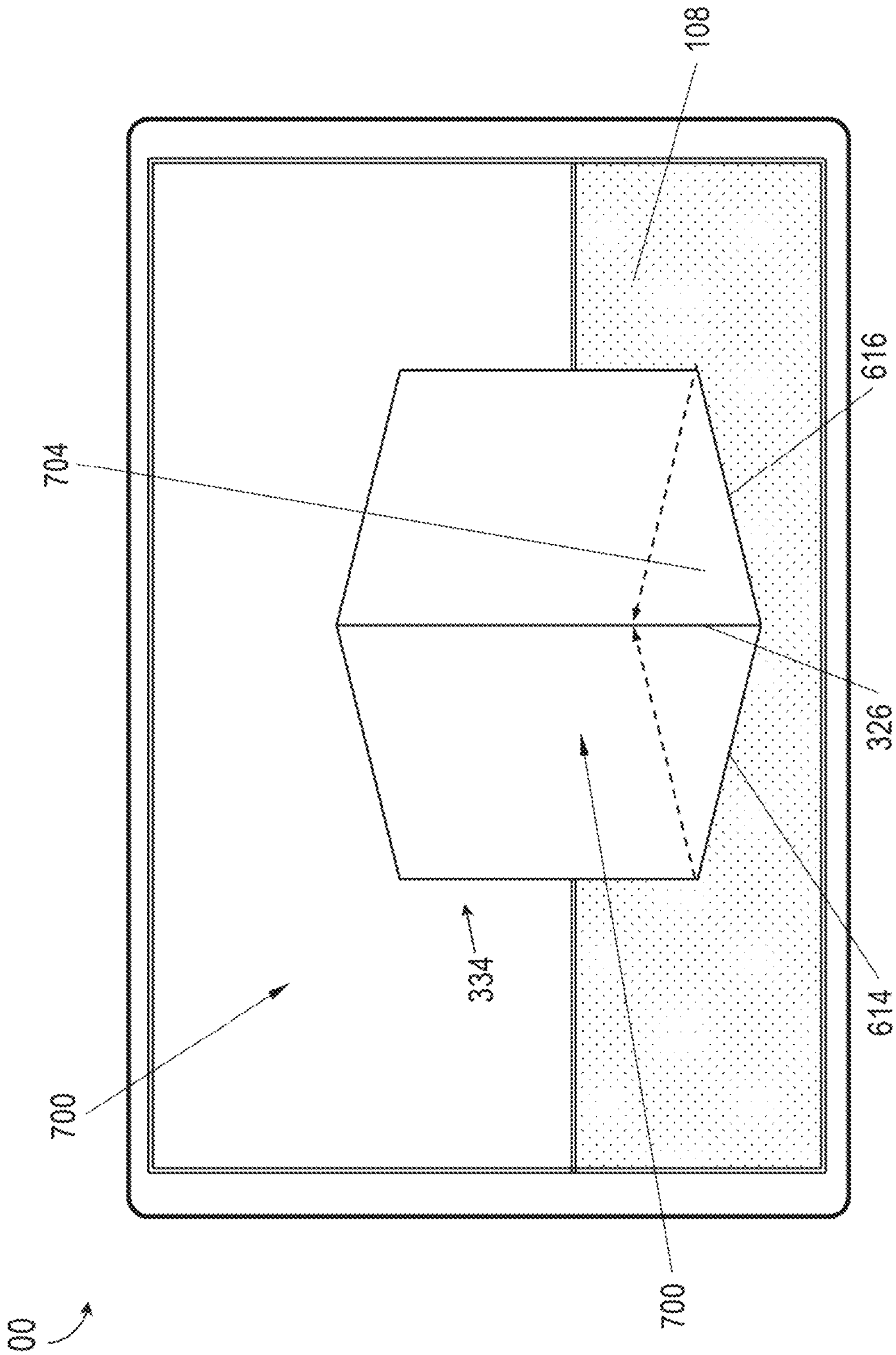


FIG. 7E

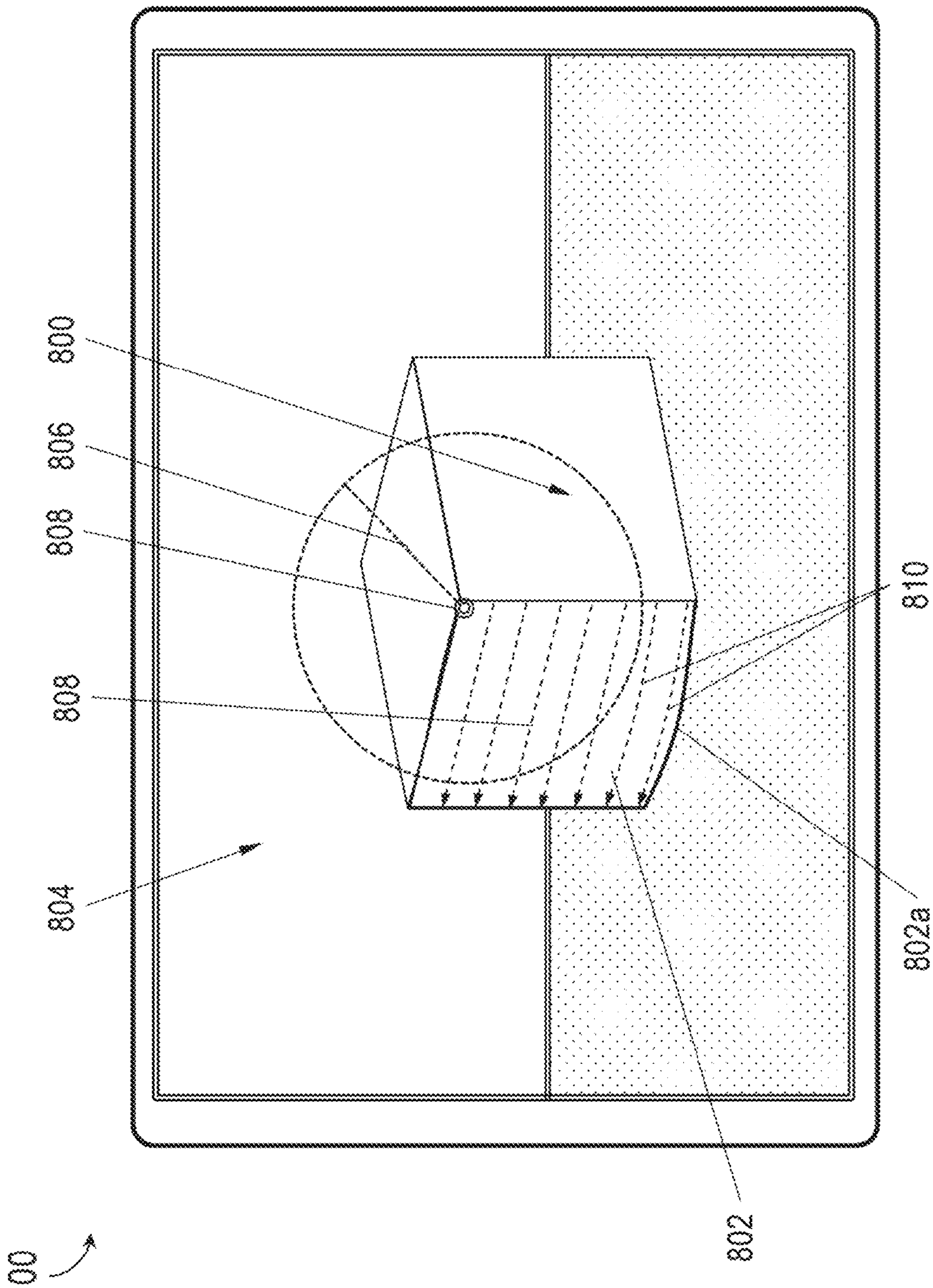


FIG. 8

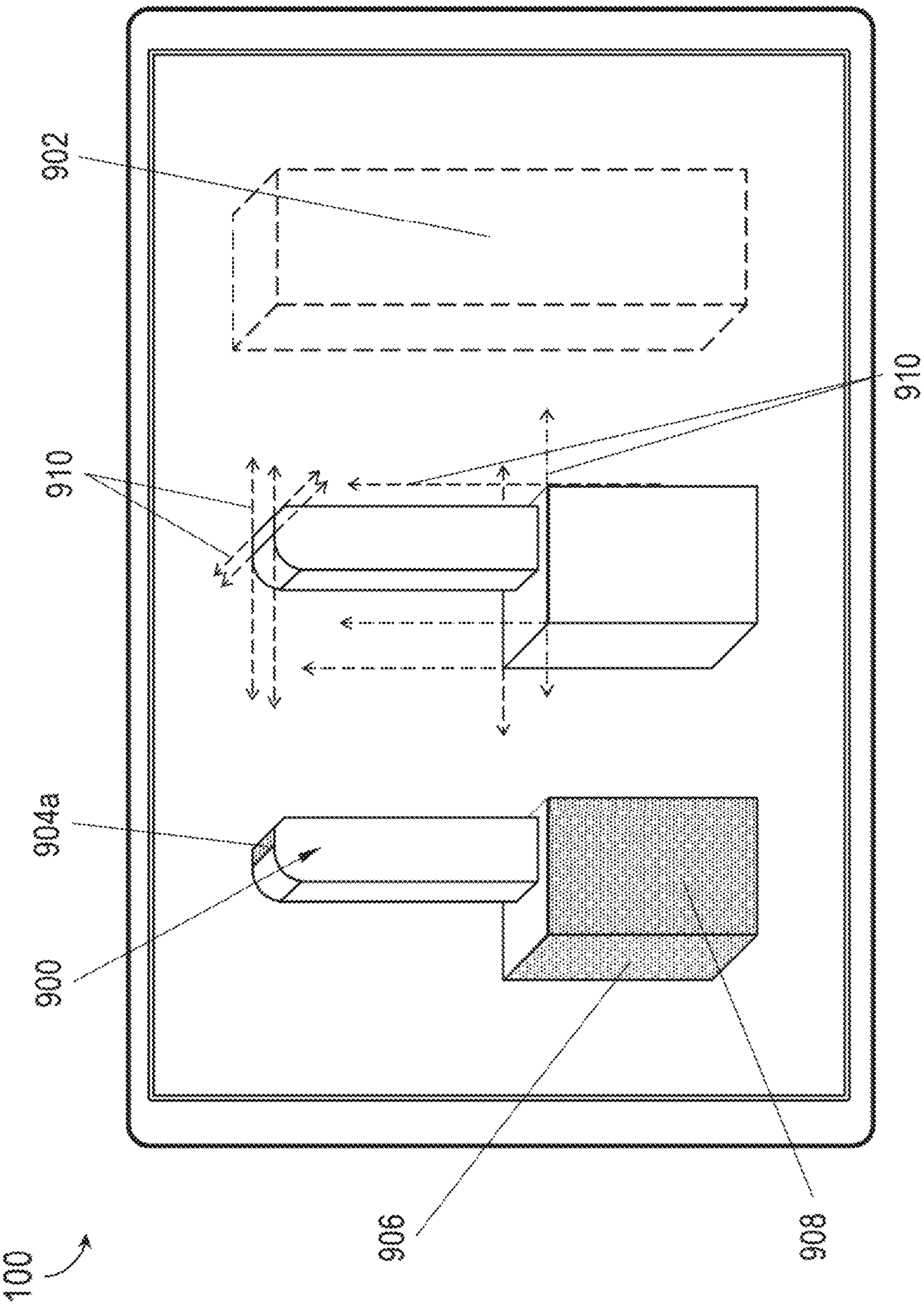


FIG. 9A

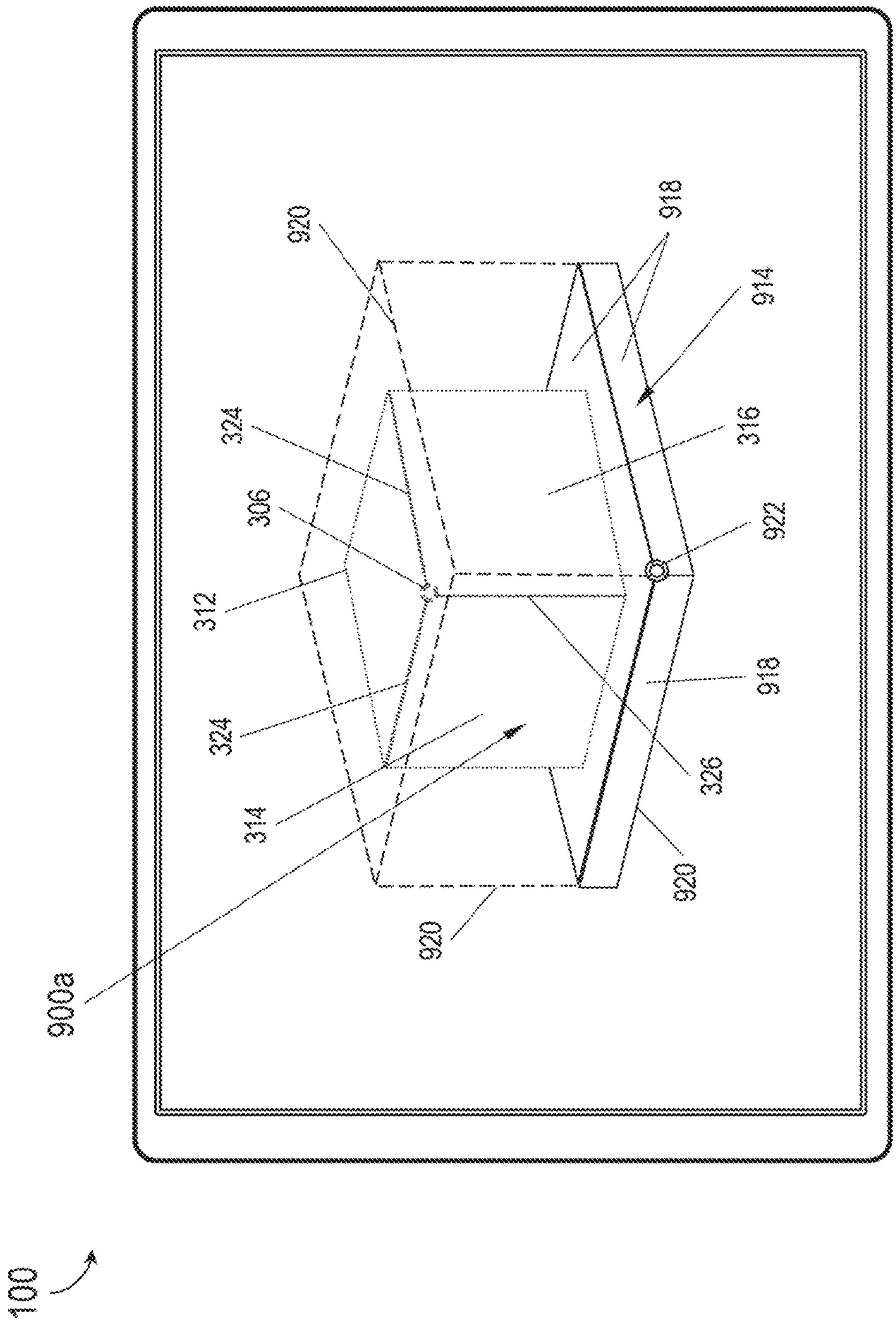


FIG. 9B

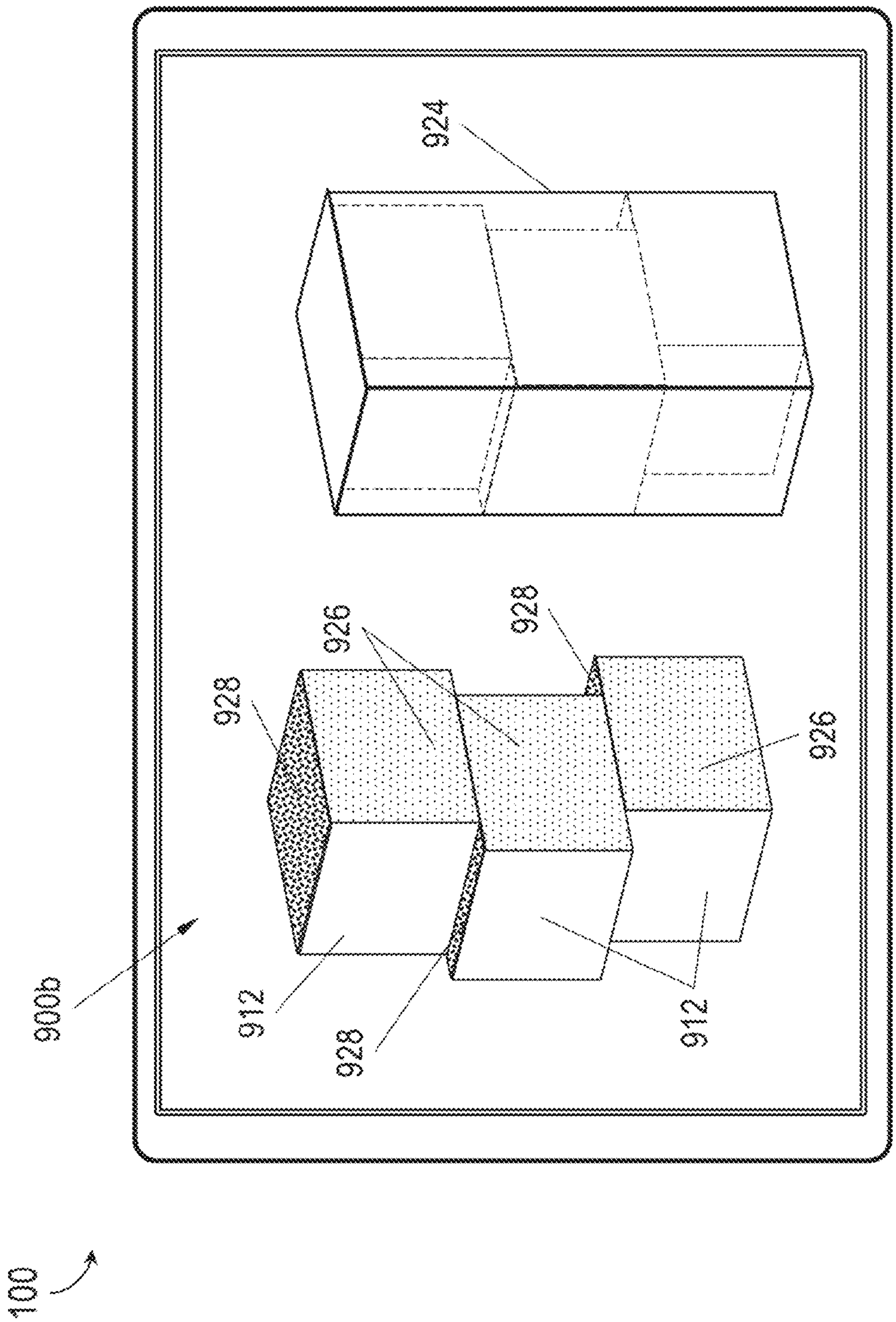


FIG. 9C

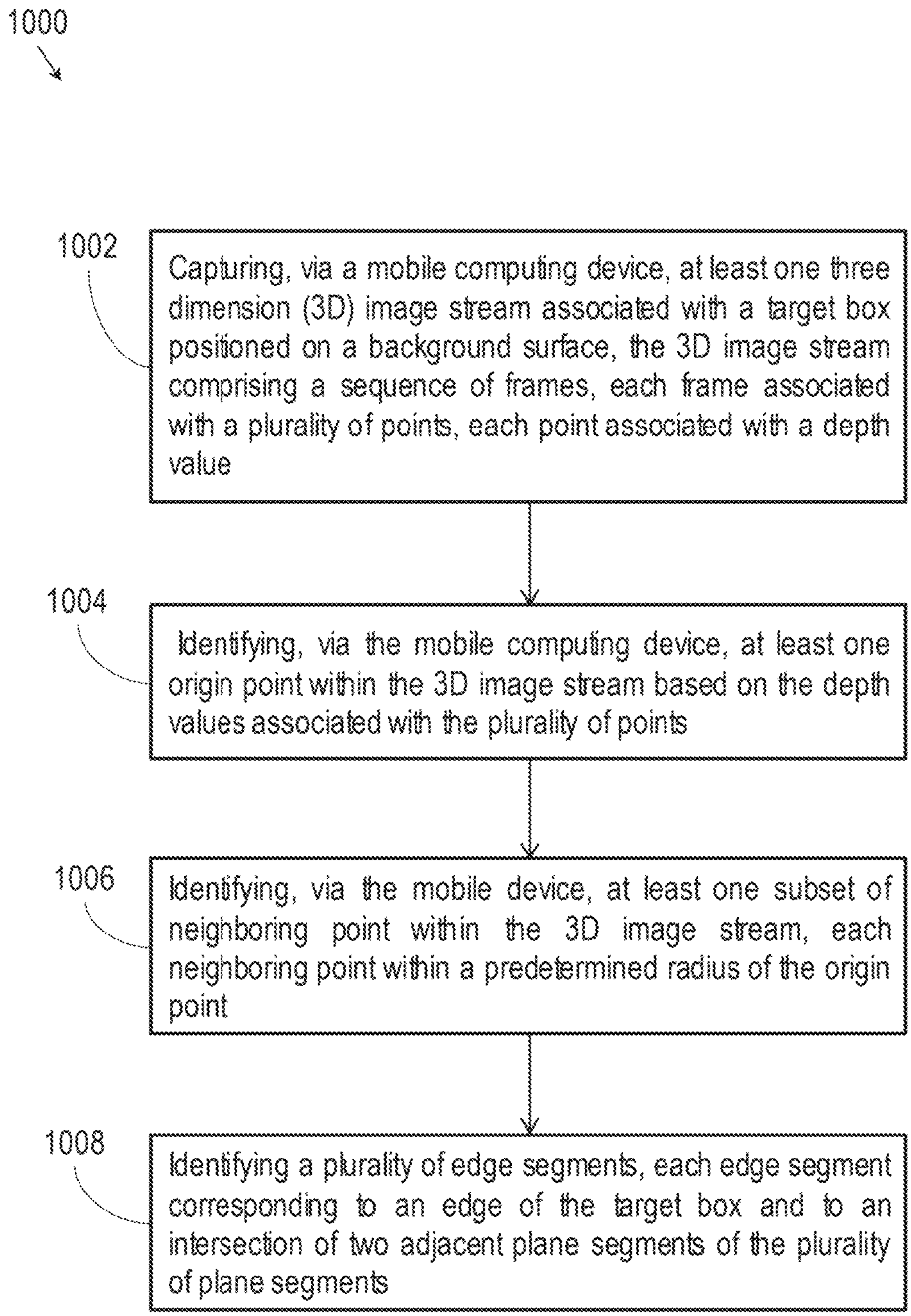

1000
1002
Capturing, via a mobile computing device, at least one three dimension (3D) image stream associated with a target box positioned on a background surface, the 3D image stream comprising a sequence of frames, each frame associated with a plurality of points, each point associated with a depth value
1004
Identifying, via the mobile computing device, at least one origin point within the 3D image stream based on the depth values associated with the plurality of points
1006
Identifying, via the mobile device, at least one subset of neighboring point within the 3D image stream, each neighboring point within a predetermined radius of the origin point
1008
Identifying a plurality of edge segments, each edge segment corresponding to an edge of the target box and to an intersection of two adjacent plane segments of the plurality of plane segments

FIG. 10A

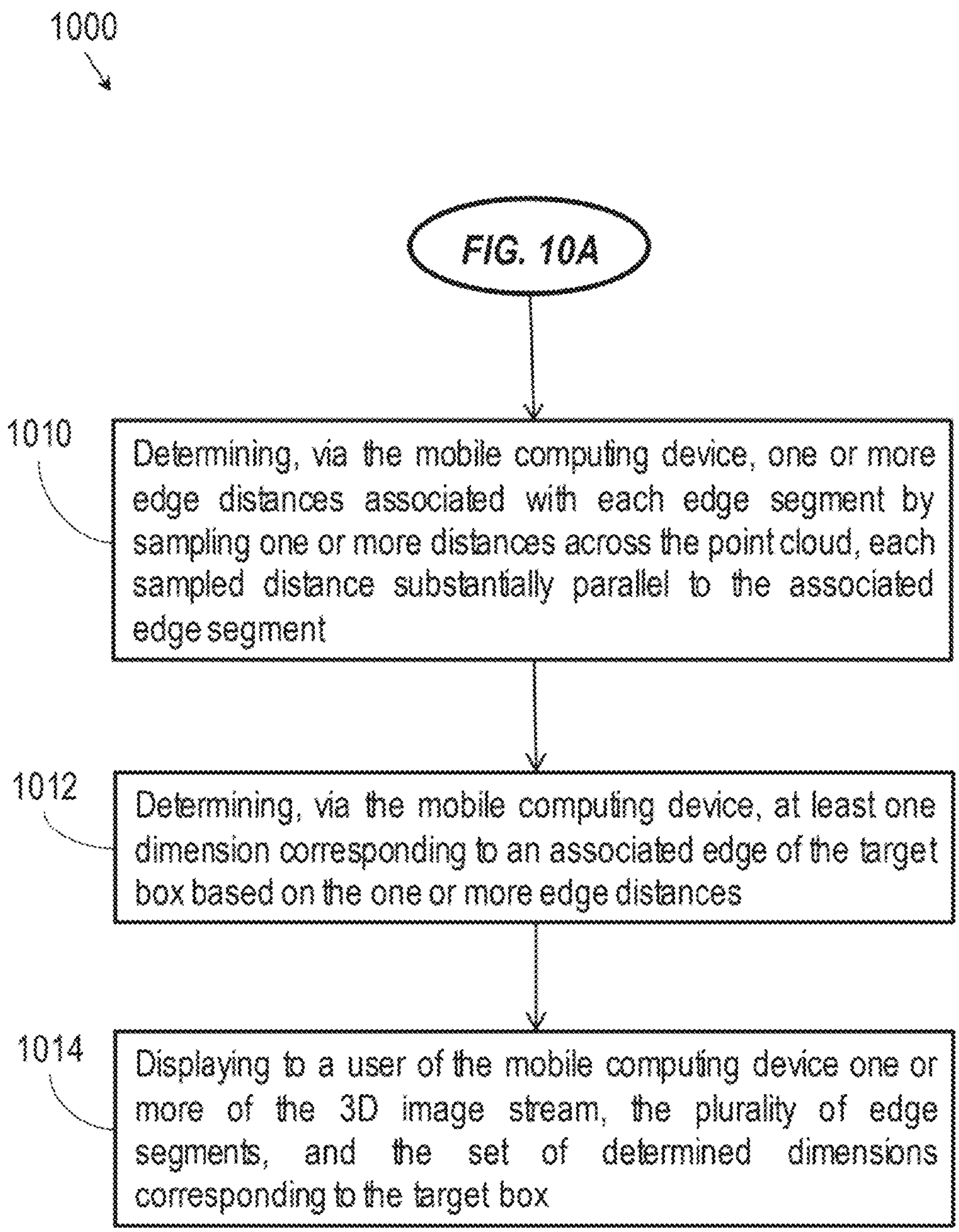
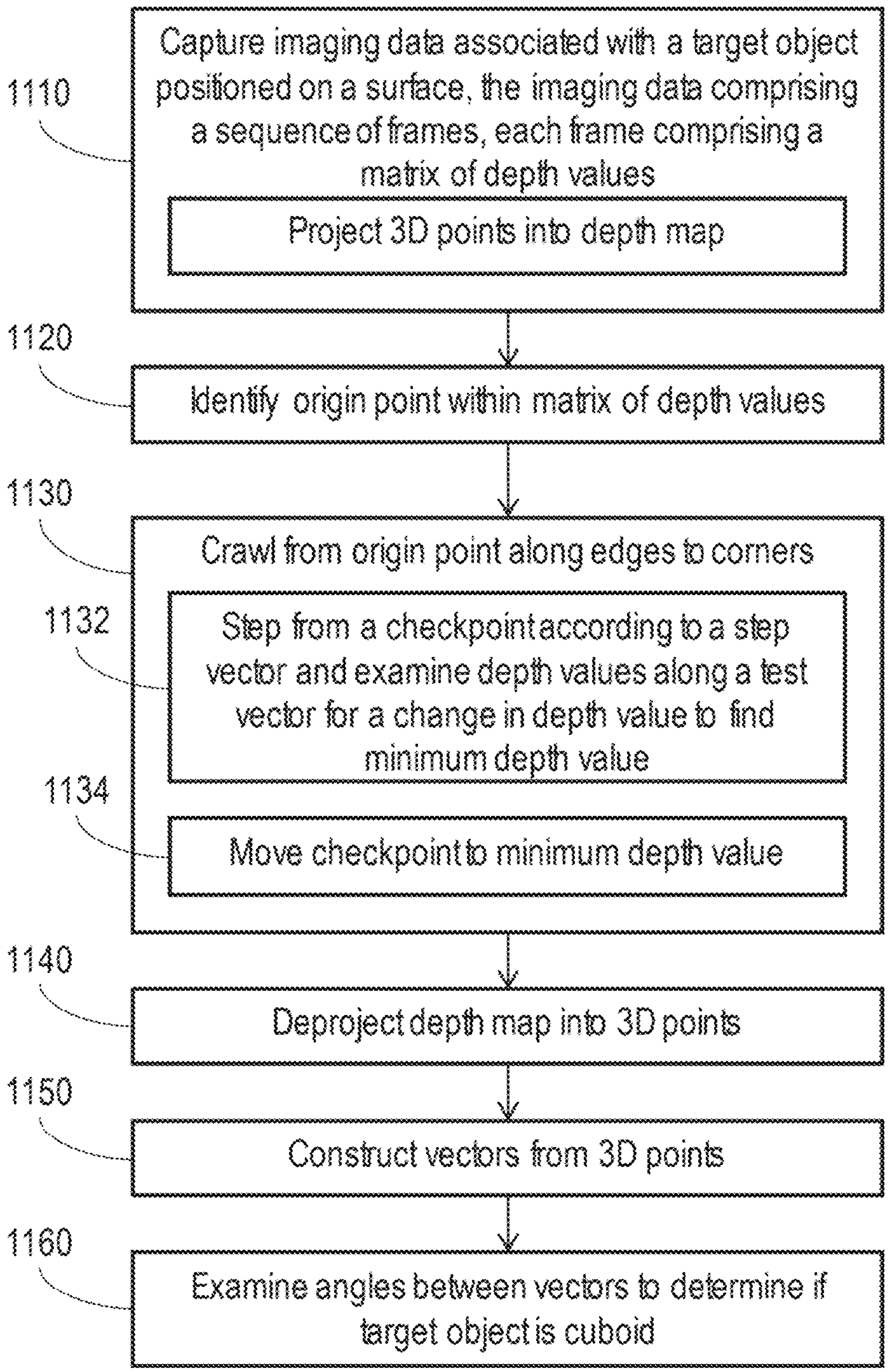

1000
FIG. 10A
1010
Determining, via the mobile computing device, one or more edge distances associated with each edge segment by sampling one or more distances across the point cloud, each sampled distance substantially parallel to the associated edge segment
1012
Determining, via the mobile computing device, at least one dimension corresponding to an associated edge of the target box based on the one or more edge distances
1014
Displaying to a user of the mobile computing device one or more of the 3D image stream, the plurality of edge segments, and the set of determined dimensions corresponding to the target box

FIG. 10B



1110
Capture imaging data associated with a target object positioned on a surface, the imaging data comprising a sequence of frames, each frame comprising a matrix of depth values
Project 3D points into depth map
1120
Identify origin point within matrix of depth values
1130
Crawl from origin point along edges to corners
1132
Step from a checkpoint according to a step vector and examine depth values along a test vector for a change in depth value to find minimum depth value
1134
Move checkpoint to minimum depth value
1140
Deproject depth map into 3D points
1150
Construct vectors from 3D points
1160
Examine angles between vectors to determine if target object is cuboid

FIG. 11

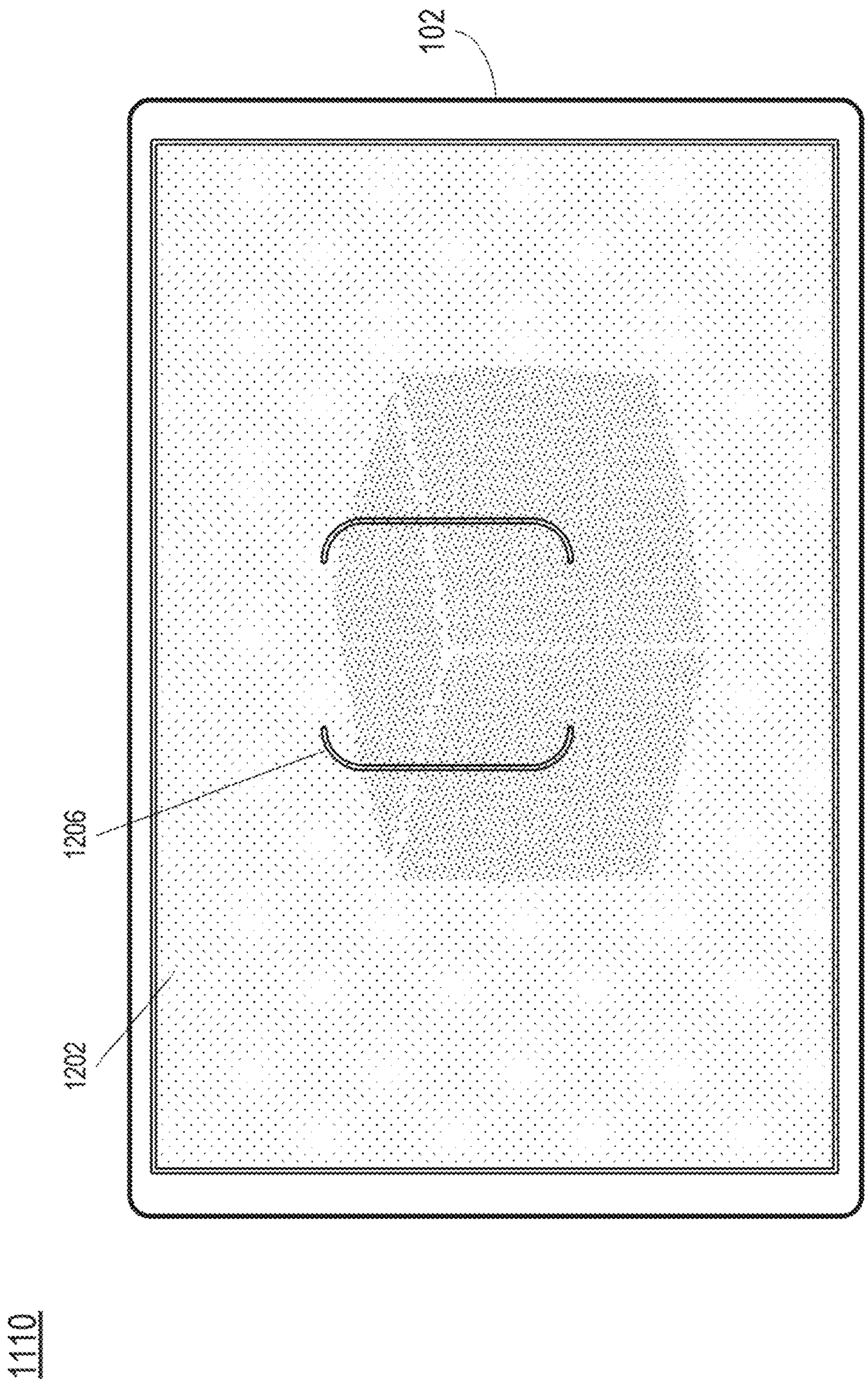


FIG. 12A

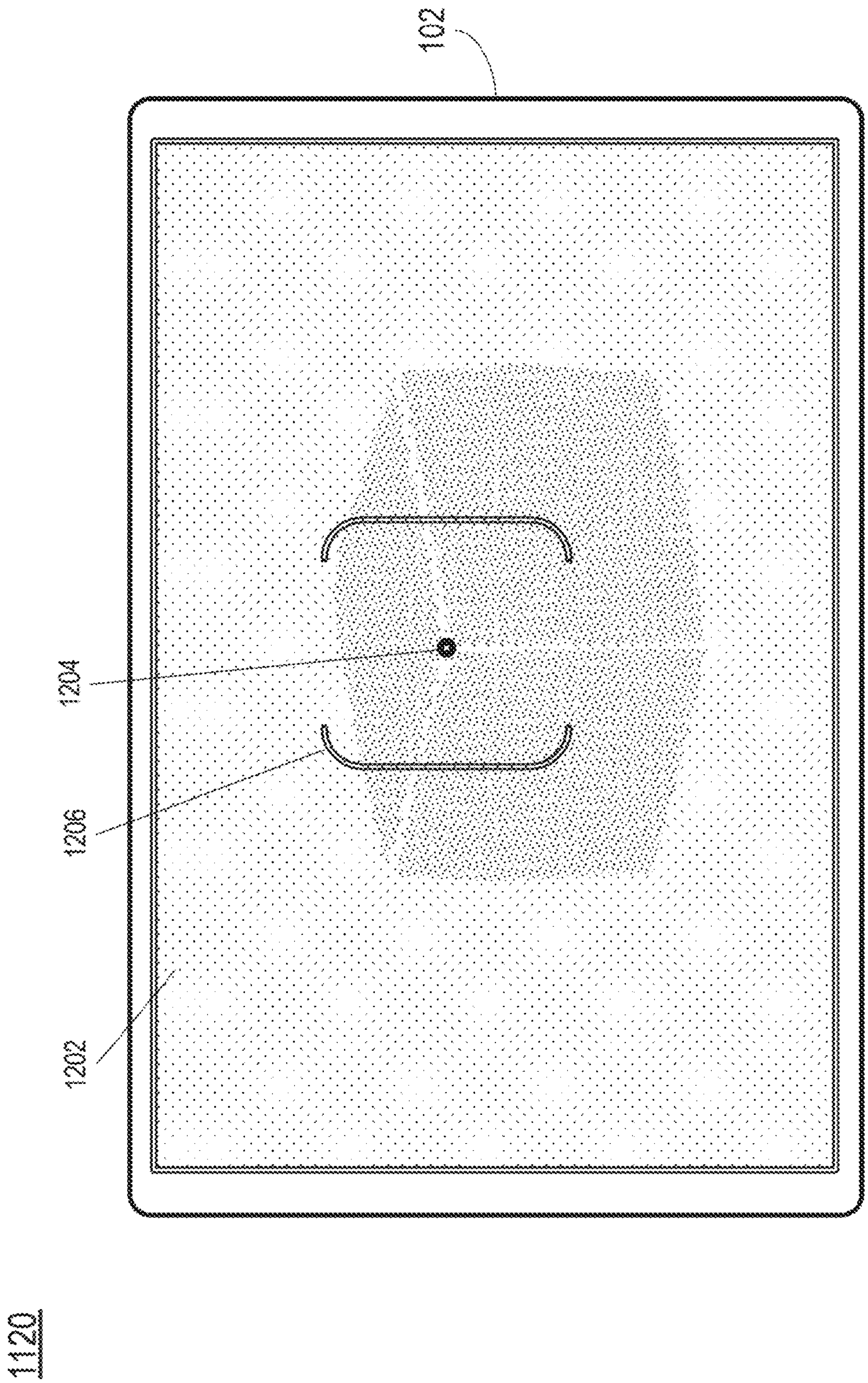


FIG. 12B

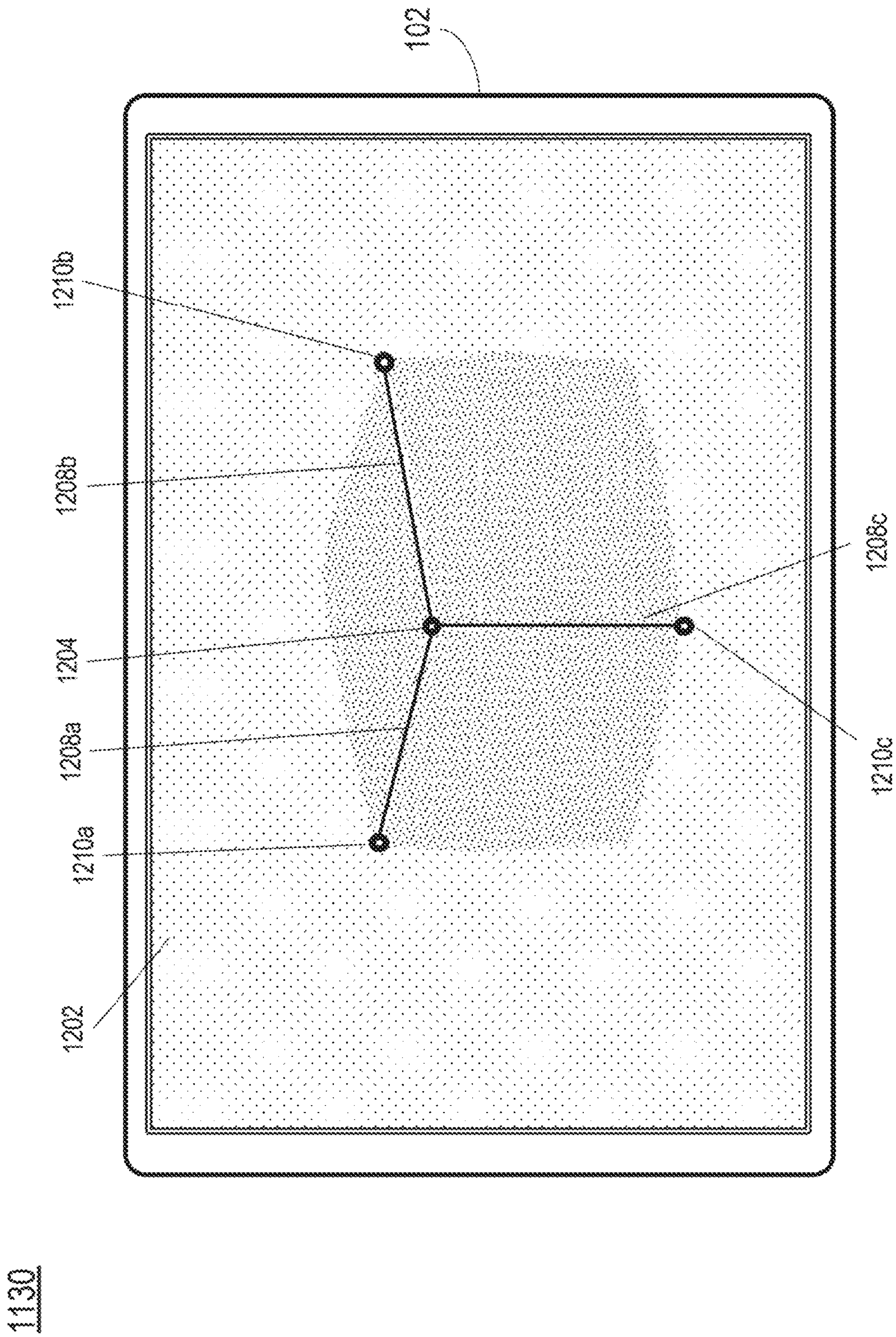


FIG. 12C

1130

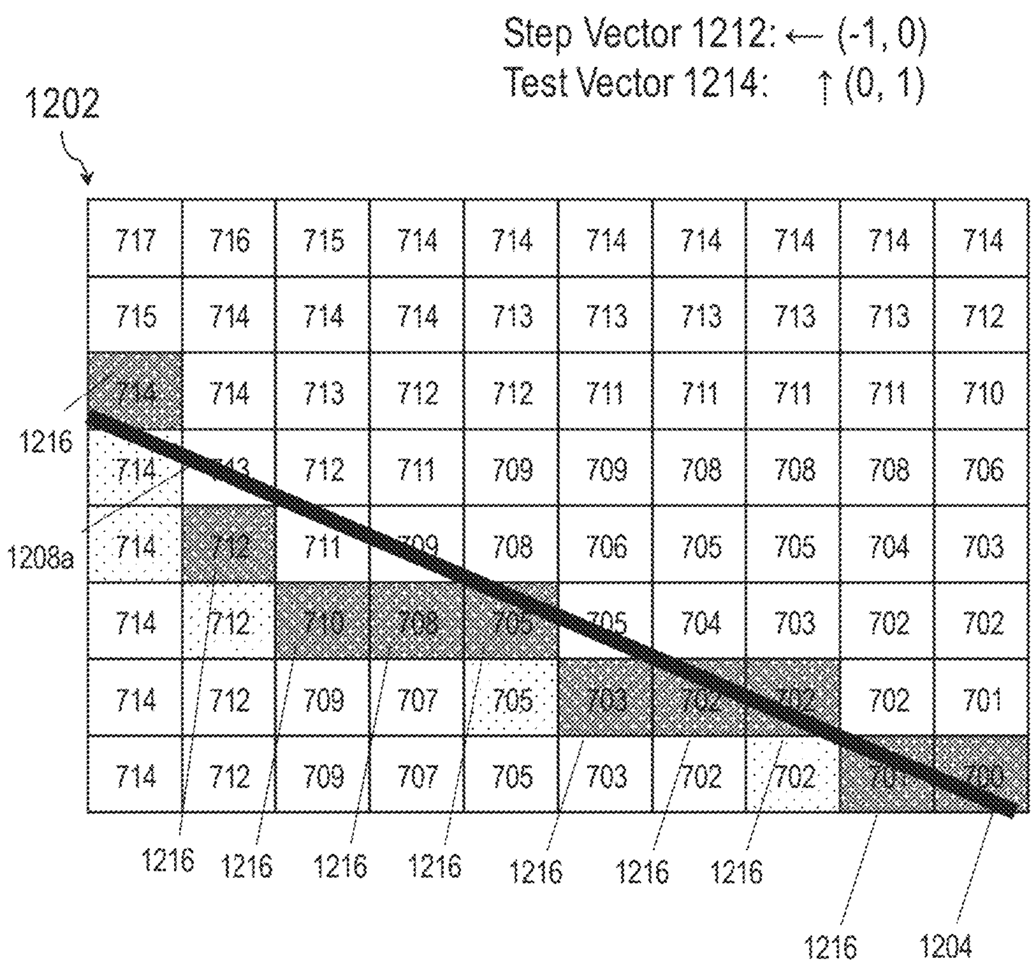

Step Vector 1212: ← (-1, 0)
Test Vector 1214: ↑ (0, 1)
1202
717 716 715 714 714 714 714 714 714 714
715 714 714 714 713 713 713 713 713 712
714 714 713 712 712 711 711 711 711 710
714 713 712 711 709 709 708 708 708 706
714 712 711 709 708 706 705 705 704 703
714 712 710 708 705 705 704 703 702 702
714 712 709 707 705 703 702 702 702 701
714 712 709 707 705 703 702 702 701 700
1216
1208a
1216
1216
1216
1216
1216
1216
1216
1216
1204

FIG. 12D

1130

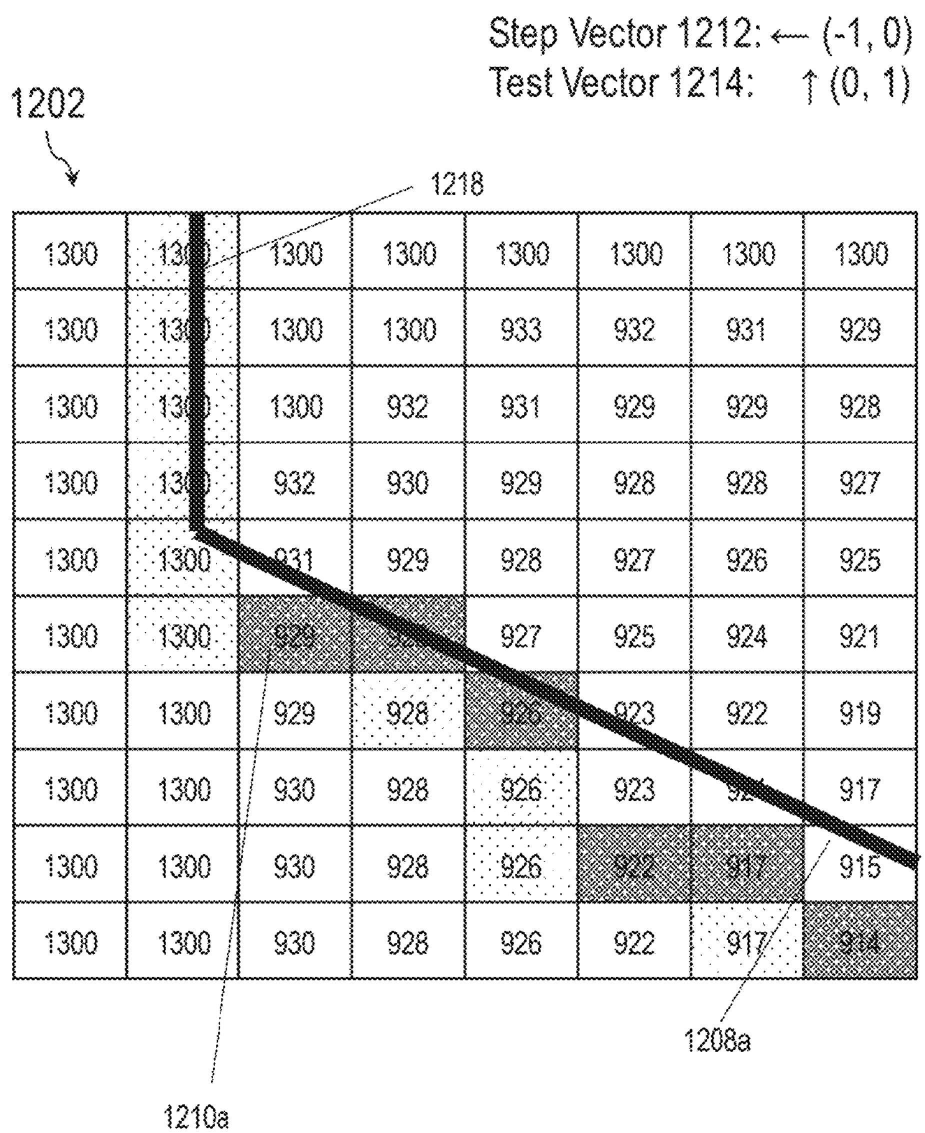

Step Vector 1212: ← (-1, 0)
Test Vector 1214: ↑ (0, 1)
1202
1218
1208a
1210a

FIG. 12E

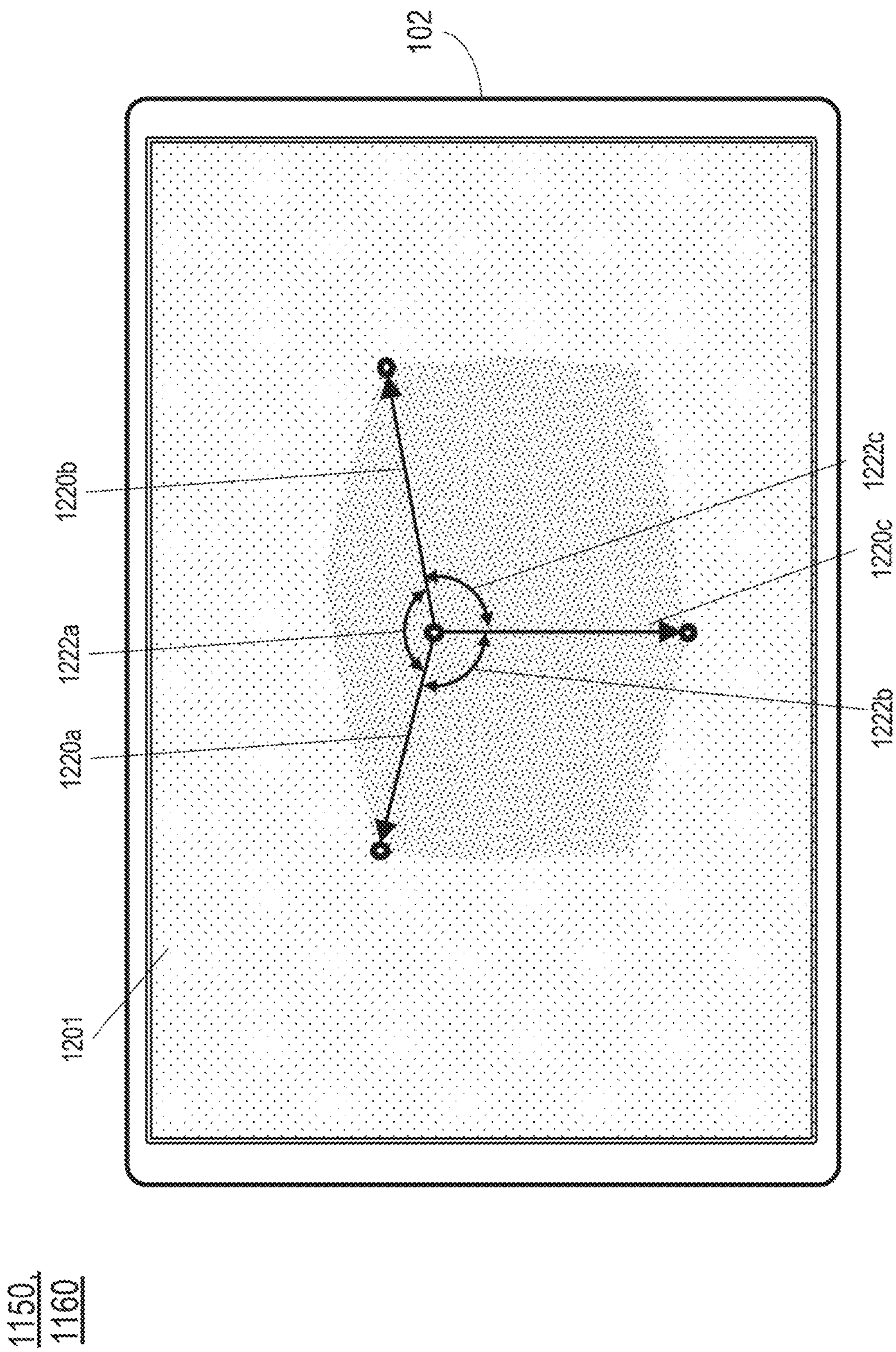


FIG. 12F

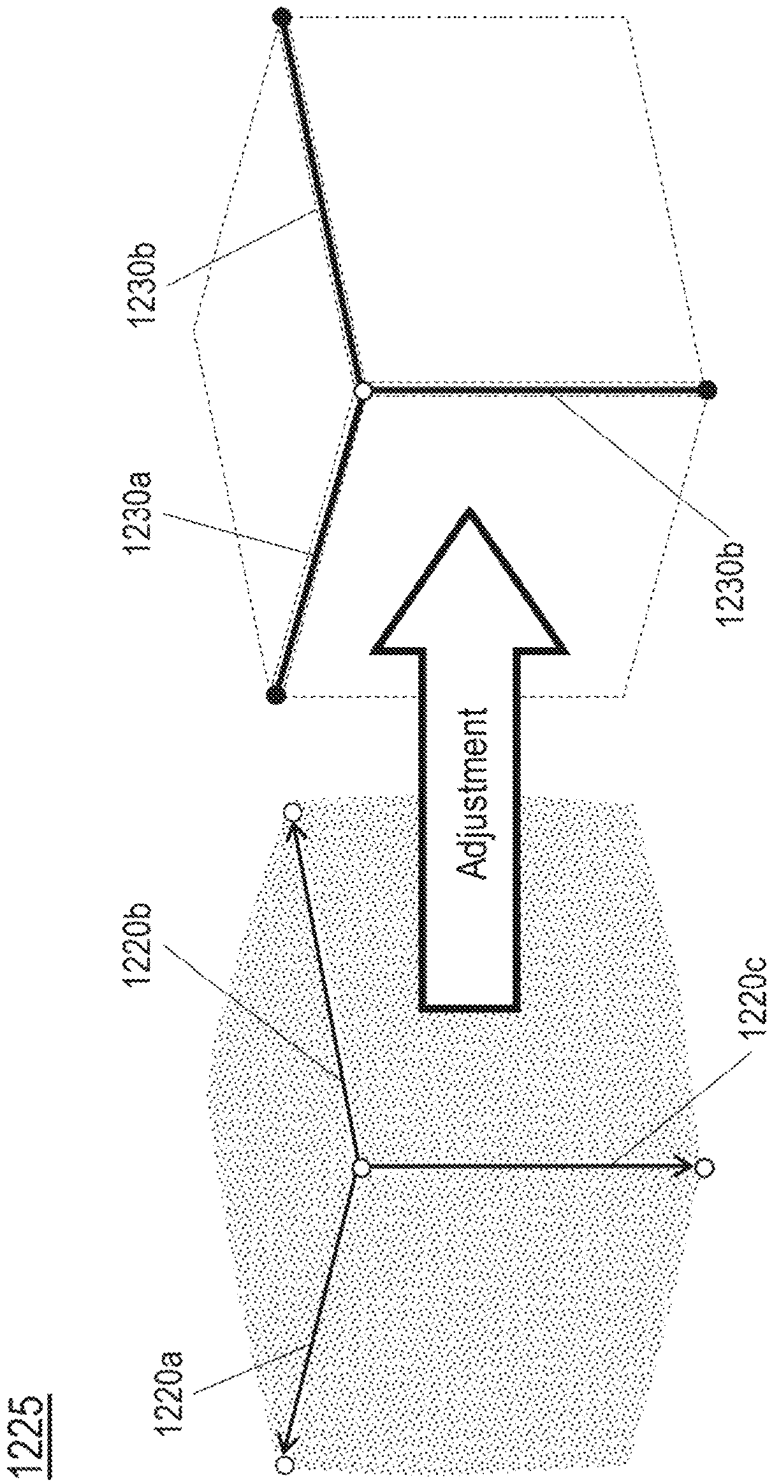


FIG. 12G

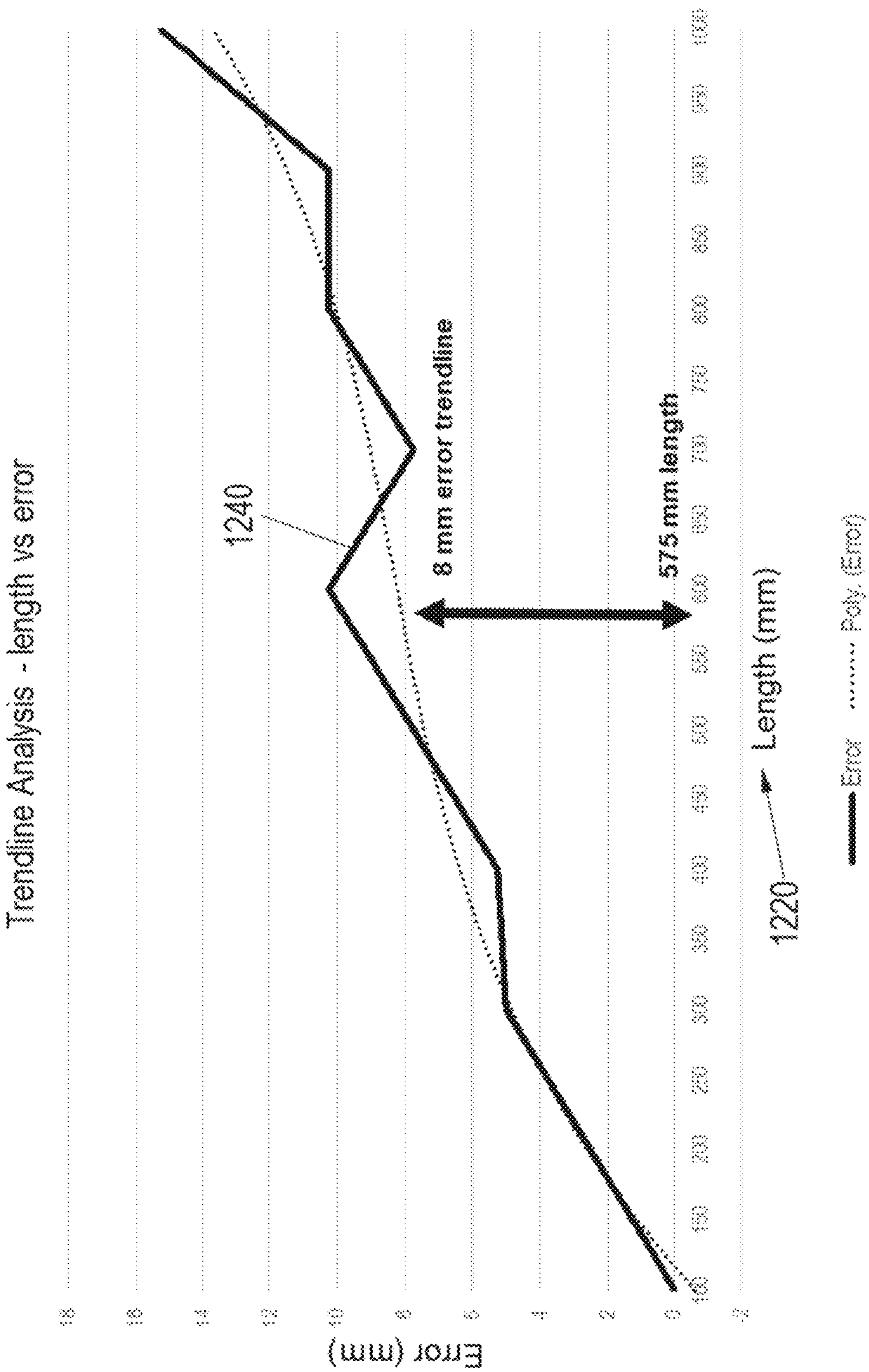

Trendline Analysis - length vs error
1240
8 mm error trendline
575 mm length
Error (mm)
Length (mm)
1220
Error
Poly. (Error)

FIG. 12H

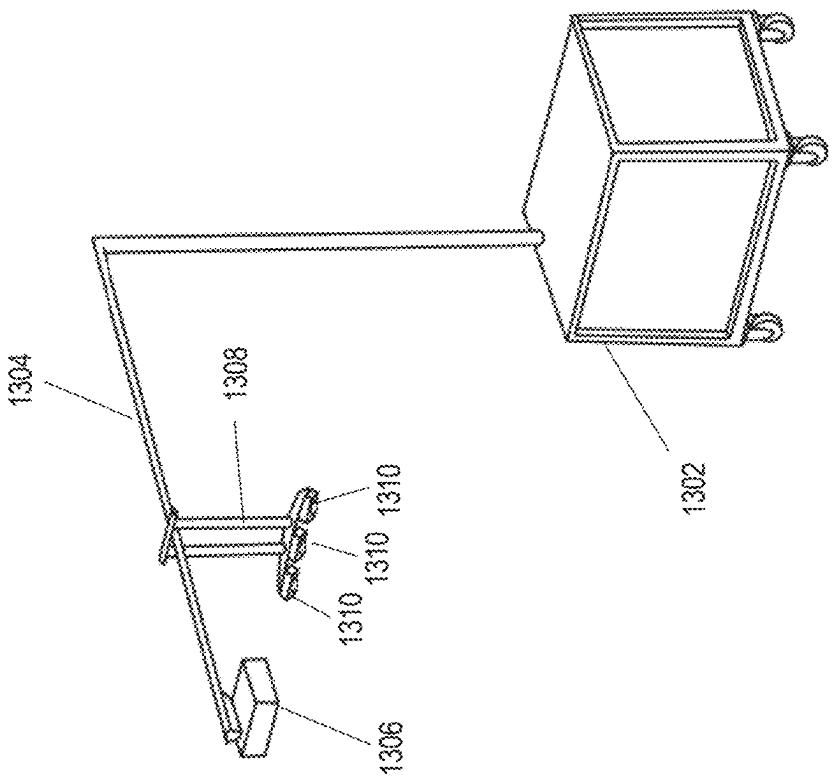


FIG. 13A

1300

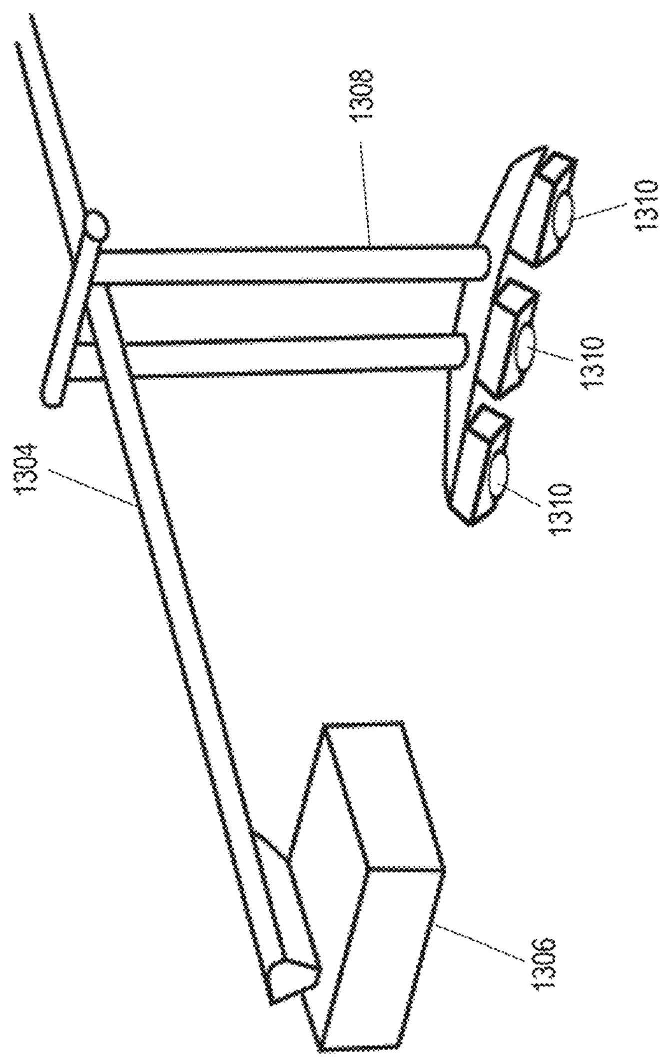


FIG. 13B

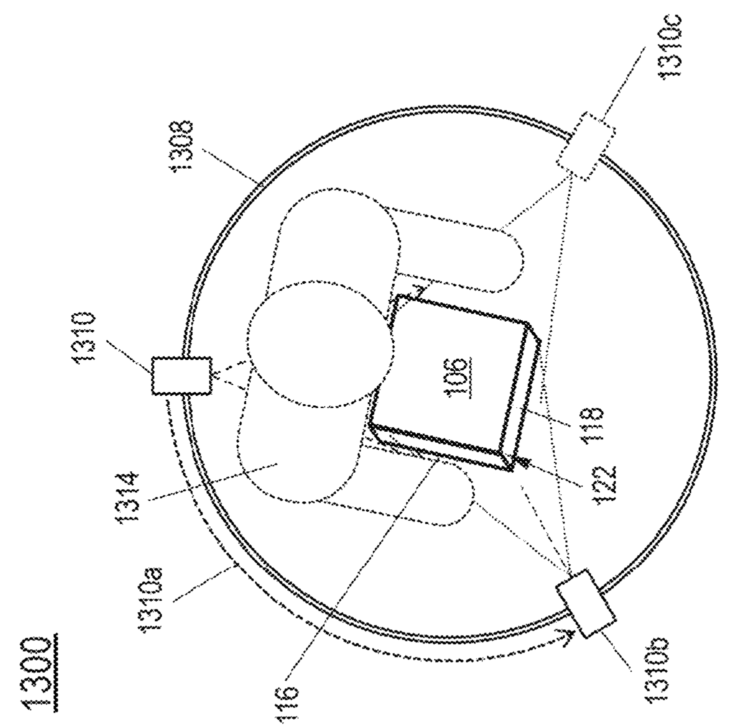


FIG. 13D

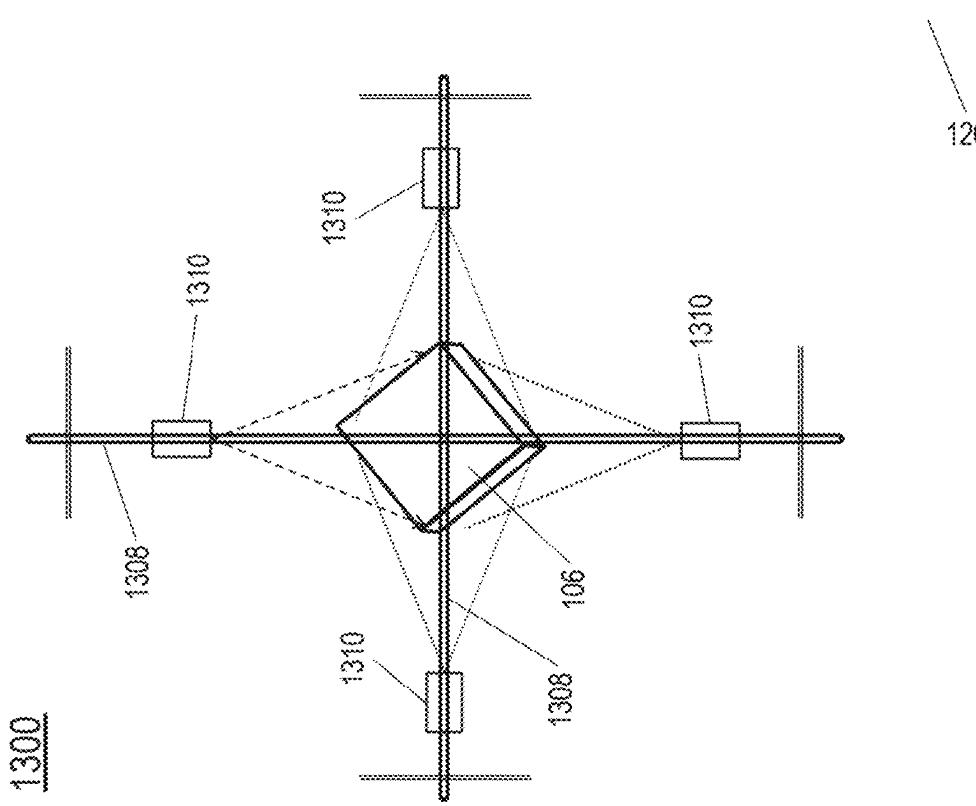


FIG. 13C

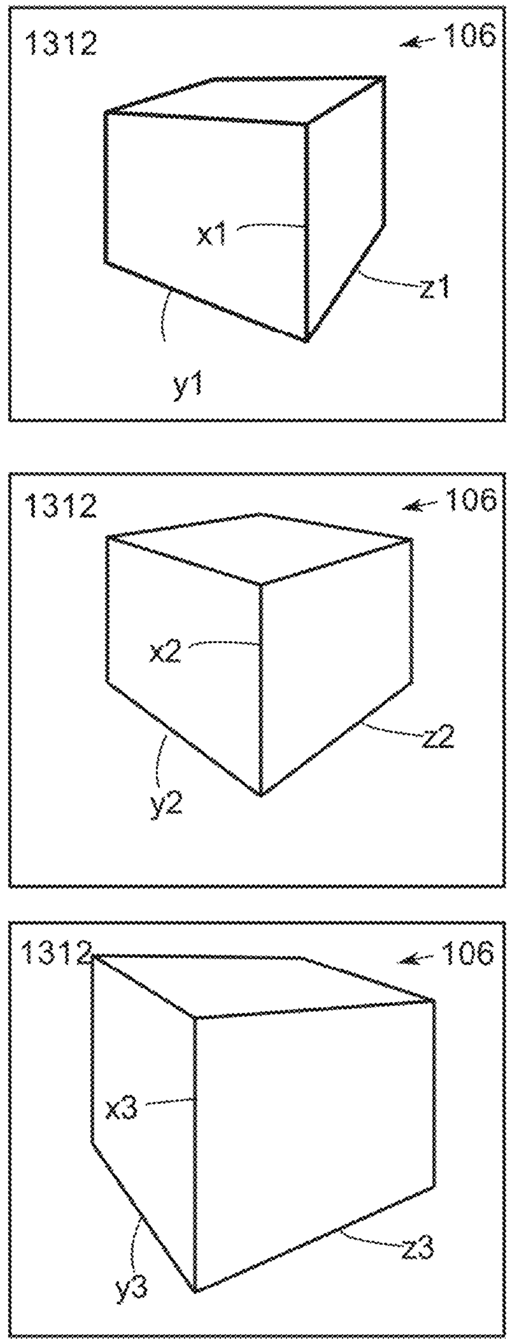


FIG. 14

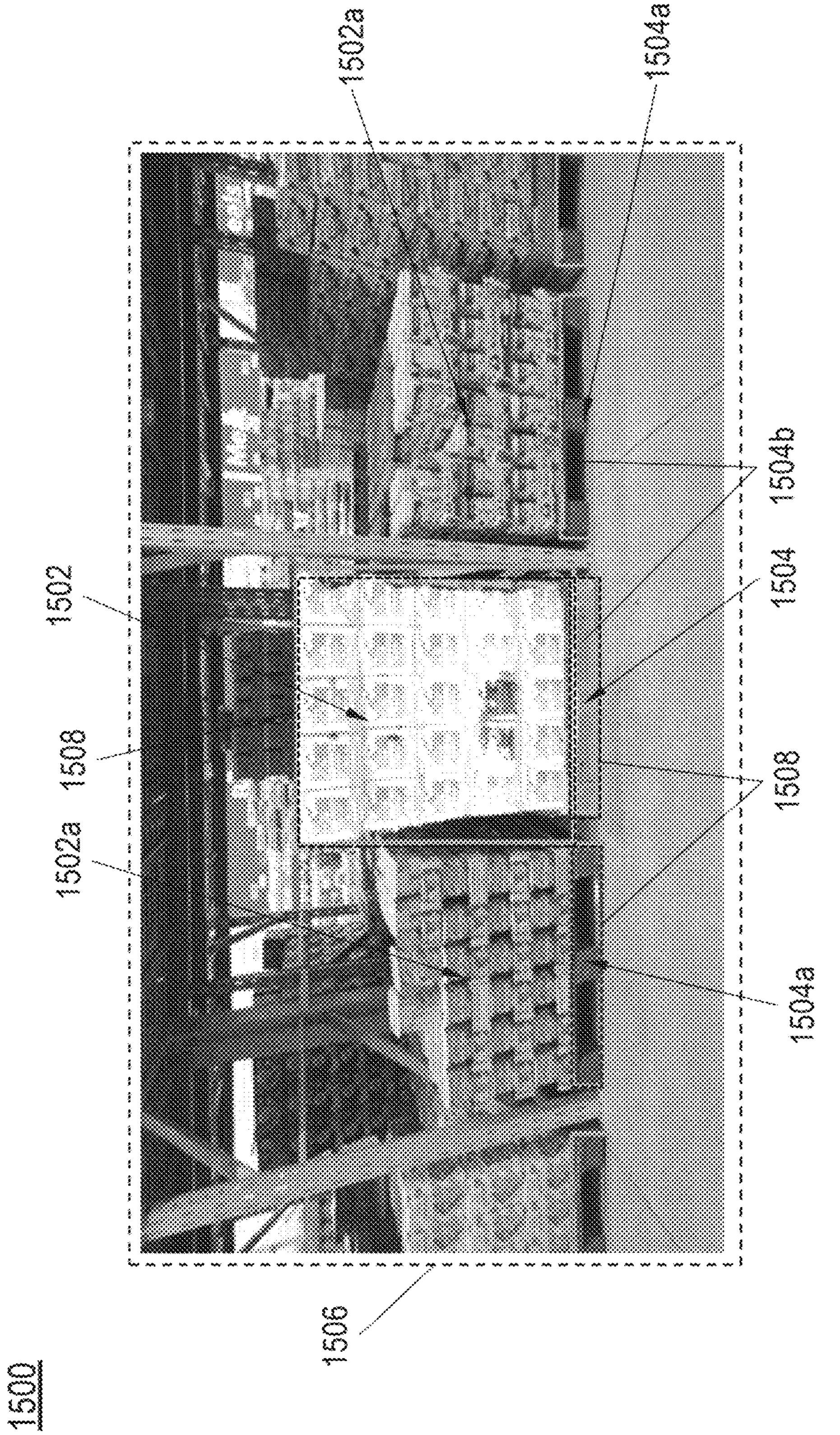


FIG. 15A

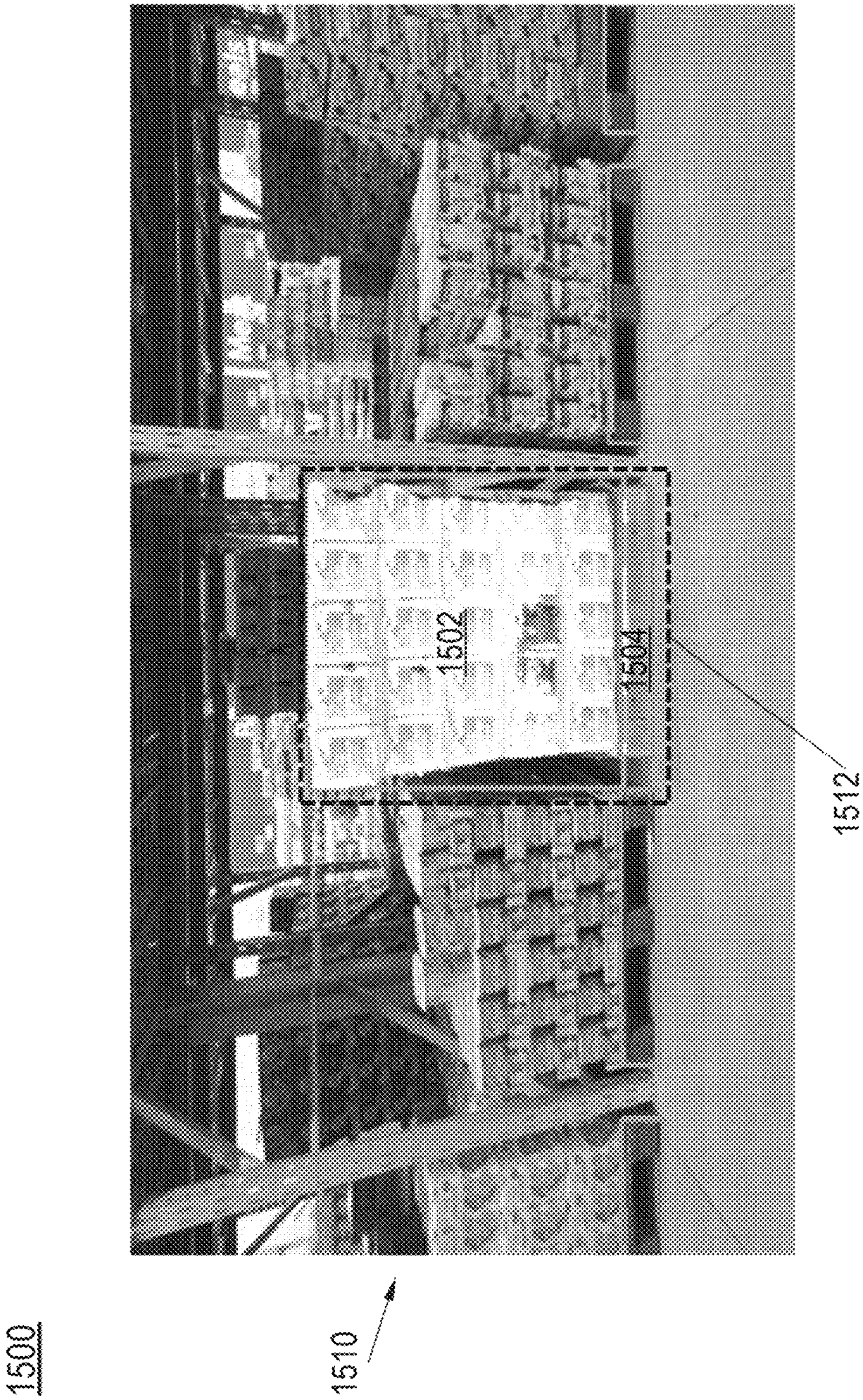


FIG. 15B

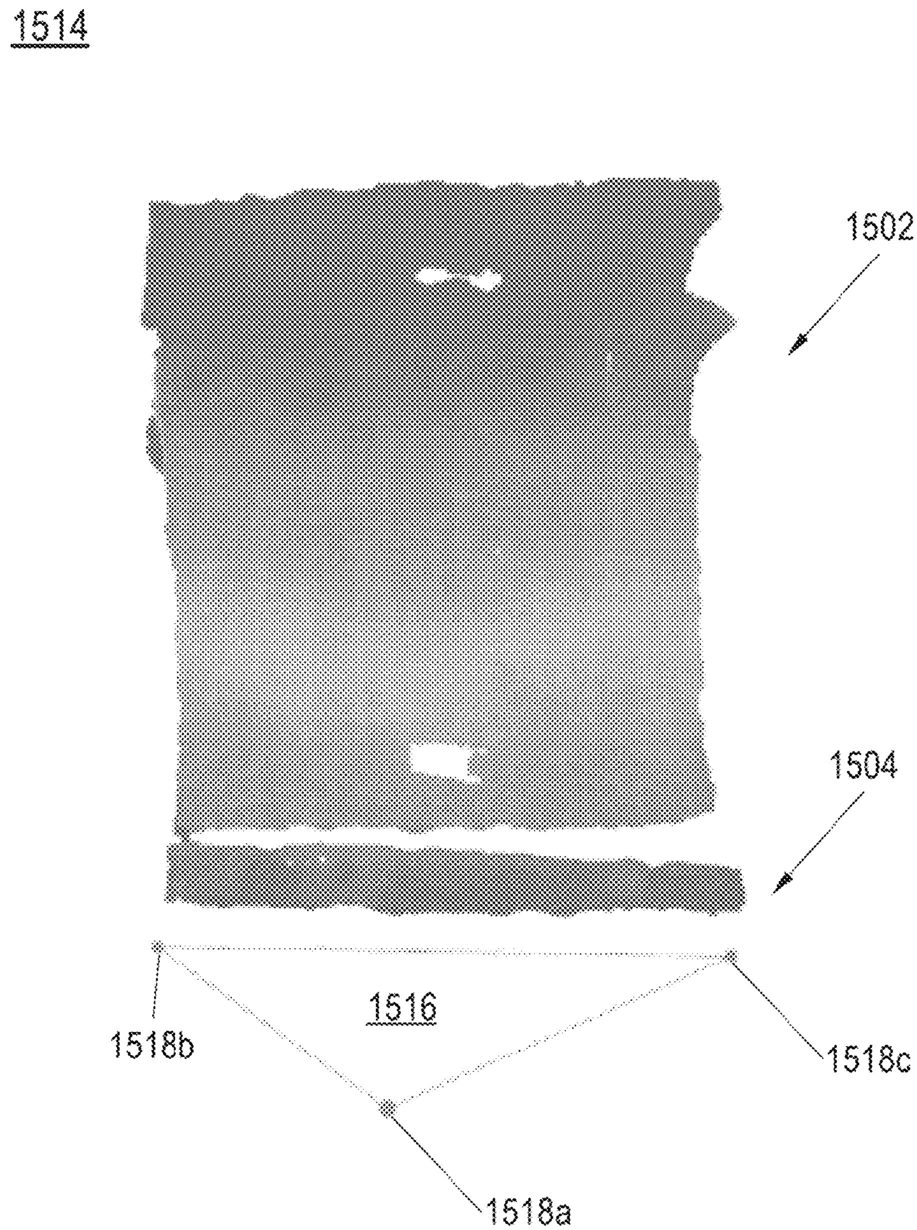


FIG. 15C

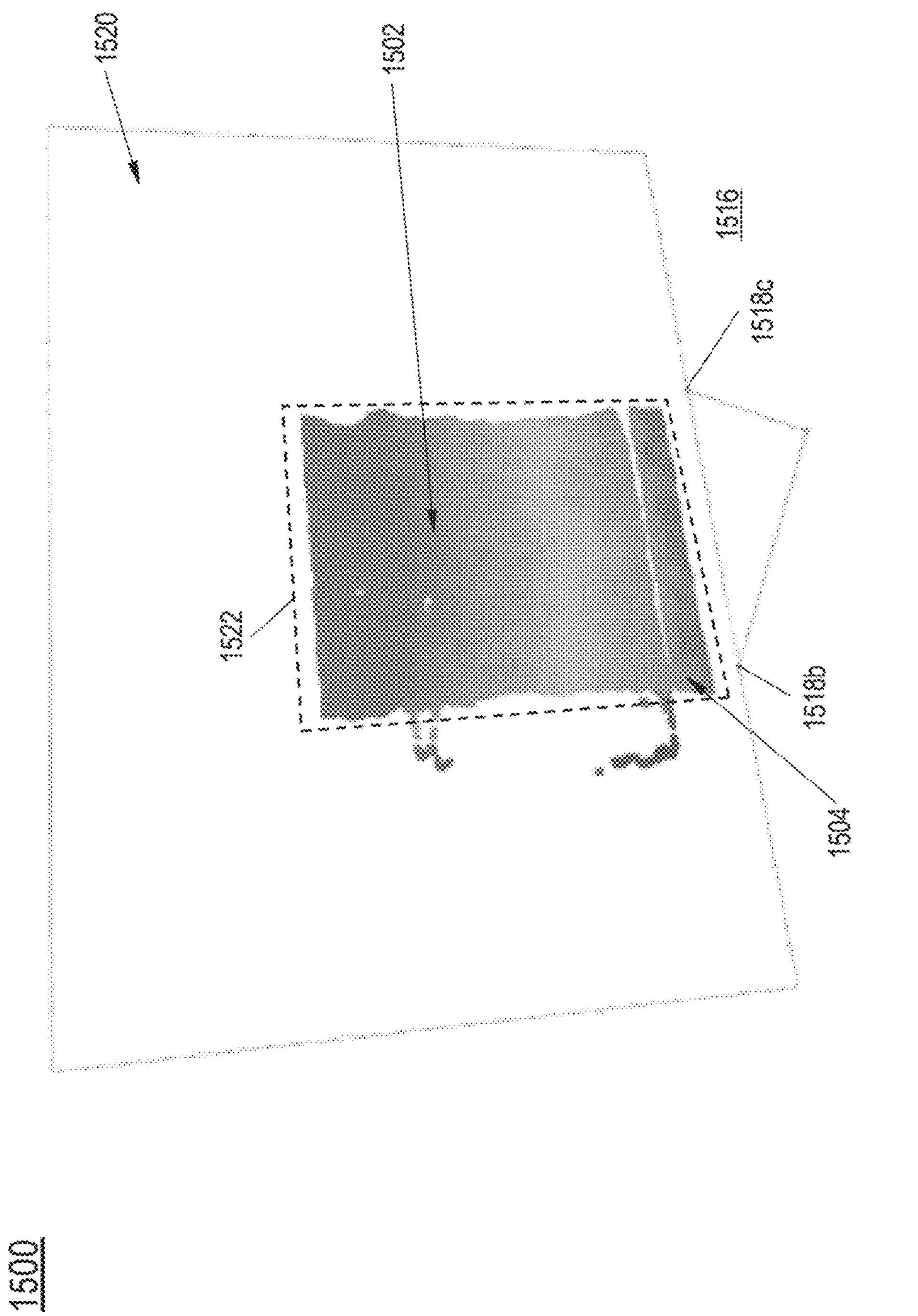


FIG. 15D

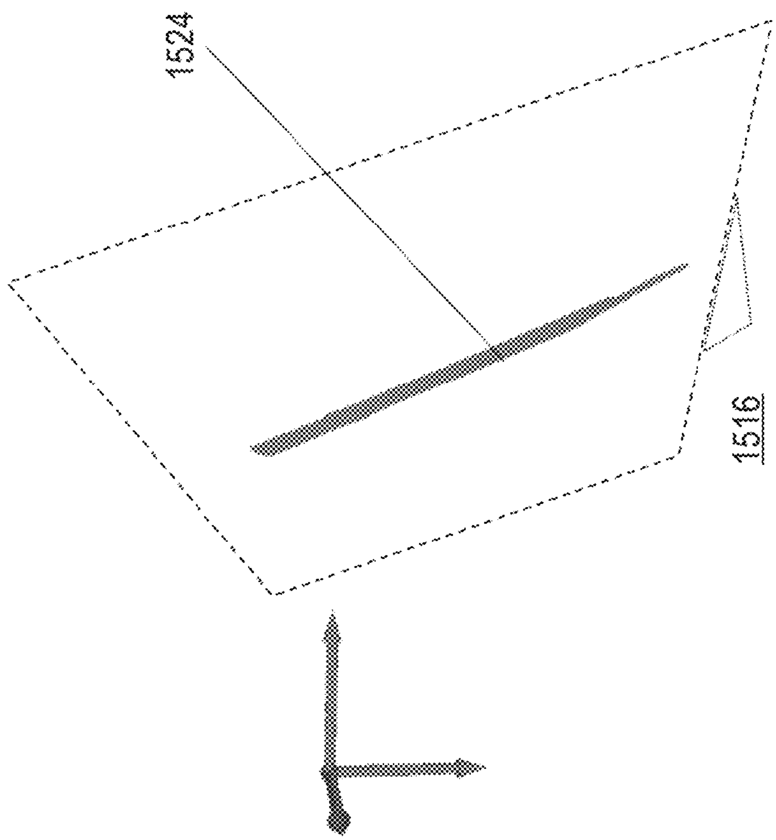


FIG. 15E

1500

1500

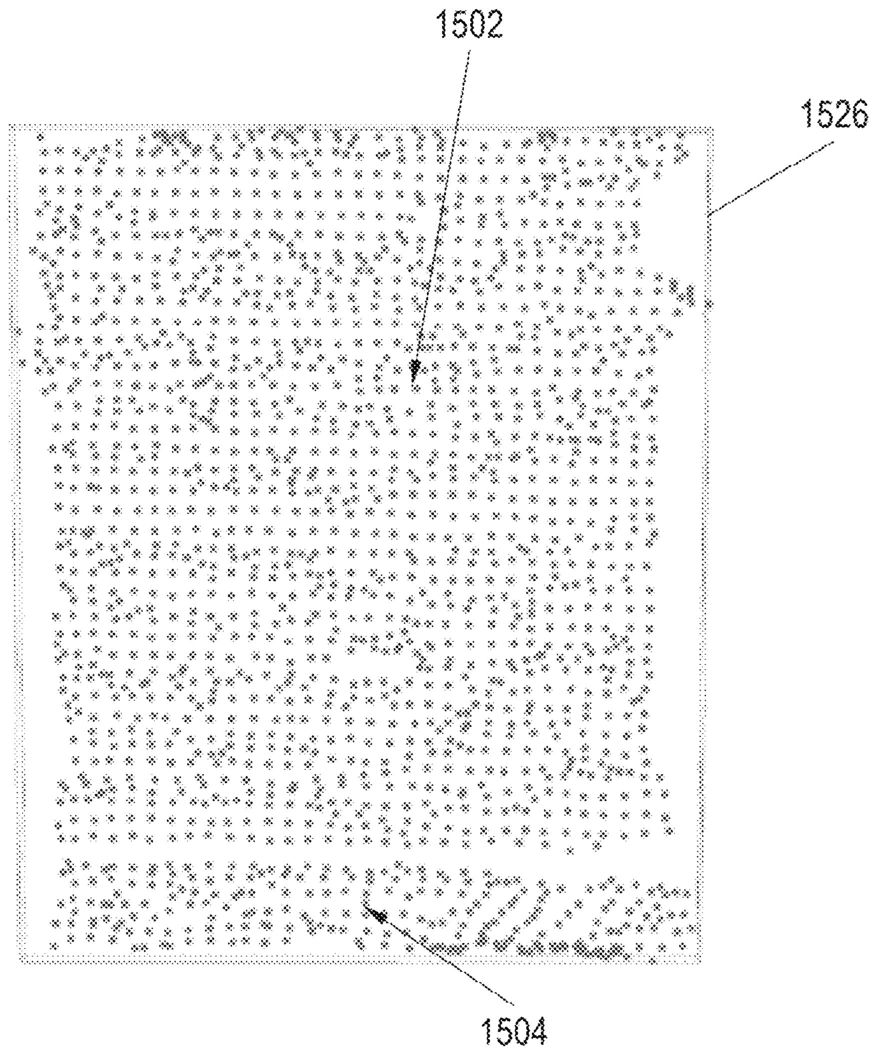


FIG. 15F

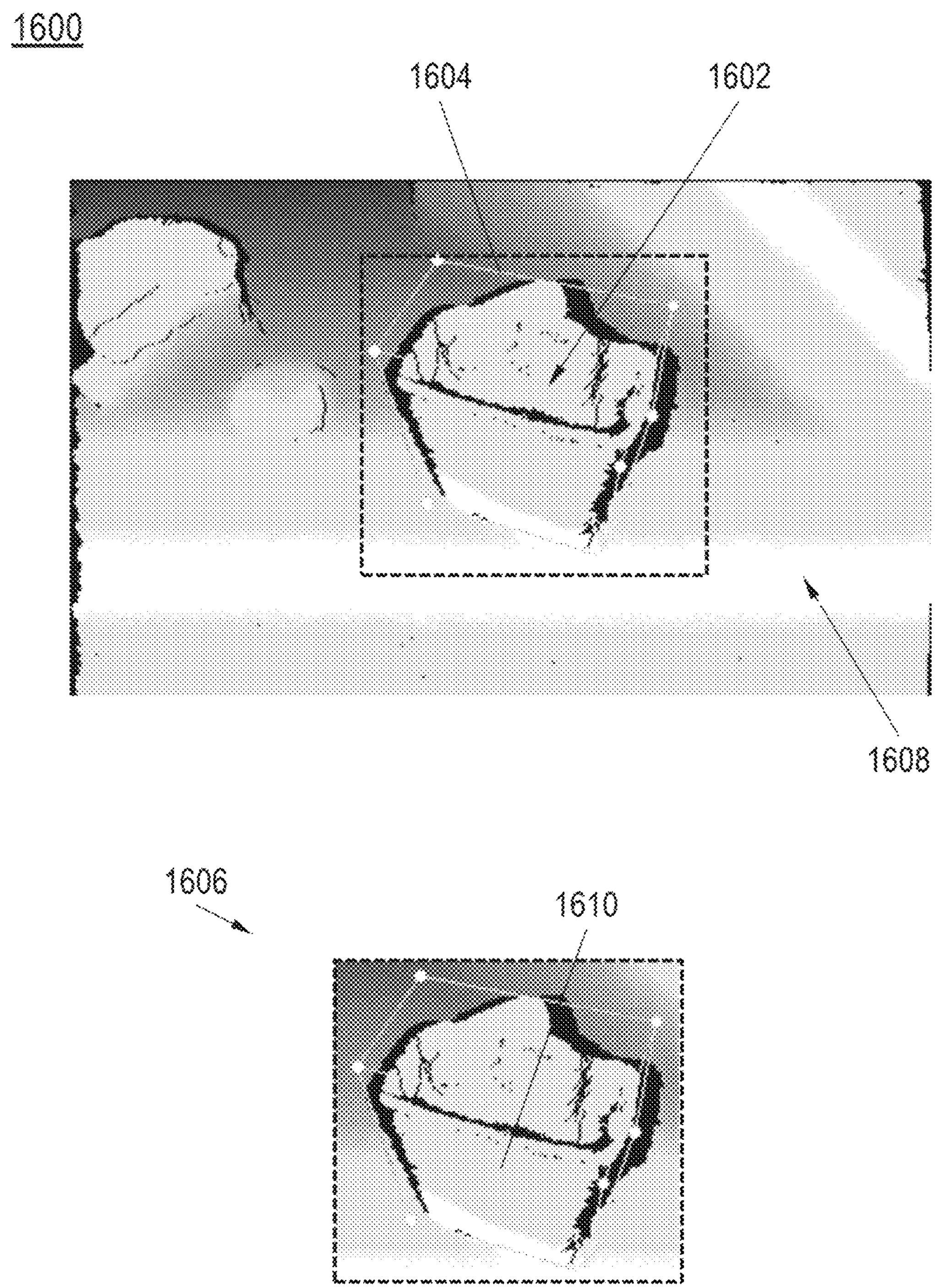


FIG. 16A

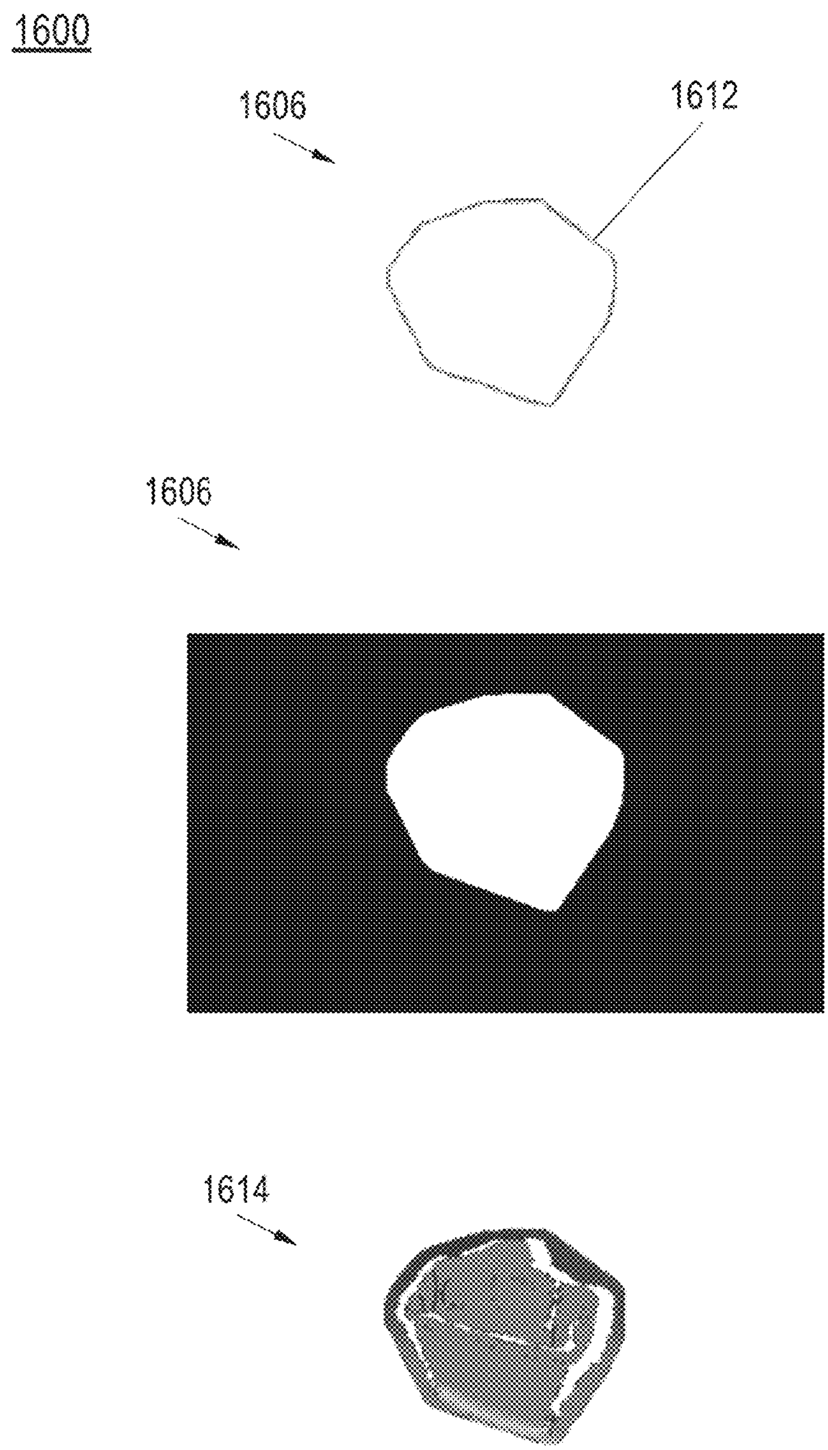


FIG. 16B

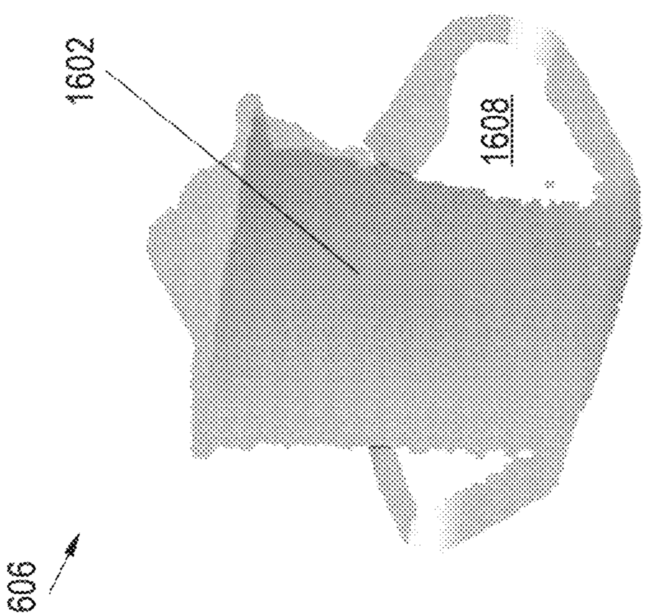


FIG. 16C

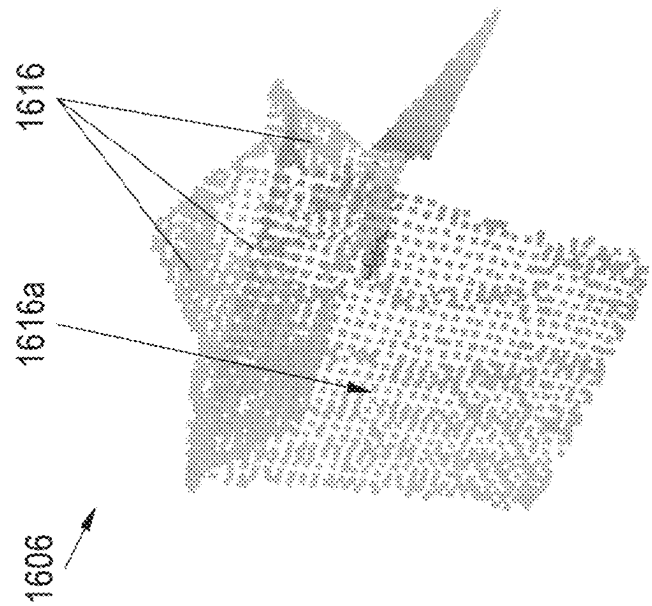


FIG. 16D

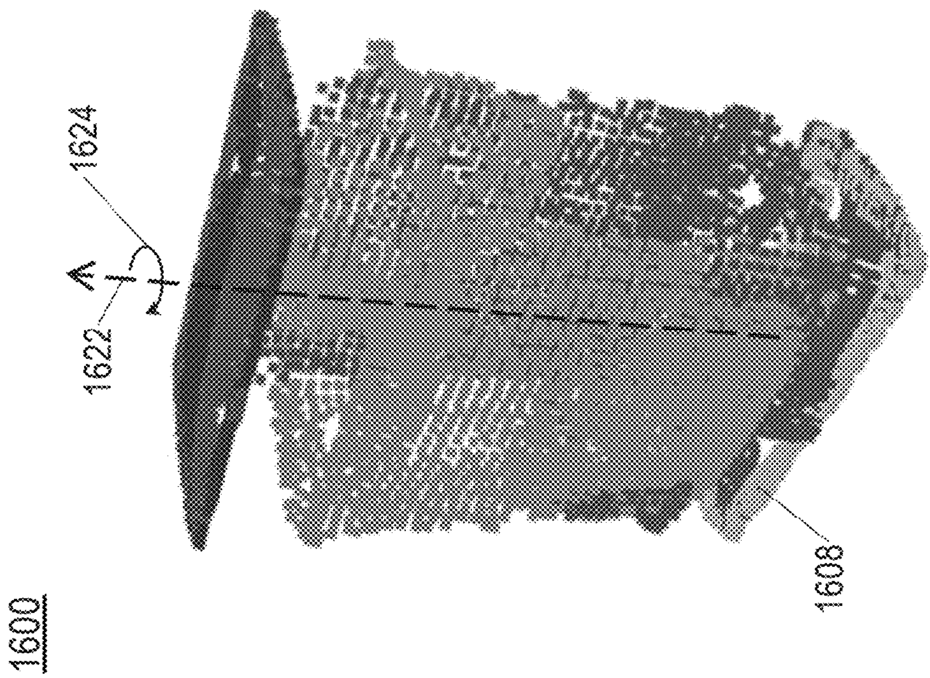


FIG. 16F

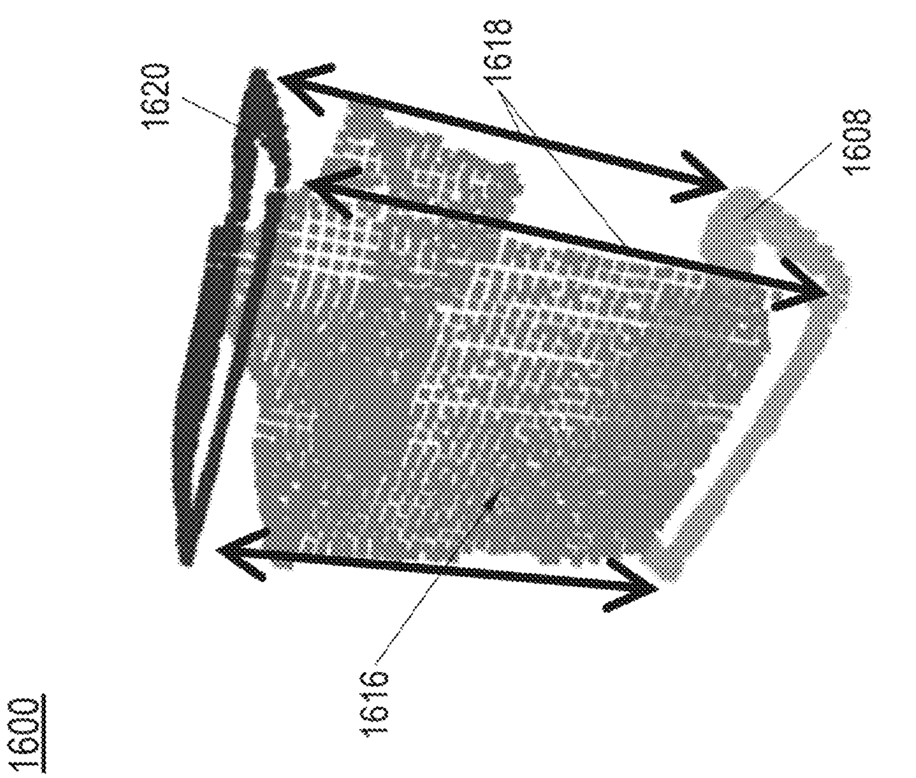


FIG. 16E

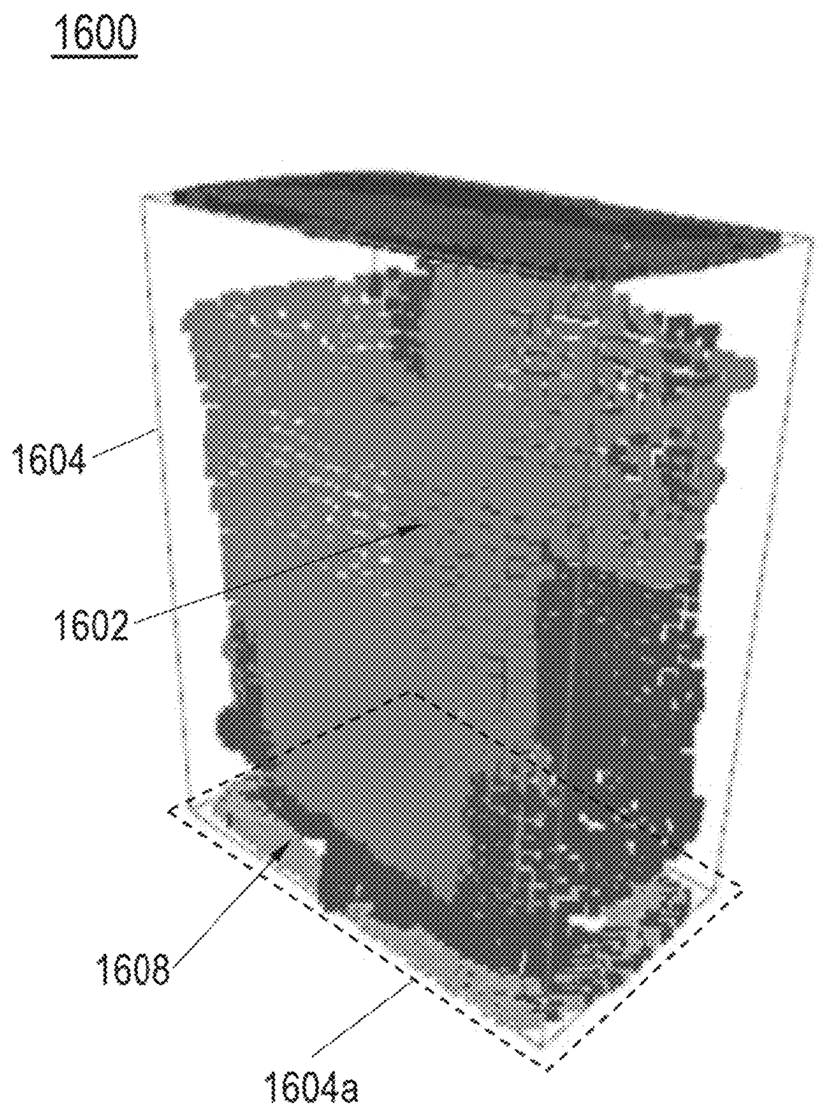


FIG. 16G

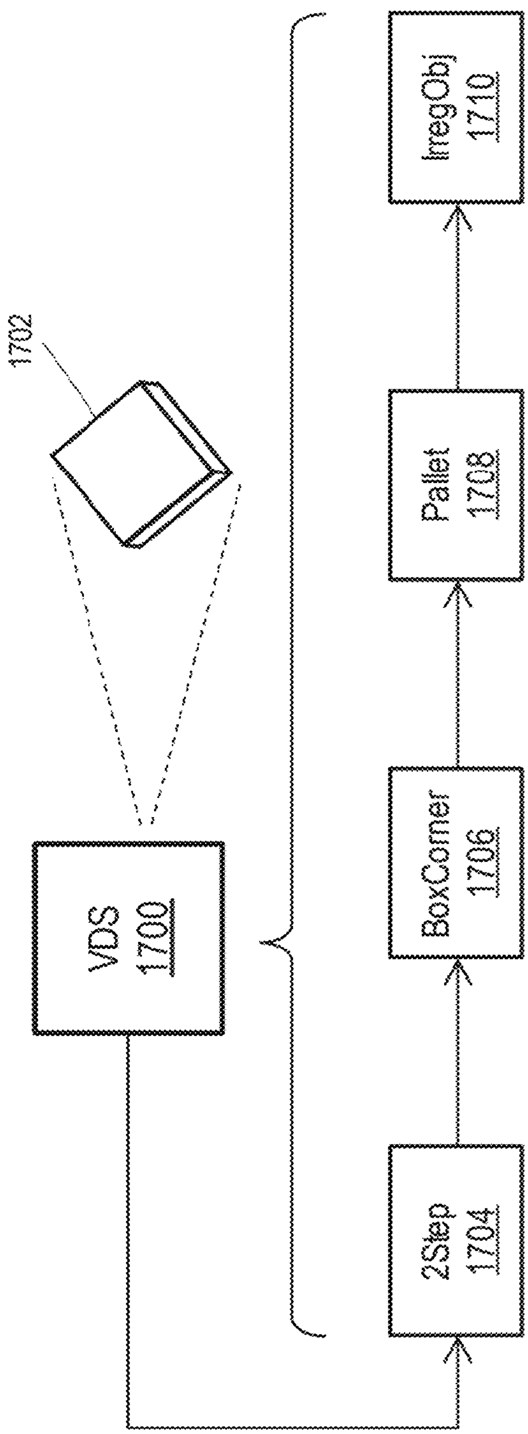

1702
VDS
1700
2Step
1704
BoxCorner
1706
Pallet
1708
IrregObj
1710

FIG. 17

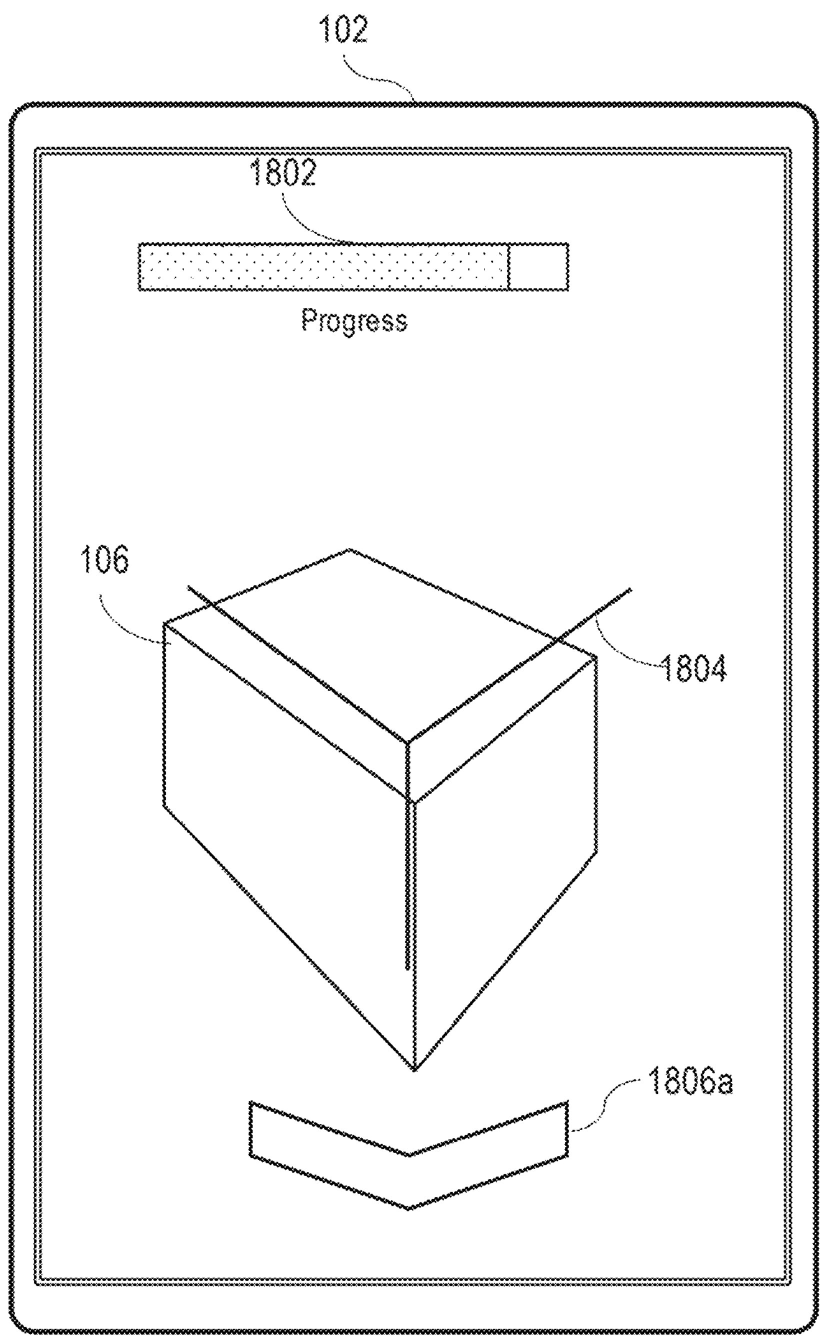


FIG. 18A

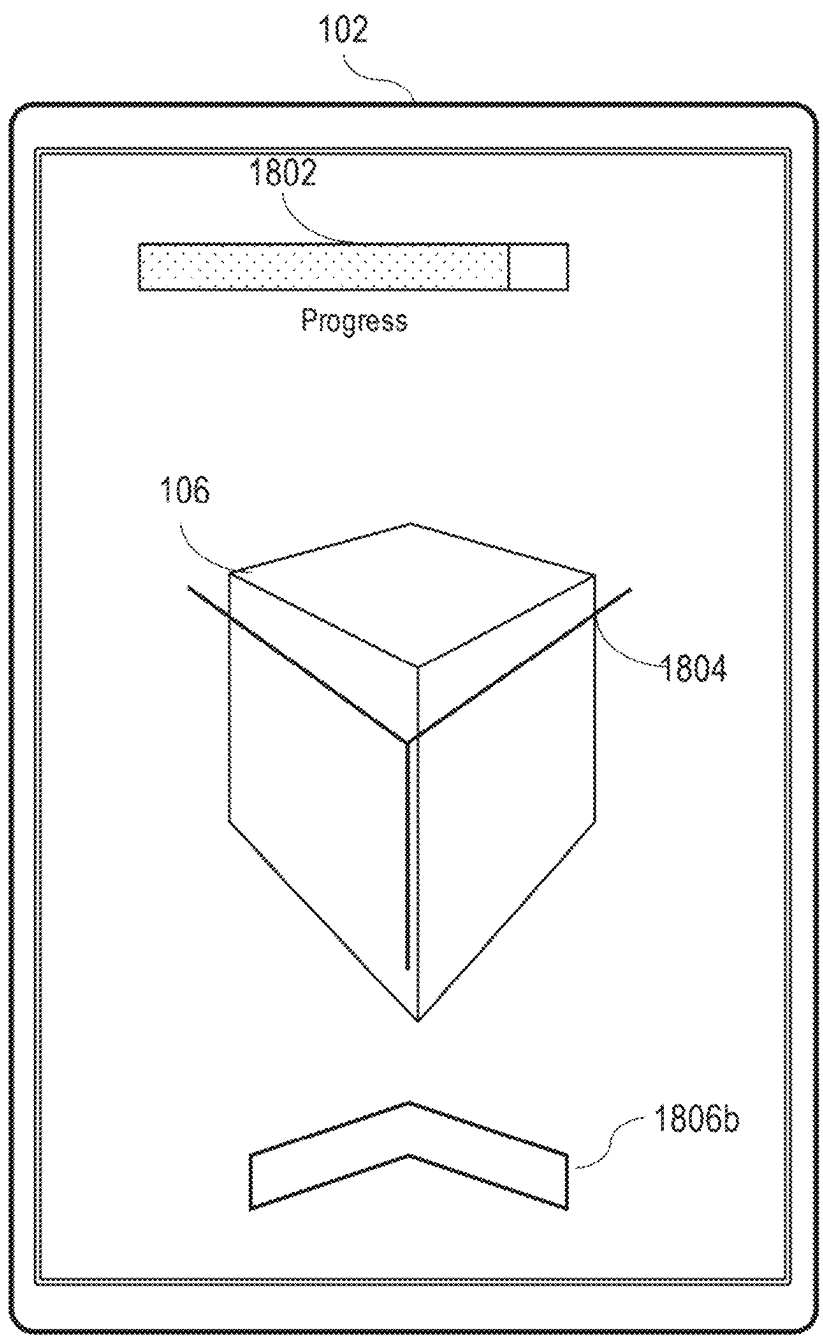


FIG. 18B

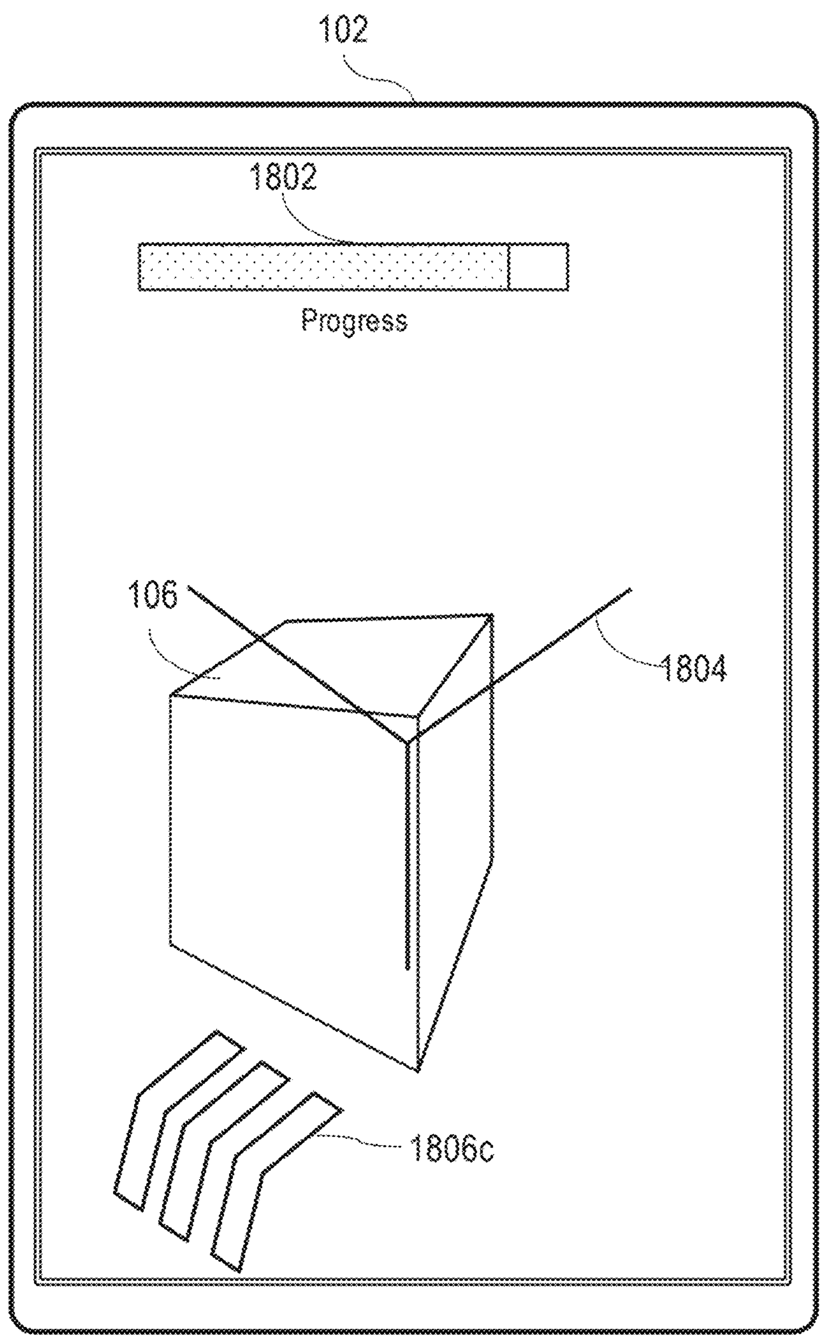


FIG. 18C

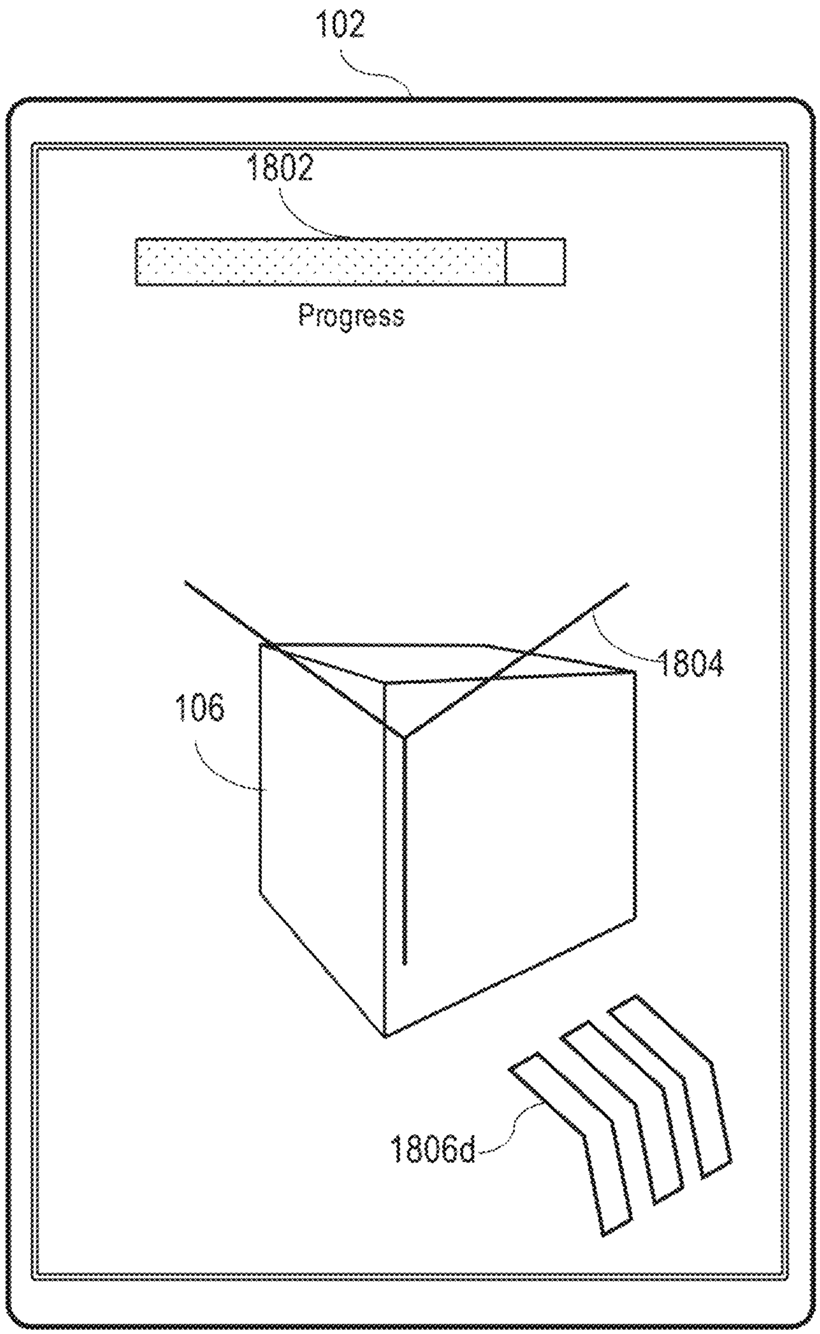


FIG. 18D

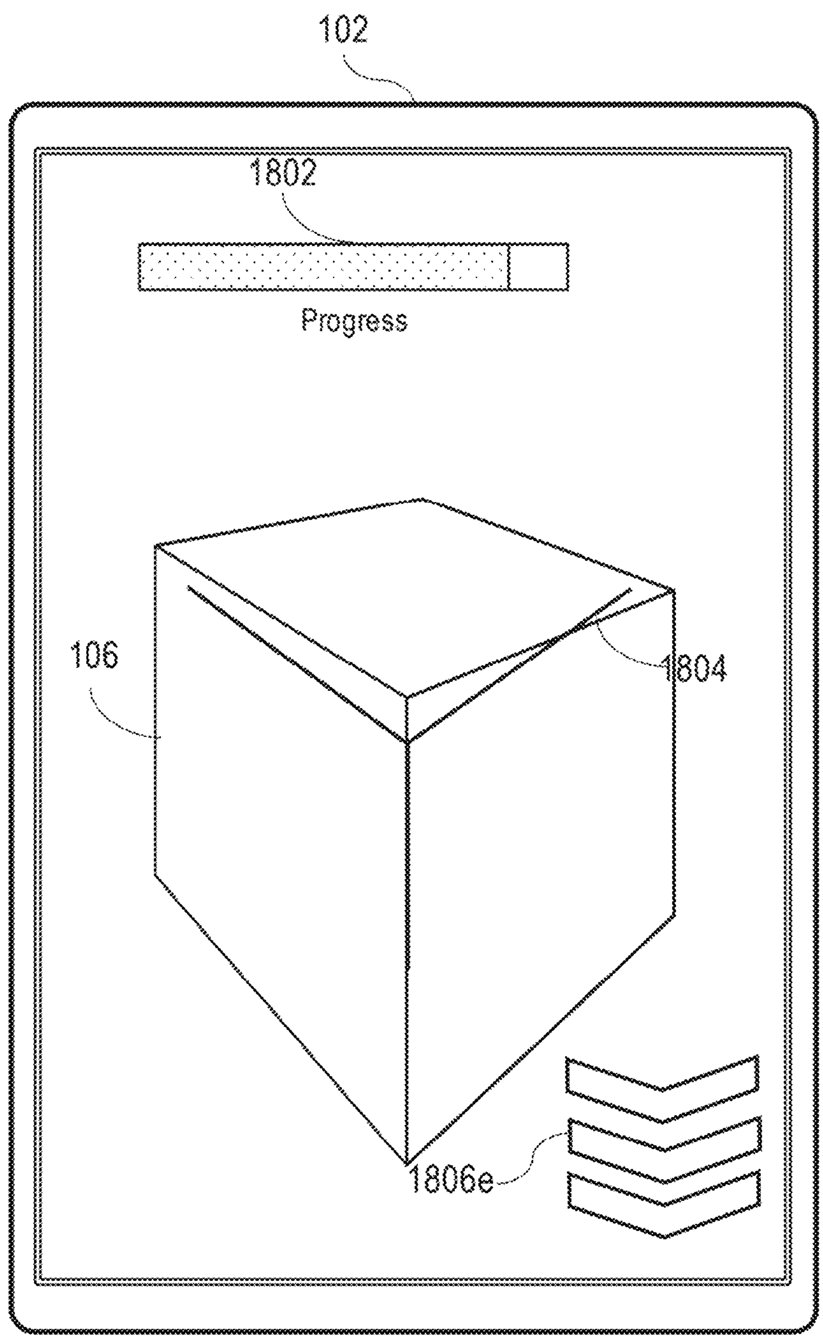


FIG. 18E

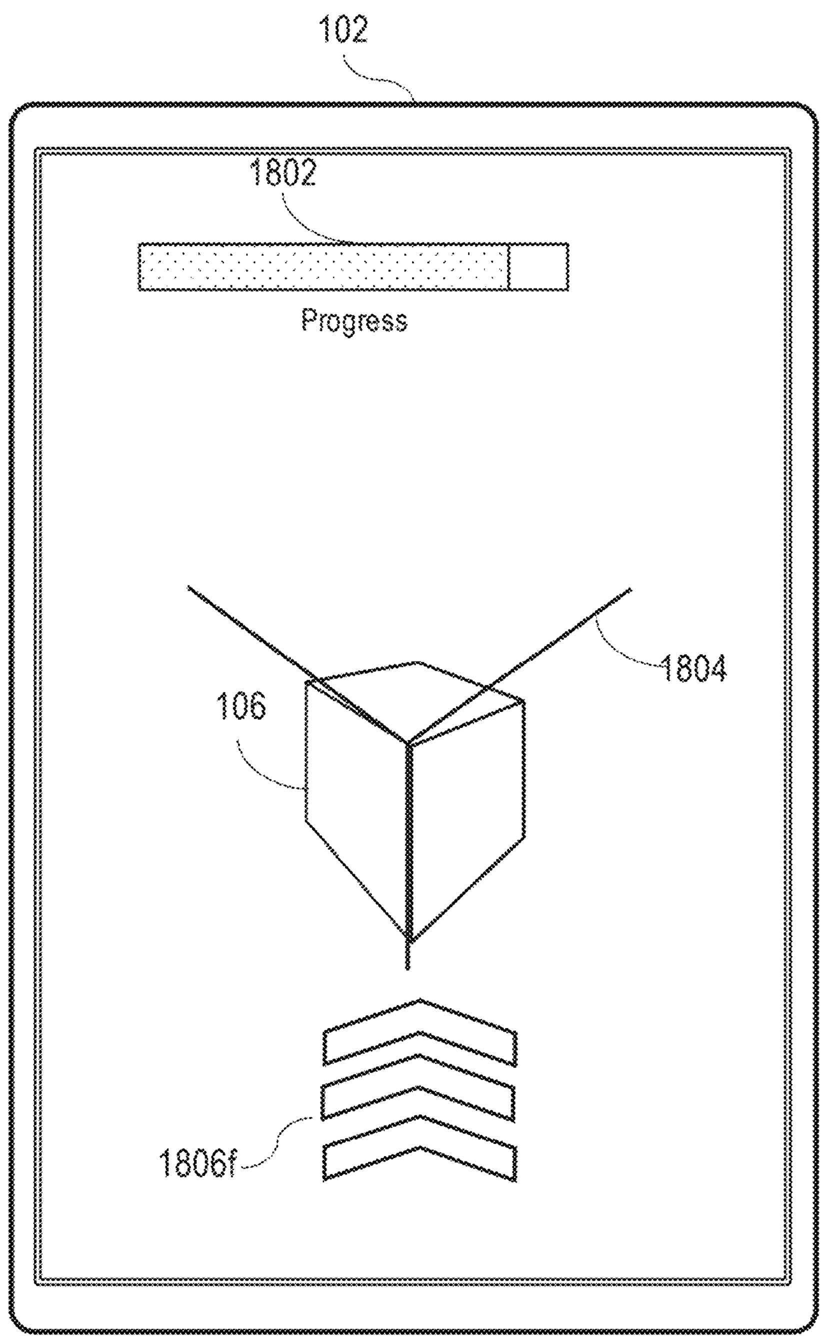


FIG. 18F

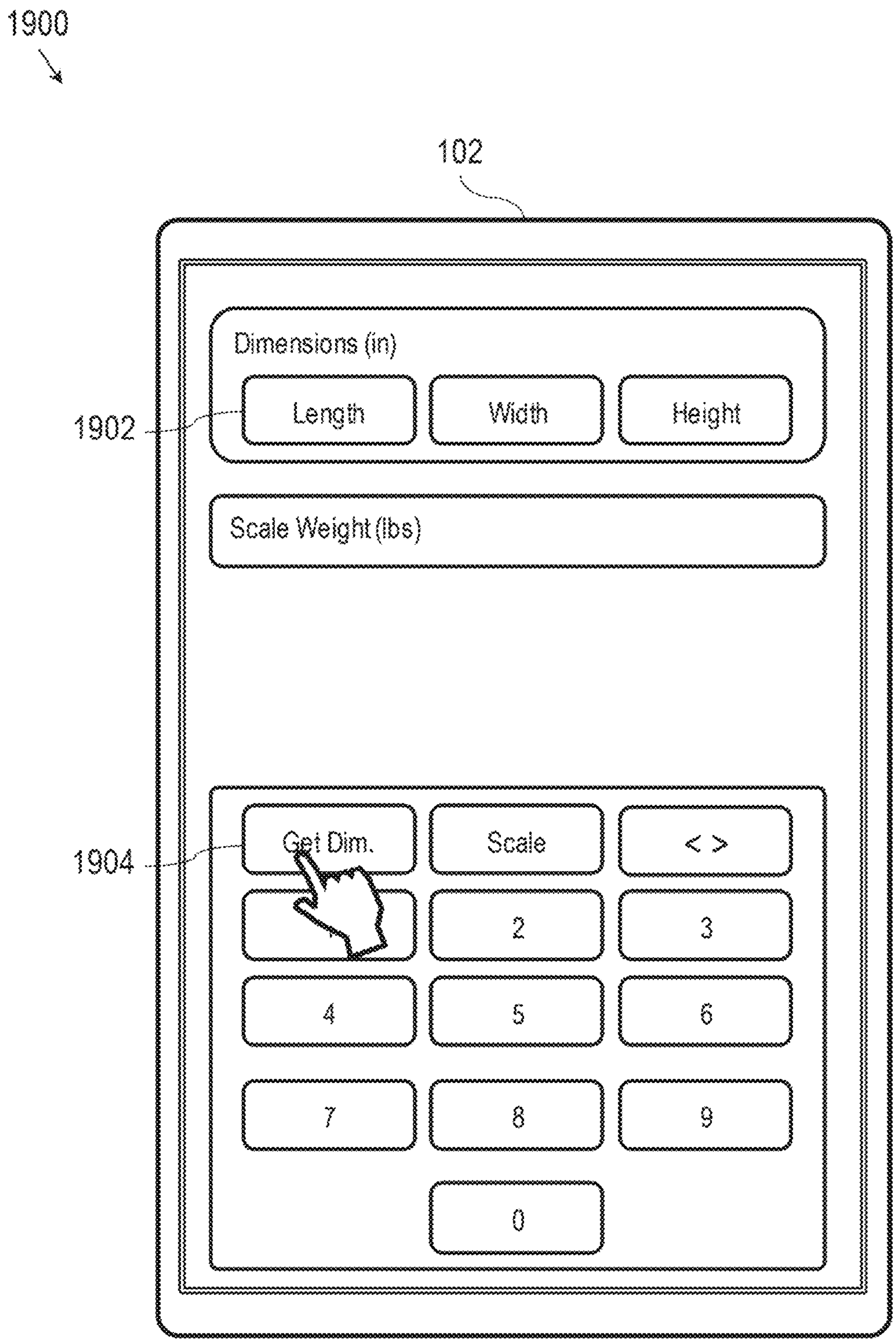

1900
102
Dimensions (in)
Length
Width
Height
1902
Scale Weight (lbs)
1904
Get Dim.
Scale
< >
2
3
4
5
6
7
8
9
0

FIG. 19A

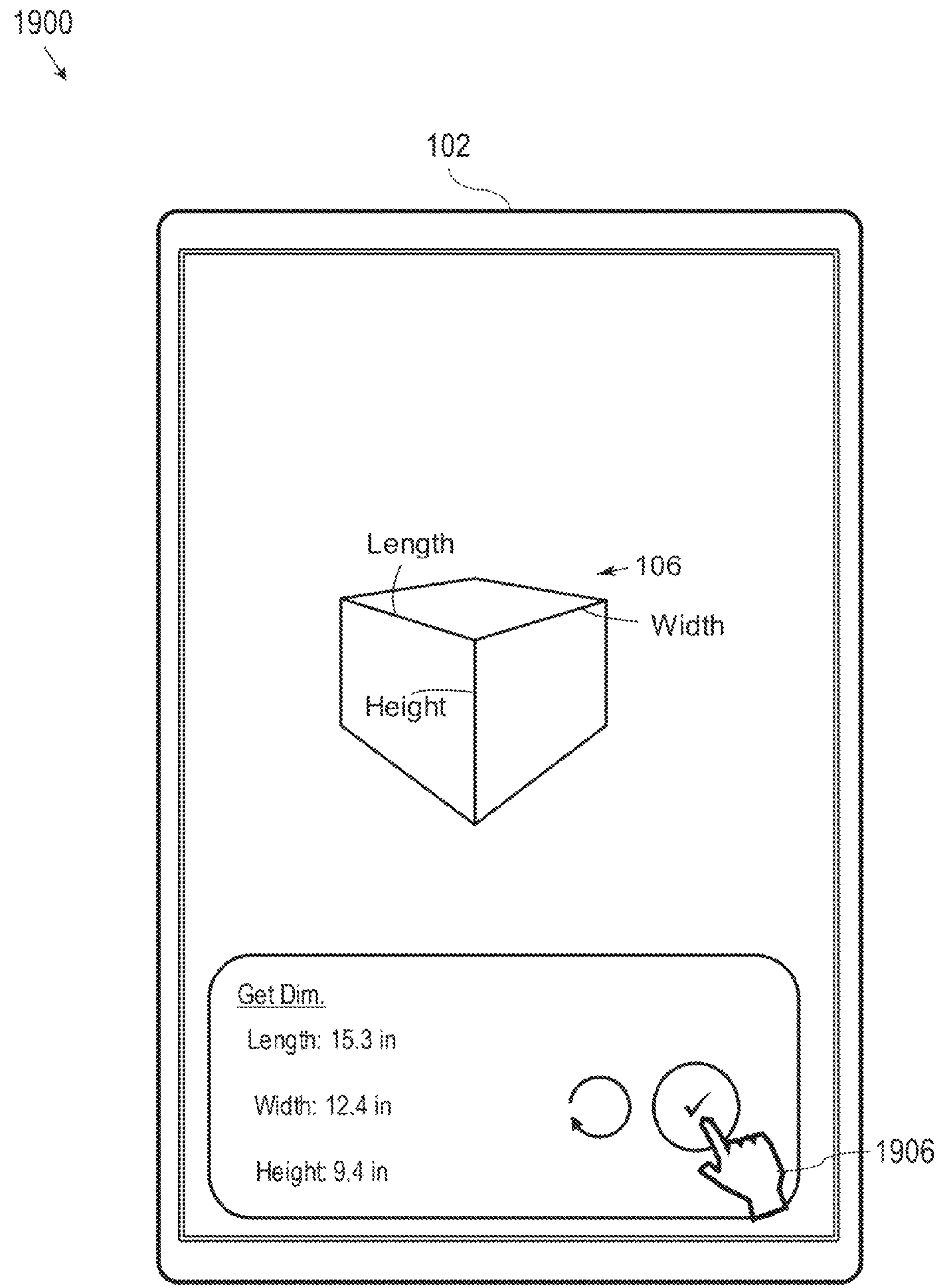

1900
102
Length
106
Width
Height
Get Dim.
Length: 15.3 in
Width: 12.4 in
Height: 9.4 in
1906

FIG. 19B

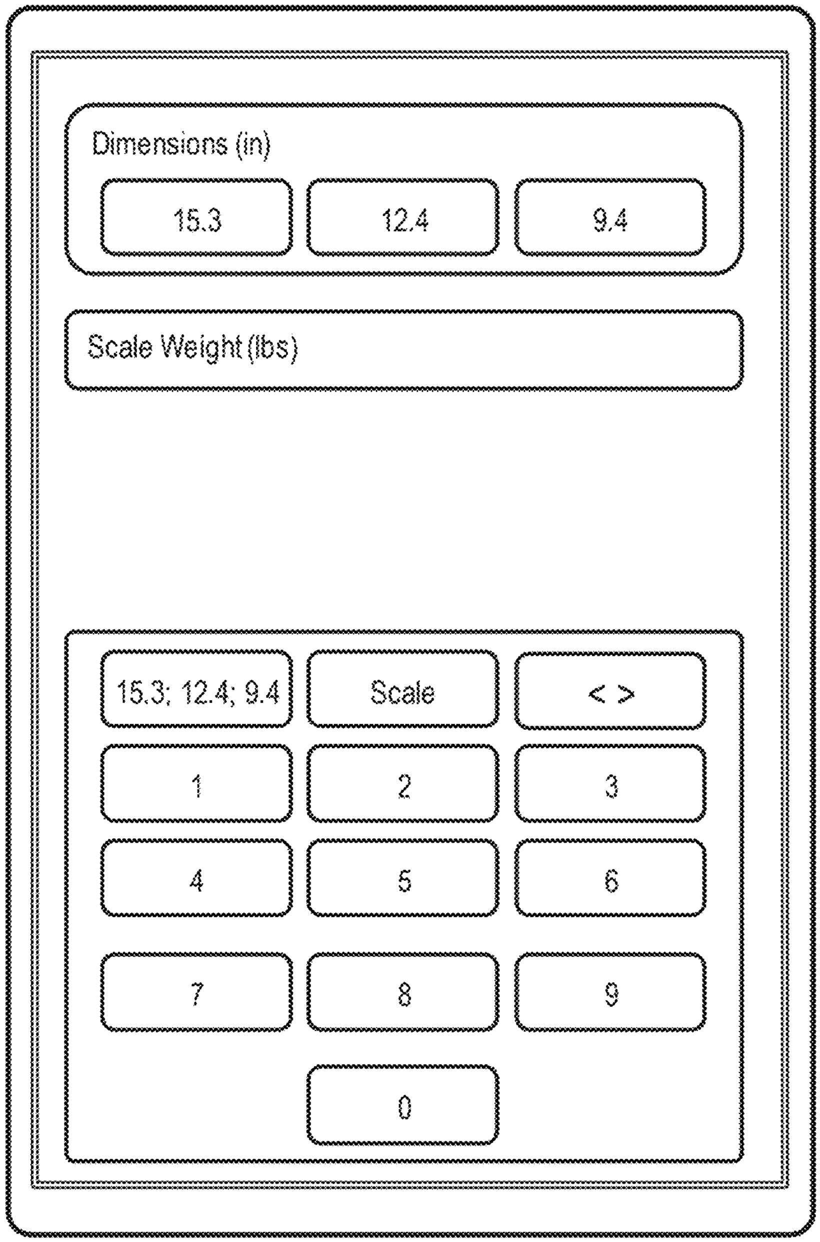

Dimensions (in)
15.3
12.4
9.4
Scale Weight (lbs)
15.3; 12.4; 9.4
Scale
< >
1
2
3
4
5
6
7
8
9
0

FIG. 19C

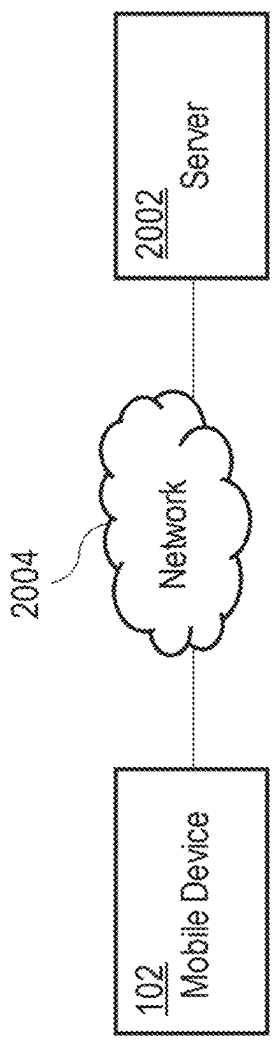


FIG. 20

SYSTEM AND METHOD FOR BOX SEGMENTATION AND MEASUREMENT

CROSS-REFERENCE TO RELATED APPLICATION

The present application is related to and claims the benefit of the earliest available effective filing dates from the following listed applications (the "Related Applications") (e.g., claims earliest available priority dates for other than provisional patent applications (e.g., under 35 USC § 120 as a continuation in part) or claims the benefit under 35 USC § 119(e) for provisional applications, for any and all parent, grandparent, great-grandparent, etc. applications of the Related Applications).

RELATED APPLICATIONS

- U.S. patent application Ser. No. 17/114,066 entitled SYSTEM AND METHOD FOR THREE-DIMENSIONAL BOX SEGMENTATION AND MEASUREMENT, filed Jul. 10, 2020.
- U.S. patent application Ser. No. 16/786,268 entitled SYSTEM FOR VOLUME DIMENSIONING VIA HOLOGRAPHIC SENSOR FUSION, filed Feb. 10, 2020.
- U.S. patent application Ser. No. 16/390,562 entitled SYSTEM FOR VOLUME DIMENSIONING VIA HOLOGRAPHIC SENSOR FUSION, filed Apr. 22, 2019, which issued Feb. 11, 2020 as U.S. Pat. No. 10,559,086;
- U.S. patent application Ser. No. 15/156,149 entitled SYSTEM AND METHODS FOR VOLUME DIMENSIONING FOR SUPPLY CHAINS AND SHELF SETS, filed May 16, 2016, which issued Apr. 23, 2019 as U.S. Pat. No. 10,268,892;
- U.S. Provisional Patent Application Ser. No. 63/113,658 entitled SYSTEM AND METHOD FOR THREE-DIMENSIONAL BOX SEGMENTATION AND MEASUREMENT, filed Nov. 13, 2020;
- U.S. Provisional Patent Application Ser. No. 62/694,764 entitled SYSTEM FOR VOLUME DIMENSIONING VIA 2D/3D SENSOR FUSION, filed Jul. 6, 2018;
- and U.S. Provisional Patent Application Ser. No. 62/162,480 entitled SYSTEMS AND METHODS FOR COMPREHENSIVE SUPPLY CHAIN MANAGEMENT VIA MOBILE DEVICE, filed May 15, 2015.

Said U.S. patent application Ser. Nos. 17/114,066; 16/786,268; 16/390,562; 15/156,149; 63/113,658; 62/162,480; and 62/694,764 are herein incorporated by reference in their entirety.

The chain of priority is now described: The present application is a continuation-in-part of U.S. Ser. No. 17/114,066; said U.S. Ser. No. 17/114,066 claims the benefit of provisional U.S. 63/113,658 and is a continuation-in-part of U.S. Ser. No. 16/786,268; said U.S. Ser. No. 16/786,268 is a continuation of U.S. Ser. No. 16/390,562; said U.S. Ser. No. 16/390,562 claims the benefit of provisional U.S. 62/694,764 and is a continuation-in-part of U.S. Ser. No. 15/156,149; said U.S. Ser. No. 15/156,149 claims the benefit of provisional U.S. 62/162,480.

BACKGROUND

While many smartphones, pads, tablets, and other mobile computing devices are equipped with front-facing or rear-facing cameras, these devices may now be equipped with three-dimensional imaging systems incorporating cameras configured to detect infrared radiation combined with infrared or laser illuminators (e.g., light detection and ranging (LIDAR) systems) to enable the camera to derive depth information. It may be desirable for a mobile device to capture three-dimensional (3D) images of objects, or two-dimensional (2D) images with depth information, and derive from the captured imagery additional information about the objects portrayed, such as the dimensions of the objects or other details otherwise accessible through visual comprehension, such as significant markings, encoded information, or visible damage.

However, elegant sensor fusion of 2D and 3D imagery may not always be possible. For example, 3D point clouds may not always map optimally to 2D imagery due to inconsistencies in the image streams; sunlight may interfere with infrared imaging systems, or target surfaces may be highly reflective, confounding accurate 2D imagery of planes or edges.

SUMMARY

A method is described, in accordance with one or more embodiments of the present disclosure. The method may be implemented by one or more processors of a mobile device. The method includes obtaining, via an image sensor of a mobile device, imaging data associated with a target object positioned on a surface, the imaging data comprising a sequence of frames, each frame comprising a depth map with two-dimensional (2D) pixel coordinates and a plurality of depth values. The method includes identifying, via one or more processors, an origin point within the plurality of depth values. The origin point is associated with a top corner of the target object. The method includes crawling, via the one or more processors, from the origin point along a first edge to a first corner, along a second edge to a second corner, and along a third edge to a third corner of the target object using an edge crawling algorithm. The method includes deprojecting, via the one or more processors, the depth map into three-dimensional (3D) points. The method includes constructing, via the one or more processors, a first edge vector representing the first edge from the origin point to the first corner, a second edge vector representing the second edge from the origin point to the second corner point, and a third edge vector representing the third edge from the origin point to the third corner point using the 3D points. The method includes determining, via the one or more processors, the target object is a cuboid by examining a first angle between the first edge vector and the second edge vector, a second angle between the first edge vector and the third edge vector, and a third angle between the second edge vector and the third edge vector. The method includes estimating, via the one or more processors, a first distance of the first edge using the first edge vector, a second distance of the second edge using the second edge vector, and a third distance of the third edge using the third edge vector.

This Summary is provided solely as an introduction to subject matter that is fully described in the Detailed Description and Drawings. The Summary should not be considered to describe essential features nor be used to determine the scope of the Claims. Moreover, it is to be understood that both the foregoing Summary and the following Detailed Description are example and explanatory only and are not necessarily restrictive of the subject matter claimed.

BRIEF DESCRIPTION OF THE DRAWINGS

The detailed description is described with reference to the accompanying figures. The use of the same reference numbers in different instances in the description and the figures may indicate similar or identical items. Various embodiments or examples ("examples") of the present disclosure are disclosed in the following detailed description and the accompanying drawings. The drawings are not necessarily to scale. In general, operations of disclosed processes may be performed in an arbitrary order, unless otherwise provided in the claims. In the drawings:

FIG. **1** is a diagrammatic illustration a volume dimensioning system including a user aiming a mobile device at a target object, in accordance with example embodiments of this disclosure.

FIG. **2** is a block diagram illustrating the mobile device of the volume dimensioning system of FIG. **1**.

FIGS. **3**A through **3**I are diagrammatic illustrations of the mobile device of the volume dimensioning system of FIG. **1**.

FIGS. **4**A and **4**B are diagrammatic illustrations of the mobile device of the volume dimensioning system of FIG. **1**.

FIGS. **5**A and **5**B are diagrammatic illustrations of the mobile device of the volume dimensioning system of FIG. **1**.

FIGS. **6**A through **6**C are diagrammatic illustrations of the mobile device of the volume dimensioning system of FIG. **1**.

FIGS. **7**A through **7**E are diagrammatic illustrations of the mobile device of the volume dimensioning system of FIG. **1**.

FIG. **8** is a diagrammatic illustration of the mobile device of the volume dimensioning system of FIG. **1**.

FIGS. **9**A through **9**C are diagrammatic illustrations of the mobile device of the volume dimensioning system of FIG. **1**.

FIGS. **10**A and **10**B are a flow diagram illustrating a method for volume dimensioning, in accordance with one or more embodiments of the present disclosure.

FIG. **11** is a flow illustrating a method for volume dimensioning, in accordance with one or more embodiments of the present disclosure.

FIGS. **12**A through **12**C are diagrammatic illustrations of the mobile device of the volume dimensioning system of FIG. **1**.

FIGS. **12**D and **12**E are views of a depth map, in accordance with one or more embodiments of the present disclosure.

FIG. **12**F is a view of a three-dimensional image data including edge vectors, in accordance with one or more embodiments of the present disclosure.

FIG. **12**G is a view of measured values adjusted (e.g., adjusted to reduce error relative to actual physical values), by the volume dimensioning system of FIG. **1**.

FIG. **12**H is a graphical representation of trends in measured values and predicted errors (e.g., relative to actual physical values) with respect to the volume dimensioning system of FIG. **1**.

FIGS. **13**A and **13**B depict a volume dimensioning system, in accordance with one or more embodiments of the present disclosure.

FIGS. **13**C and **13**D depict overhead views of a volume dimensioning system, in accordance with one or more embodiments of the present disclosure.

FIG. **14** depicts sets of image data of a target object generated by a volume dimensioning system including three image sensors, in accordance with one or more embodiments of the present disclosure.

FIGS. **15**A through **15**F depict a volume dimensioning system including pallet segmentation and measurement, in accordance with one or more embodiments of the present disclosure.

FIGS. **16**A through **16**G depict a volume dimensioning system for irregular (e.g., non-cuboid, non-hexahedral) target objects, in accordance with one or more embodiments of the present disclosure.

FIG. **17** depicts a multi-mode volume dimensioning system in accordance with one or more embodiments of the present disclosure.

FIGS. **18**A through **18**F depict diagrammatic illustrations of the mobile device with three-dimensional guidance, in accordance with one or more embodiments of the present disclosure.

FIGS. **19**A through **19**C depict diagrammatic illustrations of the mobile device with a sensor fusion keyboard, in accordance with one or more embodiments of the present disclosure.

FIG. **20** depicts an edge computing system, in accordance with one or more embodiments of the present disclosure.

DETAILED DESCRIPTION

Before explaining one or more embodiments of the disclosure in detail, it is to be understood that the embodiments are not limited in their application to the details of construction and the arrangement of the components or steps or methodologies set forth in the following description or illustrated in the drawings. In the following detailed description of embodiments, numerous specific details may be set forth in order to provide a more thorough understanding of the disclosure. However, it will be apparent to one of ordinary skill in the art having the benefit of the instant disclosure that the embodiments disclosed herein may be practiced without some of these specific details. In other instances, well-known features may not be described in detail to avoid unnecessarily complicating the instant disclosure.

As used herein a letter following a reference numeral is intended to reference an embodiment of the feature or element that may be similar, but not necessarily identical, to a previously described element or feature bearing the same reference numeral (e.g., 1, 1a, 1b). Such shorthand notations are used for purposes of convenience only and should not be construed to limit the disclosure in any way unless expressly stated to the contrary.

Further, unless expressly stated to the contrary, "or" refers to an inclusive or and not to an exclusive or. For example, a condition A or B is satisfied by anyone of the following: A is true (or present) and B is false (or not present), A is false (or not present) and B is true (or present), and both A and B are true (or present).

In addition, use of "a" or "an" may be employed to describe elements and components of embodiments disclosed herein. This is done merely for convenience and "a" and "an" are intended to include "one" or "at least one," and the singular also includes the plural unless it is obvious that it is meant otherwise.

Finally, as used herein any reference to "one embodiment" or "some embodiments" means that a particular element, feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment disclosed herein. The appearances of the phrase "in some embodiments" in various places in the specification are not necessarily all referring to the same embodiment, and embodiments may include one or more of the features expressly described or inherently present herein, or any combination of sub-combination of two or more such features, along with any other features which may not necessarily be expressly described or inherently present in the instant disclosure.

A system for segmentation and dimensional measurement of a target object based on three-dimensional (3D) imaging is disclosed. In embodiments, the segmentation and measurement system comprises 3D image sensors incorporated into or attached to a mobile computing device e.g., a smartphone, tablet, phablet, or like portable processor-enabled device. The segmentation captures 3D imaging data of a rectangular cuboid solid (e.g., "box") or like target object positioned in front of the mobile device and identifies planes, edges and corners of the target object, measuring precise dimensions (e.g., length, width, depth) of the object.

Referring to FIG. **1**, a system **100** for 3D box segmentation and measurement is disclosed. The system **100** may also be referred to as a volume dimensioning system. The system **100** may include a mobile device **102** (e.g., tablet, smartphone, phablet) capable of being carried by a user **104** (e.g., operator) and aimed at a target object **106** (e.g., a rectangular cuboid solid ("target box") or like object the user wishes to measure in three dimensions, the object positioned on a floor **108** or flat surface. For example, the system **100** may return dimensional information of the target object **106**, e.g., a length **110**, width **112**, and depth **114** of the target object. In some embodiments, the system **100** will characterize the greatest of the length **110**, width **112**, and depth **114** as the length of the target object **106**; in some embodiments, the system **100** may derive additional information corresponding to the target object **106** based on the determined length **110**, width **112**, and depth **114** (or as disclosed in greater detail below). In embodiments, the mobile device **102** may be optimally oriented to the target object **106** such that three mutually intersecting planes of the target object, e.g., a left-side plane **116**, a right-side plane **118**, and a top plane **120**, are clearly visible, and such that the mobile device **102** is positioned nearest a top corner **122** of the target object (e.g., where the three planes **116**, **118**, **120** intersect) at an angle **124** (e.g., a 45-degree angle). For example, the system **100** may prompt the user **104** to reposition or reorient the mobile device **102** to achieve the optimal orientation described above.

Referring also to FIG. **2**, the mobile device **102** may include 2D image sensors **202** (e.g., a visible-light camera), 3D image sensors **204** (e.g., a 3D imager), image and control processors **206**, a touch-sensitive display surface **208**, and a wireless transceiver **210**. The mobile device **102** may additionally include a clock **212** or time sensor, a Global Positioning System (GPS) receiver **214** or similar position sensor for determining a current position of the mobile device, and an inertial measurement unit **216** (IMU) or similar inertial sensor (e.g., accelerometer, magnetometer, gyro-meter, compass) for determining a current orientation of the mobile device (or for tracking the orientation, and the rate of change thereof, over time). Instead of, or in addition to, onboard IMUs **216** of the mobile device **102**, the system **100** may incorporate IMUs integrated into the 2D image sensors **202** or into the 3D image sensors **204**. The 3D image sensors **204** may include imaging systems including infrared illuminators combined with multiple embedded cameras (e.g., Intel RealSense or other like triangulating systems), laser-based light detection and ranging (LIDAR) systems incorporating onboard photodetectors to track reflected beams and return distance information of the target object **106**, time of flight (ToF) camera systems, or any other like sensor system capable of producing 3D spatial information of proximate objects. As noted above, the 3D image sensors **204** may incorporate inertial or orientation sensors or combinations thereof, e.g., accelerometers, gyroscopes, and compasses. The 3D image sensors may include any suitable sensors for determining depth data of the target object, such as, but not limited to, distance sensors. For example, distance sensors may include sensors equipped to detect infrared radiation together with infrared or laser illuminators (e.g., light detection and ranging (LIDAR) systems.

In embodiments, the mobile device **102** may be oriented toward the target object **106** in such a way that the 3D image sensors **204** capture 3D imaging data from a field of view in which the target object **106** is situated. For example, the target object **106** may include a shipping box or container currently traveling through a supply chain, e.g., from a known origin to a known destination. The target object **106** may be freestanding on a floor **108**, table, or other flat surface; in some embodiments the target object **106** may be secured to a pallet or similar structural foundation, either individually or in a group of such objects, for storage or transport (as disclosed below in greater detail). The target object **106** may be preferably substantially cuboid (e.g., cubical or rectangular cuboid) in shape, e.g., having six rectangular planar surfaces intersecting at right angles. In embodiments, the target object **106** may not itself be perfectly cuboid but may fit perfectly within a minimum cuboid volume of determinable dimensions (e.g., the minimum cuboid volume necessary to fully surround or encompass the target object) as disclosed in greater detail below.

In embodiments, the system **100** may detect the target object **106** via 3D imaging data captured by the 3D image sensors **204**, e.g., a point cloud (see FIG. **3**A, point cloud **300**) comprising every point in the field of view of the 3D image sensors. For example, the point cloud **300** may correspond to an array of XY points (where XY corresponds to an imaging resolution, e.g., X vertical arrays of Y pixels each), each point within the point cloud having a depth value corresponding to a distance of the point (e.g., in millimeters) from the 3D image sensors **204** (or, e.g., a distance from the mobile device **102**).

3D image data **128** may include a stream of pixel sets, each pixel set substantially corresponding to a frame of 2D image stream **126**. Accordingly, the pixel set may include a point cloud **300** substantially corresponding to the target object **106**. Each point of the point cloud **300** may include a coordinate set (e.g., XY) locating the point relative to the field of view (e.g., to the frame, to the pixel set) as well as plane angle and depth data of the point, e.g., the distance of the point from the mobile device **102**.

The system **100** may analyze depth information about the target object **106** and its environment as shown within its field of view. For example, the system **100** may identify the floor (**108**, FIG. **1**) as a plane of gradually increasing depth that meets an intersecting plane (e.g., left-side plane **116**, a right-side plane **118**, a top-side plane **120**, FIG. **1**) of the target object **106**. Based on the intersections of the plane of the target object **106** (e.g., with each other or with the floor **108**), the system **100** may identify candidate edges. Similarly, the intersection of three plane surfaces, or the intersection of two candidate edges, may indicate a candidate corner (e.g., vertex).

In embodiments, the wireless transceiver **210** may enable the establishment of wireless links to remote sources, e.g., physical servers **218** and cloud-based storage **220**. For example, the wireless transceiver **210** may establish a wireless link **210***a* to a remote operator **222** situated at a physical distance from the mobile device **102** and the target object **106**, such that the remote operator may visually interact with the target object **106** and submit control input to the mobile device **102**. Similarly, the wireless transceiver **210** may establish a wireless link **210***a* to an augmented reality (AR) viewing device **224** (e.g., a virtual reality (VR) or mixed reality (MR) device worn on the head of a viewer, or proximate to the viewer's eyes, and capable of displaying to the viewer real-world objects and environments, synthetic objects and environments, or combinations thereof). For example, the AR viewing device **224** may allow the user **104** to interact with the target object **106** and/or the mobile device **102** (e.g., submitting control input to manipulate the field of view, or a representation of the target object situated therein) via physical, ocular, or aural control input detected by the AR viewing device.

In embodiments, the mobile device **102** may include a memory **226** or other like means of data storage accessible to the image and control processors **206**, the memory capable of storing reference data accessible to the system **100** to make additional determinations with respect to the target object **106**. For example, the memory **226** may store a knowledge base comprising reference boxes or objects to which the target object **106** may be compared, e.g., to calibrate the system **100**. For example, the system **100** may identify the target object **106** as a specific reference box (e.g., based on encoded information detected on an exterior surface of the target object and decoded by the system) and calibrate the system by comparing the actual dimensions of the target object (e.g., as derived from 3D imaging data) with the known dimensions of the corresponding reference box, as described in greater detail below.

In embodiments, the mobile device **102** may include a microphone **228** for receiving aural control input from the user/operator, e.g., verbal commands to the volume dimensioning system **100**.

Referring to FIG. 3A, a point cloud **300** within the field of view of, and captured by, the mobile device **102**, is disclosed.

In embodiments, the system **100** may determine the dimensions of the target object (**106**, FIG. **1**) (e.g., length **110**, width **112**, depth **114**; FIG. **1**) by capturing and analyzing 3D imaging data of the target object via the 3D image sensors (**204**, FIG. **2**) of the mobile device **102**. For example, the 3D image sensors **204** may, for each frame captured, generate a point cloud including the target object **106** and its immediate environment (e.g., including the floor **108**, FIG. **1**) on which the target object is disposed and a wall **302** (or other background) in front of which the target object is disposed). The point cloud **300** may be generated based on a depth map (not depicted) captured by the 3D image sensors **204**.

For example, the 3D image sensors **204** may ray cast (**304**) directly ahead of the image sensors to identify a corner point **306** closest to the image sensors (e.g., closest to the mobile device **102**). In embodiments, the corner point **306** should be near the intersection of the left-side, right-side, and top planes (**116**, **118**, **120**; FIG. **1**) and should, relative to the point cloud **300**, have among the lowest depth values (representing a position closest to the 3D image sensors **204**), corresponding to the top center corner (**122**, FIG. **1**) of the target object **106**. Any discrepancies between the identified corner point **306** and the actual top center corner **122** may be resolved as described below.

Referring also to FIG. **3**B, the point cloud **300***a* may be implemented similarly to the point cloud **300** of FIG. **3**A, except that the system **100** may identify points within the point cloud **300***a* corresponding to the target object (FIG. **1**, **106**).

In embodiments, the system **100** may perform radius searching within the point cloud **300***a* to segment all points within a predetermined radius **308** (e.g., distance threshold) of the corner point **306**. For example, the predetermined radius **308** may be set according to, or may be adjusted (**308***a*) based on, prior target objects dimensioned by the system **100** (or, e.g., based on reference boxes and objects stored to memory (FIG. **2**, **226**)). In embodiments, the system **100** may perform nearest-neighbors searches (e.g., k-NN) of the point cloud **300***a* to identify a set of neighboring points **310** likely corresponding to the target object **106**.

Referring also to FIG. 3C, the point cloud **300***b* may be implemented similarly to the point cloud **300***a* of FIG. **3**B, except that the system **100** may perform within the point cloud **300***b* plane segmentation on the set of neighboring points (**310**, FIG. 3B) identified within the point cloud **300***a*.

In embodiments, the system **100** may algorithmically identify the three most prominent planes **312**, **314**, **316** from within the set of neighboring points **310** (e.g., via random sample consensus (RANSAC) and other like algorithms). For example, the prominent planes **312**, **314**, **316** may correspond to the left-side, right-side, and top planes (**116**, **118**, **120**; FIG. **1**) of the target object (**106**, FIG. **1**) (e.g., provided the target object **106** is in or near an optimal orientation to the mobile device (**102**, as best shown by FIG. **1**) and may be fit to the left-side, right-side, and top planes **116**, **118**, **120**.

In embodiments, the system **100** may further analyze the angles **318** at which the prominent planes **312**, **314**, **316** mutually intersect to ensure that the intersections correspond to right angles (e.g., 90°) and therefore to edges **322**, **324**, **326** of the target object **106**. The system **100** may identify an intersection point (**306***a*) where the prominent planes **312**, **314**, **316** mutually intersect, for example, the intersection point **306***a* should substantially correspond to the actual top center corner (**122**, FIG. **1**) of the target object **106**. Furthermore, the system **100** may identify edge segments (e.g., edge segment **326***a*, FIG. **3**H) associated with an intersection of two adjacent planes of the prominent planes **312**, **314**, **316**.

Referring also to FIG. **3**D, the identified intersection point **306***a* may differ from the previously identified corner point **306**. In embodiments, the system may repeat the radius searching and plane segmentation operations shown above by FIGS. **3**B and **3**C based on the identified intersection point **306***a*, e.g., to more accurately identify the left-side, right-side, and top planes **116**, **118**, **120** of the target object **106**. Such refinement of radius searching and plane segmentation operations may be performed iteratively until some criterion is satisfied (e.g., a number of iterations); in some embodiments, the criterion may be adjusted based on user priorities (e.g., speed vs. precision). In some embodiments, the system **100** may display (e.g., via the display surface (**208**, FIG. **2**)) to the user (**104**, FIG. **1**) a positionable cursor **328**. For example, the user **104** may position the cursor **328** to assist the system **100** in selecting, e.g., an edge **322**, **324**, **326** or intersection point of the target object **106**. In some embodiments, the system **100** may be trained according to machine learning techniques, e.g., via a series of reference boxes of known dimensions as described below, to more quickly find an accurate intersection point **306***a*; prominent planes **312**, **314**, **316**; and edges **322**, **324**, **326**.

Referring also to FIGS. **3**E-**3**G, the point cloud **300***c* may be implemented similarly to the point cloud of **300***b* of FIG. **3**C, except that the system **100** may perform distance sampling of edge segments associated with the edges **322**, **324**, **326** identified by the prominent planes **312**, **314**, **316** of the point cloud **300***b*.

In embodiments, the system **100** may determine lengths of the edges **322**, **324**, **326** by measuring from the identified intersection point **306***a* along edge segments associated with the edges **322**, **324**, **326**. The measurement of edge segment associated with edges **322**, **324**, **326** may be performed until a number of points are found in the point cloud **300***c* having a depth value indicating the points are not representative of the target object (**106**, FIG. **1**), said non-representative points instead associated with, e.g., the floor **108** or the wall **302**. The system **100** may then perform a calculation (e.g., a Euclidean distance calculation) between the corner point **306** and one or more measured points along the edge segment to determine a distance associated with the corresponding edge.

In embodiments, the system **100** may then perform a search at intervals **330***a-c* along the edges **322**, **324**, **326** to verify the previously measured edges **322**, **324**, **326**. For example, the intervals **330***a-c* may be set based on the measured length of edge segments associated with edges **322**, **324**, **326**. Additionally or alternatively, the intervals **330***a-c* may also be set according to, or may be adjusted, based on prior target objects dimensioned by the system **100** (or, e.g., based on reference boxes and objects stored to memory (**226**, FIG. **2**)). In embodiments, the system **100** may perform nearest-neighbors searches (e.g., k-NN) of the point cloud **300***c* to identify a set of neighboring points **332***a-c* likely corresponding to the target object **106** within the intervals **330***a-c*. Based on the neighboring points **332**, the system **100** may determine a plurality of distances **334***a-c* associated with the edges **322**, **324**, **326**. Similar to determining the distance associated with the edge **322**, **324**, **326**, the system **100** may then perform a calculation (e.g., a Euclidean distance calculation) between two furthest points among each of the intervals **330***a-c* to determine the plurality of distances **334***a-c*.

In embodiments, as shown by FIG. **3**E, the search is performed on an identified prominent plane **314** (e.g., a candidate match for the left-side plane (**116**, FIG. **1**)) to determine a distance **334***a* associated with the edge **326**. For example, the edge **322**, which has been previously measured from the corner point **306***a*, may be segmented into an interval **330***a*. The interval **330***a* may be searched from the edge **322** along the plane **314** to identify neighboring points **332***a* of the point cloud **300***c*. Based on the neighboring points **332***a*, the distance **334***a* may be determined. The search may then be repeated along the remaining intervals **330** of the edge **322** to determine a sample set of distances **334** associated with the edge **326**. Based on the sample set, a length of the edge **326** may be determined (e.g., via a mean or median value of the sample set of distances **334**).

In embodiments, as shown by FIG. **3**F, the search may also be performed across the prominent plane **314** to determine a length **334***b* associated with the edge **322**. For example, the edge **326**, which had been previously measured from the corner point **306***a*, is segmented into intervals **330***b*. The interval **330***b* may be searched from the edge **326** to identify neighboring points **332***b* of the point cloud **300***c*. Based on the neighboring points **332***a*, the distance **334***b* may be determined. The search may then be repeated along one or more intervals **330***b* of the edge **326** to determine a sample set of distances **334***b* associated with the edge **322**. Based on the sample set of distances **334***b*, a length of the edge **322** may be determined (e.g., via a mean value of the sample set of distances).

In embodiments, as shown by FIG. **3**G, the search depicted in FIG. **3**E-**3**F may also be performed on the identified prominent planes **312**, **316** (e.g., candidate matches for, respectively, the right-side plane **118** and the top plane **120**) to determine a sample set of distances **334**, each distance **334** associated with the edge **324** (and, e.g., the edges **322**, **326**).

For example, each of the edges **322**, **324**, **326** may include distances **334** taken from multiple prominent planes **312**, **314**, **316**. The edge **322** may have sample sets of distances **334** taken from the identified prominent planes **314**, **316**. By way of another example, the edge **324** may have a sample set of distances **334** taken from the identified prominent planes **312**, **316**. By way of another example, the edge **326** may have a sample set of distances **334** taken from the identified prominent planes **314**, **316**. By sampling multiple sets of distances **334** for each edge **322**, **324**, **326**, the system **100** may account for general model or technology variations, errors, or holes (e.g., incompletions, gaps) in the 3D point cloud **300** which may skew individual edge measurements (particularly if the hole coincides with a corner (e.g., vertex, an endpoint of the edge).

In embodiments, the number and width of intervals **330** used to determine edge distances **334** is not intended to be limiting. For example, the interval **330** may be a fixed width for each plane. By way of another example, the interval **330** may be a percentage of the width of a measured edge. By way of another example, the interval **330** may be configured to vary according to a depth value of the points in the point cloud **300** (e.g., as the depth value indicates a further away point, the interval may be decreased). In this regard, a sensitivity of the interval may be increased.

In embodiments, the user (**104**, FIG. **1**) may select a setting which indicates the target object **106** has an oblong shape (not depicted). Upon the selection by the user, a width of the interval **330** may be adjusted accordingly. In the case of a target object **106** with an extra-long plane, the width of the interval for the extra-long plane may be increased relative to the other planes. Similarly, in the case of a target object **106** with an extra-short plane, the width of the interval **330** for the extra-short plane may be decreased relative to the other planes.

Referring also to FIGS. **3**H and **3**I, the point cloud **300***d* may be implemented similarly to the point cloud **300***c* of FIGS. **3**E-**3**G, except that the system **100** may be configured to account for divergences of the point cloud **300***d* from one or more edge segments.

In embodiments, the system **100** may be configured to account for points in the point cloud **300***d* which diverge from identified edge segments. For example, the system **100** may segment prominent planes (**312**, **314**, **316**; FIG. **3**G) and edges (**322**, **324**, **326**, FIG. **3**G). The system **100** may establish edge vectors **336** along which the system may sample at intervals to establish distances of the edge **322**, **324**, **326** segments (and, e.g., refine each distance by sampling at intervals across each prominent plane **312**, **314**, **316**, as shown by FIGS. **3**E through **3**G). However, as the system **100** samples along an edge vector **336** (e.g., associated with the edge segment **326**) from the origin point **306** (or, e.g., from a refined intersection point (**306***a*, FIGS. **3**C/D)), the component points of the point cloud **300***d* may diverge from the edge vector. For example, the system **100** may begin by searching for points in the point cloud **300***d* within a radius **338** of the edge vector **336**. As the component points of the point cloud **300***d* corresponding to the edge segment **326** diverge (**326***a*) from the edge vector **336** (e.g., due to a reflectivity of the floor **108**), the system **100** may need to enlarge the radius (**338***a*) within which it searches for points corresponding to the edge **326**. A significant divergence (**326***a*) from the edge vector **336** may affect distance measuring.

In embodiments, the system **100** may account and/or compensate for the divergence by searching within the radius **338** of a previous point **340** (as opposed to, e.g., searching at intervals (**330***a-b*, FIGS. **3**E/F)) for the next point **340***a* of the edge segment **326***a*. For example, the edge vector **336** may be updated based on a weighted average of the initial or current vector and the vector from the previous point **340** to the next point **340***a*, updating the edge vector to account for the actual contour of the divergent edge segment (**326***a*) as a component of the point cloud **300***d*.

In this regard, the system **100** may determine an updated edge segment **326***b* consistent with the point cloud **300***d*. The system **100** may then determine a distance of the edge **326** associated with the updated edge segment **326***b*, as discussed previously (e.g., by a Euclidean distance calculation). In some embodiments, the system **100** may generate a "true edge" **326***c* based on, e.g., weighted averages of the original edge vector **336** and the divergent edge segment **326***a*.

The ability to determine an updated edge segment **326***b* based on diverging points in the point cloud **300***d* may allow the system **100** to more accurately determine a dimension of the target object **106**. In this regard, where the points diverge from the initial edge vector **336** (e.g., edge segment **326***a*) a search may prematurely determine that an end of the edge segment has been reached (e.g., because no close points are found within the radius **338**), unless the system **100** is configured to account for the divergence. This may be true even if there are additional neighboring points (**310**, FIG. **3**B) associated with the target object **106**. Furthermore, where the target object **106** includes elongated planes and/or edges (see, e.g., FIGS. **4**A/B below), any divergence of points from an edge segment **326** may be magnified through a crawl of the edge segment (e.g., from the origin point **306** to an endpoint **342**), as compared to a shorter plane.

In embodiments, the system **100** is configured to capture and analyze 3D imaging data of the target object **106** at a plurality of orientations. For example, it may be impossible or impractical to capture the left-side plane, right-side plane, and top plane (**116**, **118**, **12-0**; FIG. **1**) within the field of view of the mobile device **102**, e.g., the target object **106** may be a cuboid having one or more highly elongated edges (**402**) and/or surfaces which may complicate radius searching and plane segmentation operations from a single perspective. Accordingly, in embodiments the system **100** may combine 3D imaging data from multiple perspectives to determine the dimensions of the target object **106**.

Referring to FIG. **4**A, the system **100** may image the target object **106** at a first orientation to determine a first point cloud **404** (e.g., first frame dataset). As depicted in FIG. **4**B, the system **100** may image the target object **106** at a second orientation to determine a second point cloud **406** (e.g., second frame dataset). The system **100** may further be configured for 3D reconstruction. Based on the first point cloud **404** and the second point cloud **406**, the system **100** may construct a 3D reconstruction of the target object **106**, e.g., matching the prominent plane **408** identified within the first point cloud **404** and the prominent plane **410** identified within the second point cloud **406** to a common prominent plane within the 3D reconstruction (e.g., **314**, FIGS. **3**A-F). The system **100** may then store the 3D reconstruction in a frame dataset (e.g., for determining one or more dimensions of the target object **106**).

Referring to FIG. **5**A, in embodiments the system **100** may be configured to dimension a target object **502** with edges **504**, **506**, and **508**. For example, the system **100** may be configured to determine one or more dimensions of the target object **502** by plane segmentation and distance sampling (as discussed above). The determined dimensions may then be compiled in memory (**226**, FIG. **2**) of the system **100**. Similarly, one or more frames of image data captured by the 3D imager (e.g., an image stream) may be compiled with the determined dimensions in the memory **226**. In this regard, the memory **226** may include captured images and dimensions determined based on the captured images.

In embodiments, the memory **226** may further include reference dimensions of the target object **502**. Such reference dimensions may be the dimensions of the target object **502** which may be known or determined by a conventional measuring technique. For example, the system **100** may be tested according to machine learning techniques (e.g., via identifying reference objects and/or comparing test measurements to reference dimensions) to quickly and accurately (e.g., within 50 ms) dimension target objects (**106**, FIG. **1**) according to National Type Evaluation Program (NTEP) accuracy standards.

In embodiments, the system **100** may then compare the determined dimensions and the reference dimensions to determine a difference between the determined dimensions and the reference dimensions. Such comparison may allow the system **100** to establish an accuracy of the determined dimensions. If the determined difference between the measured dimensions and the reference dimensions exceeds a threshold value, the system **100** may provide a notification to the user (**104**, FIG. **1**). As may be understood, the threshold value can be any appropriate value (e.g., an absolute value, from 1 cm to 5 inches or more, or a relative value, e.g., ±2 percent of the total dimension of an edge **504**-**508**). The threshold value may optionally be set by the user **104**.

If the determined difference between the measured dimensions and the reference dimensions exceeds the threshold value, the user **104** may take appropriate action. When notified, the user **104** may be prompted to do any of the following: redo the dimension capture, enter notes explaining the difference in dimensions, notify an individual qualified to investigate the discrepancy, or the like. Additionally, the system **100** may also notify the user of a new TI-HI value to help determine how many of a particular target object **502** will fit on a pallet. This may support packaging processes in a warehouse by determining a better slot in a warehouse for the storing of the particular target object **502**. This may also help recalculate the best shipping method (e.g., parcel or freight) for the particular target object **502**.

As may be understood, the target object **502** may include an identifier, such as a Quick-Response (QR) code **510** or other identifying information encoded in 2D or 3D format. The system may be configured to scan the QR code **510** of the target object **502** and thereby identify the target object **502** as a reference object. Furthermore, the QR code **504** may optionally include reference data particular to the target object **502**, such as the reference dimensions. Although the target object **502** is depicted as including a QR code **504**, this is not intended to limit the encoded information identifying the target object **502** as a reference object. In this regard, the user **104** may measure the reference dimensions of the target object **502**. The user **104** may then input the reference dimensions to the system **100**, saving the target object **502** as a reference object or augmenting any information corresponding to the reference object already stored to memory **226**.

In embodiments, referring also to FIG. **5**B, the system **100** may compare a compilation **512** of data determined by the system **100** to reference data (e.g., stored to the memory **226**, FIG. **2**) in order to make additional determinations with respect to the target object **502**. For example, the compilation **512** may include determined dimensions **514** and frame of image data associated with the target object **502** after the dimensions of the target object **502** which have been determined to a sufficient level of accuracy or confidence.

In embodiments, the system **100** may compare the determined dimensions **514** of the target object **502** to the dimensions of reference shipping boxes (**516**) or predetermined reference templates (**518**) corresponding to shipping boxes or other known objects having known dimensions (e.g., stored to memory **226** or accessible via cloud-based storage (**220**, FIG. **2**) or remote databases stored on physical servers (**218**, FIG. **2**)). For example, the system **100** may display for the user's selection (e.g., via a searchable menu **520**) reference templates **518** corresponding to storage containers, storage bins, or storage locations and sublocations within racking, shelving or organizing systems of various sizes. In embodiments, the user may compare the determined dimensions **514** of the target object **502** to a predetermined template **518**, e.g., to determine, whether the target object **502** corresponds to a reference template **518** (e.g., within an adjustable margin), whether the target object **502** will fit inside a larger object or within a given shipping space, to audit and/or certify a dimension measurement (e.g., to NTEP standards), or to calibrate or verify the accuracy of the system **100**. For example, the user may manually enter reference dimensions to which the measured dimensions **514** of the target object **502** may be compared (e.g., if the orientations of a template **518** do not precisely match a target object **502** to which the template dimensions may otherwise correspond). If insufficient information about the target object **502** is known (e.g., guidelines for storage, transport, or perishability), the system **100** may infer this information from what is known about similarly sized shipping boxes **516** or their contents. Similarly, the user may fill in the dimensions **514** of the target object **502** based on a corresponding template **518** that approximates or matches the dimensions of the target object **502**. The user may create a new template by measuring a target object **502** and adding its dimensions **514** as a new known reference object. For example, the user **104** may create a template called "SMALL BOX" having predefined dimensions (e.g., 8.00 in×11.50 in×6.75 in), measuring a target object **502** corresponding to these dimensions via the system **100** to calibrate the system and "learn" the new template for future reference (or, e.g., determine if further training of the system is necessary).

In embodiments, the system **100** may employ machine learning techniques to determine dimensions **514** of a new known reference template. For example, the system **100** may determine dimensions **514** of a new known reference template by averaging dimensions of target objects **502** having the same shop keeping unit (SKU). Further, the system **100** may determine dimensions **514** of a new known reference template by using the last measured dimensions **514** by the system **100**.

In embodiments, the system **100** may include a server for collecting information on the target object **502** being scanned by the system **100**. The server may collect information on the target object **502** including: 3D/2D dimensions, a weight, the identified shop keeping unit (SKU), captured images that are associated with a same SKU, and a QR code. The collected information may be uploaded from the server to a larger database (e.g., eCommerce listings or product databases) for further use.

Referring generally to FIGS. **6**A-**6**C, the system **100** may be configured to segment one or more background planes within the point cloud **300**, e.g., a floor **108**, flat surface, or wall **302**. For example, it may not be possible to accurately identify or segment the three prominent planes (**312**, **314**, **316**; FIGS. **3**A-F) and thus a plane segmentation may be augmented by inferring a prominent plane from the floor **108**, flat surface, or wall **302**.

In embodiments, referring in particular to FIG. **6**A, a plane of the floor **108** (e.g., a floor plane) is to be segmented. For example, the 3D image sensors **204** may ray cast (**304**) directly ahead of the image sensors to identify a corner point **602**. The corner point **602** may be disposed between the floor **108**, the left-side prominent plane **314**, and the right-side prominent plane **316**. The corner point **602** may be determined by any suitable method, such as, but not limited to, the ray cast **304** based on a depth value of the corner point **602**. For example, the left-side prominent plane **314** and the right-side prominent plane **316** may have depth values which converge on the corner point **602**.

In embodiments, referring also to FIG. **6**B, the system **100** may perform a radius search to determine a point segmentation **604** of neighboring points within a predetermined radius **606** from the corner point **602**, in accordance with one or more embodiments of the present disclosure.

In embodiments, referring also to FIG. **6**C, the system **100** may determine planes associated with the point segmentation **604**, such as a floor plane **608**, a left-side plane **610**, and a right-side plane **612**. The system **100** may further determine the edge **326** disposed between the left-side plane **610** and the right-side plane **612**, an edge **614** disposed between the left-side plane **610** and the floor plane **608**, and an edge **616** disposed between the right-side plane **612** and the floor plane **608**, by an intersection of the planes **608**, **610**, **612**. The system **100** may further perform an additional segmentation to refine the corner point **602** and iteratively determine the edges **326**, **614**, **616** as described above (see, e.g., FIGS. **3**C/D and accompanying text). In embodiments, the ability to segment edges **614**, **616** from the floor **108** may aid in addressing artifacts associated with a high reflectivity of the floor **108** or flat surface, e.g., especially near the edges **614**, **616**. For example, reflective artifacts may create a curl in the depth data reducing an accuracy of points in the point cloud (**300**, FIGS. **3**C/D) near the edges **614**, **616**. Accordingly, the system **100** may compensate for curl artifacts by determining the edges **604**, **606**.

Referring generally to FIG. **7**A-D, the system **100** may be configured to segment the floor **108** or the wall **302** when only two planes of the target object (**106**, FIG. **1**) are visible to the 3D image sensors (**204**, FIG. **2**). This may be beneficial where imaging three planes of a target object **700** via the 3D image sensors **204** is difficult (e.g., for an upright refrigerator or other tall object not compatible with the ideal orientation of mobile device (**102**, FIG. **1**) to target object **106** shown by FIG. **1**).

In embodiments, referring in particular to FIG. **7**A, the system may obtain a point cloud **702** of the target object **700** when only the left-side plane **610** and the right-side plane **612** of the target object **106** are visible. For example, the 3D image sensors **204** may ray cast **304** directly ahead of the image sensors to identify a corner point **602**, as discussed above in one or more embodiments.

In embodiments, referring also to FIG. **7**B, the system **100** may perform radius searching based on a radius **703** from the corner point **602** to determine a point segmentation **604** as discussed above in one or more embodiments.

In embodiments, referring also to FIG. **7**C, the system **100** may determine one or more segmented planes e.g., a floor plane **608**, the left-side plane **610**, and a right-side plane **612**. The system **100** may further determine the edge **326** disposed between the left-side plane **610** and the right-side plane **612**, the edge **614** disposed between the left-side plane **610** and the floor plane **608**, and the edge **616** disposed between the right-side plane **612** and the floor plane **608**, by an intersection of the planes **608**, **610**, **612**.

In embodiments, referring also to FIGS. **7**D and **7**E, a plurality of distances **334** associated with the edges **326**, **614**, and **616** may be determined, in accordance with one or more embodiments. Based on these distances **334**, dimensions for edges **326**, **614**, and **616** may be determined (e.g., via a median value). Further, by dimensioning the edges **614** and **616**, the system **100** may accurately dimension the top plane or surface (see, e.g., **312**, FIGS. **3**A-F) of the target object **700** (and substantially parallel both to the floor **108** and to a bottom surface **704** adjacent to the floor) although the top plane or surface may not be visible to the 3D image sensors **204**.

Referring to FIG. **8**, the system **100** may be configured to dimension a target object **800** with an anomalous plane **802** (e.g., and/or anomalous edge **802***a*). For example, the system **100** may generate a point cloud **804** and perform a radius search and a plane segmentation (**604**, FIGS. **6**A-C) of the target object **800**, as discussed previously. The plane segmentation **604** may attempt to determine three prominent planes (**312**, **314**, **316**; FIGS. **3**A-G) typical to a cuboid object. The system **100** may further include a check to determine whether the plane segmentations determined are sufficiently in accordance with a target object having a substantially cuboid shape. In this regard, depth values associated with the points of the point cloud in the plane segmentation are expected to decrease, e.g., as a radius **806** increases from an origin point **808** corresponding to an intersection of prominent planes **312**-**316**. However, a target object **800** with an anomalous plane **802** may have depth values which do not follow this trend (e.g., due to a bulge (anomalous edge **802***a*) in a wall of a box). Upon determining the presence of the anomalous plane **802**, the system **100** may adjust a sampling of edge distances **334** based on the anomalous plane **802** (e.g., to identify and eliminate outlying or inconsistent edge distances **810**).

Referring generally to FIG. **9**A through **9**C, the system **100** may be configured to dimension a nonstandard target object **900**, e.g., target objects having a substantially non-cuboid shape, collections of objects stacked upon either other, or objects positioned upon a pallet or like shipping structure. For example, the system **100** may be trained according to machine learning techniques, and based on example templates, to identify and dimension particular types of nonstandard target objects (e.g., or groups thereof, as described below). In some embodiments, a neural network may be trained to detect and/or measure points of the target object.

In embodiments, referring in particular to FIG. **9**A, the target object **900** may have a substantially non-cuboid shape, e.g., a shipping container for a chainsaw or similar object in a non-cuboid container. For example, the target object **900** may present inconsistent planes and edges through several iterations of ray casting, radius searching, and plane segmentation (see, e.g., FIGS. **3**A-G and accompanying text above). In embodiments, the system **100** may fit the target object **900** into a bounding box **902** by segmenting extreme planes **904**, **906**, **908** (e.g., based on extreme depth values and/or distance information) and extending the edges **910** of the extreme planes. For example, the system **100** may determine (e.g., which determination may include additional user input or may be taught to the system according to machine learning techniques and common nonstandard objects) that the bounding box **902** is the minimum bounding box, e.g., the smallest possible bounding box capable of completely enclosing the target object **900**.

Referring now to FIGS. **9**B and **9**C, the nonstandard target objects **900***a*-*b* may be implemented similarly to the nonstandard target object **900** of FIG. **9**A, except that the nonstandard target object **900***a* may be positioned on/attached to a pallet **914** or other similar shipping structure or foundation, and the nonstandard target object **900***b* may consist of two or more stacked sub-objects **912**.

In embodiments, referring in particular to FIG. **9**B, the system **100** may account for any pallets **914** or other shipping structures/foundations **820** to which the nonstandard target object **900***a* is attached, determining the minimum possible dimensions **916** (e.g., a minimum bounding box) of the palleted nonstandard target object **900***a* (e.g., based on the minimum possible amount of shelf space the nonstandard target object **900***a* attached to the pallet **914** would occupy in a vehicle, in a warehouse, or elsewhere in the supply chain) in addition to the dimensions of the nonstandard target object **900***a* without the pallet **914**. For example, the system **100** may account for the pallet **914** by distinguishing segments consistent with the pallet (e.g., plane segments **918**, edges **920**) from plane segments, most prominent planes **312**, **314**, **316** and/or edges **322**, **324**, **326** consistent with the target object **900***a* (e.g., unpalleted box) itself. Accordingly, the system **100** may determine a corner point **306** associated with the target object **900***a* proper, and a corner point **922** associated with the pallet **914**. Such plane and edge segmentation operations may be assisted by input from the user (**104**, FIG. **1**); e.g., the system **100** may prompt the user that a palleted target object **900***a* has been identified and request the user affirm that this is the case, whereby the system **100** may proceed with pallet-focused radius searching and plane segmentation operations.

Referring now to FIG. **9**C, the nonstandard target object **900***b* and the nonstandard target object **900***b* may consist of two or more stacked identical sub-objects **912**. In embodiments, the system **100** may generate a minimum bounding box **924** enclosing the stacked sub-objects **912** according to one or more dimensioning operations as disclosed above. In some embodiments, the system **100** may further analyze the point cloud including the nonstandard target object **900***b* to distinguish common or shared prominent planes (**926**) from inconsistent prominent planes (**928**). For example, the system **100** may prompt the user **104** to affirm that the target object **900***b* is a stack of sub-objects **912**, and may further prompt the user to identify boundaries **930** between the sub-objects, such that an accurate dimension of each individual sub-object may be measured.

Referring to FIG. **10**, a method **1000** for dimensioning an object may be implemented by embodiments of the system **100**.

At a step **1002**, a three-dimensional (3D) image stream of a target box positioned on a background surface may be obtained. The 3D image stream may be captured via a mobile computing device. The 3D image stream may include a sequence of frames. Each frame in the sequence of frame may include a plurality of points (e.g., a point cloud). Each point in the plurality of points may have an associated depth value.

At a step **1004**, at least one origin point within the 3D image stream may be determined. The origin point may be identified via the mobile computing device. The origin point may be determined based on the depth values associated with the plurality of points. In this regard, the origin point may have a depth value indicating, of all the points, the origin point is closest to the mobile computing device.

At a step **1006**, at least three plane segments of the target object may be iteratively determined. The at least three plane segments may be determined via the mobile computing device. Furthermore, step **1006** may include iteratively performing steps **1008** through **1014**, discussed below.

At a step **1008**, a point segmentation may be acquired. The point segmentation may include at least one subset of points within a radius of the origin point. The subset of points may be identified via the mobile computing device. The radius may also be predetermined.

At a step **1010**, a plurality of plane segments may be identified. For example, two or three plane segments may be acquired. The plurality of plane segments may be identified by sampling the subset of neighboring points via the mobile computing device. Each of the plurality of plane segments may be associated with a surface of the target box. In some embodiments, three plane segments are determined, although this is not intended to be limiting.

At a step **1012**, a plurality of edge segments may be identified. The plurality of edge segments may be identified via the mobile computing device. The edge segments may correspond to an edge of the target box. Similarly, the edge segments may correspond to an intersection of two adjacent plane segments of the plurality of plane segments. In some embodiments, three edge segments are determined, although this is not intended to be limiting.

At a step **1014**, an updated origin point of may be determined. The updated origin point may be based on an intersection of the edge segments or an intersection of the plane segments. Steps **1008** through **1014** may then be iterated until a criterion is met. In some instances, the criterion is a number of iterations (e.g., 2 iterations).

At a step **1016**, the edge segments may be measured from the origin point along the edge segments to determine a second subset of points. Each point in the second subset of points may include a depth value indicative of the target object. In this regard, the edge segments may be measured to determine an estimated dimension of the target object. However, further accuracy may be required.

At a step **1018**, one or more edge distances are determined by traversing each of the at least three edge segments over at least one interval. The interval may be based in part by the measured edge segments from step **1016**. Furthermore, the edge distances may be determined by sampling one or more distances across the point cloud, where each sampled distance is substantially parallel to the edge segment.

At a step **1020**, one or more dimensions corresponding to an edge of the target box may be determined based on the one or more edge distances. The determination may be performed via the mobile computing device. The determination may be based on a median value of the one or more edge distances.

Referring generally to FIGS. **1A-10**B, the system **100** is described herein. In some embodiments, the system **100** may account for imperfect data sets, e.g., gaps or holes in the point cloud, via plane identification. For example, the system may analyze 3D spatial information to infer the planes of the target object **106**, e.g., on the basis of a sufficient number of identified points aligned in a plane or nearly enough aligned (e.g., within a predetermined range) to derive the existence of a plane. By utilizing plane identification based solely on 3D spatial information collected by the 3D image sensors **204**, the system **100** may identify the target object **106** and its component planes quickly enough, or to a sufficient level of confidence, to meet user **104** needs. In this regard, system **100** must be faster than manually measuring the target object **106**.

In embodiments, the system **100** may be trained via machine learning to recognize and lock onto a target object **106**, positively identifying the target object and distinguishing the target object from its surrounding environment (e.g., the field of view of the 2D image sensors **202** and 3D image sensors **204** including the target object as well as other candidate objects, which may additionally be locked onto as target objects and dimensioned). For example, the system **100** may include a recognition engine trained on positive and negative images of a particular object specific to a desired use case. As the recognition engine has access to location and timing data corresponding to each image or image stream (e.g., determined by a clock **212**/GPS receiver **214** or similar position sensors of the embodying mobile device **102** or collected from image metadata), the recognition engine may be trained to specific latitudes, longitudes, and locations, such that the performance of the recognition engine may be driven in part by the current location of the mobile device **102***a*, the current time of day, the current time of year, or some combination thereof.

A holographic model may be generated based on edge distances determined by the system. Once the holographic model is generated by the system **100**, the user **104** may manipulate the holographic model as displayed by a display surface of the device **102**. For example, by sliding his/her finger across the touch-sensitive display surface, the user **104** may move the holographic model relative to the display surface (e.g., and relative to the 3D image data **128** and target object **106**) or rotate the holographic model. Similarly, candidate parameters of the holographic model (e.g., corner point **306**; edges **322**, **324**, **326**; planes **312**, **314**, **316**; etc.) may be shifted, resized, or corrected as shown below. In embodiments, the holographic model may be manipulated based on aural control input submitted by the user **104**. For example, the system **100** may respond to verbal commands from the user **104** (e.g., to shift or rotate the holographic model, etc.)

In embodiments, the system **100** may adjust the measuring process (e.g., based on control input from the operator) for increased accuracy or speed. For example, the measurement of a given dimension may be based on multiple readings or pollings of the holographic model (e.g., by generating multiple holographic models per second on a frame-by-frame basis and selecting "good" measurements to generate a result set (e.g., 10 measurement sets) for averaging). Alternatively or additionally, a plurality of measurements over multiple frames of edges **322**, **324**, **326** may be averaged to determine a given dimension. Similarly, if edges measure within a predetermined threshold (e.g., 5 mm), the measurement may be counted as a "good" reading for purposes of inclusion within a result set. In some embodiments, the confirmation tolerance may be increased by requiring edges **322**, **324**, **326** to be within the threshold variance for inclusion in the result set.

In some embodiments, the system **100** may proceed at a reduced confidence level if measurements cannot be established at full confidence. For example, the exterior surface of the target object **106** may be matte-finished, light-absorbing, or otherwise treated in such a way that the system may have difficulty accurately determining or measuring surfaces, edges, and vertices. Under reduced-confidence conditions, the system **100** may, for example, reduce the number of minimum confirmations required for an acceptable measure (e.g., from 3 to 2) or analyze additional frames per second (e.g., sacrificing operational speed for enhanced accuracy). The confidence condition level may be displayed to the user **104** and stored in the dataset corresponding to the target object **106**.

The system **100** may monitor the onboard IMU (**216**, FIG. **2**) of the mobile device **102** (e.g., or inertial/orientation sensors integrated into the 3D image sensors (**204**, FIG. **2**) to detect difficulty in the identification of candidate surfaces, candidate edges, and candidate vertices corresponding to the target object **106**. For example, the IMU **216** may detect excessive shifts in the orientation of the mobile device **102** as the user **104** moves the mobile device around and the system **100** attempts to lock into the parameters of the target object. Similarly, the IMU **216** may notice rotational movement by the user **104** around the target object **106** and take this movement into account in the generation of the 3D holographic model.

The three-dimensional methods described previously herein utilize a point cloud with 3D depth data on a frame-by-frame basis from a stream of frames. The point cloud is generated with each frame. As the number of frames-per-second increases, the amount of data processed in the three-dimensional methods increases. The processing time of the three-dimensional methods may be hindered by the size of the 3D depth data. For example, current generation processors may use the three-dimensional methods to determine the lengths of the edges on the order of several seconds.

Embodiments of the present disclosure are also directed to a two-dimensional method. The two-dimensional method utilizes a depth map (e.g., depth matrix) on a frame-by-frame basis. The depth map is generated with each frame. The depth map includes significantly less data than the point cloud utilized in the three-dimensional method. The depth map is a two-dimensional (e.g., xy) pixel by pixel matrix with a depth value associated with each pixel. In this regard, the two-dimensional method may process significantly less data and may perform the calculations with an order of magnitude twice as fast or more as the three-dimensional methods. For example, current generation processors may use the two-dimensional method to determine the lengths of the edges in less than a second.

Referring now to FIG. **11**, a flow diagram of a method **1100** is described, in accordance with one or more embodiments of the present disclosure. The method **1100** may refer to a method of box key-point recognition and measurement. The applicant has dubbed the method **1100** as CORNR 2D, although this is not intended to be limiting. The embodiments and enabling technology described previously herein in the context of the system **100** and the mobile device **102** should be interpreted to extend to the method **1100**. For example, the method **1100** may be implemented by the system **100** and/or the mobile device **102**. It is further recognized that the method **1100** is not limited by the system **100** and/or the mobile device **102**. The method **1100** may be further understood with reference to the exemplary illustrations in FIGS. **12**A-**12**D.

In a step **1110**, imaging data is captured by an imaging sensor. For example, the image sensor may be the 2D image sensors **202** and/or the 3D image sensors **204**, which may be different capture systems within the same 2D/3D camera device integrated or attached to the mobile device **102**. The imaging data is associated with a target object positioned on a surface. For example, the target object may be the target object **106**. The imaging data includes a sequence of frames, e.g., a video stream incorporating one frame after another. Each frame includes a depth map. Every frame includes a new depth map **1202**. The depth map **1202** is a projection of real 3D space. The depth map **1202** is a matrix with x-coordinates, y-coordinates, and depth values associated with coordinate pairs of the x-coordinates and y-coordinates. In some instances, the depth map may be illustrated to indicate the depth values (e.g., using different or gradient colors to represent different depth values), although this is not depicted in the present application. Each pixel in the frame may be defined by its x and y-coordinates and may include the depth value. The depth values indicate the distance of the pixel to the image sensor. For example, the distance may be the distance between the image sensor and one of the target object or the surface on which the target object is positioned.

In some embodiments, the image sensor captures 3D image data. The image sensor then projects the 3D image data to generate the depth map. The 3D image data includes three-dimensional points **1201** (FIG. **12**F). The three-dimensional points **1201** include point coordinates [x', y', z']. The point coordinates [x', y', z'] are provided relative to the image sensor used to generate the frame. In this regard, the point coordinate [0, 0, 0] is disposed at the image sensor. The depth map **1202** (FIGS. **12**D-E) includes two-dimensional pixel coordinates [x, y] and a depth channel. The pixel coordinate [x, y] indicate the row and column of the pixel. In this regard, the pixel coordinate [0, 0] is a pixel in a first row and first column of the frame. The three-dimensional points **1201** are projected into 2D pixel location each with an associated depth value.

In a step **1120**, an origin point **1204** (FIGS. **12**B-D) within the matrix of depth values is identified. The origin point **1204** may also be referred to as a primary point. Similarly, the step **1120** may also be referred to as primary corner estimation. The origin point **1204** may be associated with a corner of the target object. For example, the origin point **1204** may be associated with the top corner **122** of the target object **106**. The depth values may be examined for a local minimum to identify the origin point **1204**. The local minimum represents the closest pixel in the imaging data (e.g., shortest distance to the image sensor), which may or may not exclude the ground plane surface. Assuming the target object is positioned with the top corner facing the image sensor, the local minimum will be the approximately the tip of the corner.

The imaging data may also include a cursor **1206**. In some embodiments, the origin point **1204** is a local minimum of the depth values within the cursor **1206** of the imaging data. The cursor **1206** indicates a search area for a corner of the target object. The imaging sensor is manually aligned such that the corner of the target object is within the cursor **1206**. For example, the operator may position and orient the mobile device **102** relative to the target object so that the entire object is within the field-of-view of the imaging sensor and the top corner **122** is within the cursor **1206**. The cursor **1206** may be a two-dimensional shape such as a bracket, a rectangle, a circle, and the like. In some embodiments, the program instructions may display a prompt to guide the operator to adjust the target position and orientation by repositioning the imaging sensor until the origin point **1204** is disposed within the cursor **1206**.

In some embodiments, the cursor **1206** is disposed in a center of the imaging data. In some embodiments, the cursor **1206** is offset from a center of the imaging data. For example, the cursor **1206** may be offset from the center where the target object is a cuboid which is substantially longer in one dimension. The closest corner of the cuboid which is substantially longer in one dimension may be offset to enable capturing the corner within the cursor **1206** and capturing the entire target object within the imaging data. In some embodiments, the position of the cursor **1206** relative to the center of the imaging data may be adjustable in response to an input. For example, the mobile device **102** may receive an input to manually reposition the cursor **1206**. In some embodiments, the system may automatically sense a long target object, as described, and automatically adjust and reposition the cursor for the operator to better able to get the entire long target object into the viewscreen.

In some embodiments, the size of the cursor **1206** may be adjusted. Adjusting the size of the cursor **1206** may then adjust the size of the search area. The user of the mobile device **102** may more easily capture the origin point within the cursor **1206** as the size of the cursor is increased. Increasing the cursor may allow the mobile device to search for an origin point associated with the corner in a larger area at an expense of increased search time. Similarly, decreasing the search area may improve the search time at the expense of a searching for the origin point in a smaller area. In some embodiments, the size of the cursor **1206** may be adjusted in response to an input. For example, the mobile device **102** may receive an input to manually reposition the cursor **1206**. In some embodiments, the size of the cursor **1206** may be automatically adjusted based on a confidence level.

In a step **1130**, the volume dimensioning system **100** crawls from the origin point **1204** along edges of the target object to the far corners of the target object. The step **1130** may also be referred to as edge contour crawling and key-point estimation. Starting at the origin point **1204** calculated in the previous step, the left, right, and vertical edges of the target object are crawled to their respective far corners. The goal is to determine the two points to define lines to measure for each of the three edges emanating from the origin point **1204**. The volume dimensioning system **100** may crawl from the origin point along the edges via an edge crawling algorithm. For example, the edge crawling algorithm crawls from the origin point **1204** along a first edge **1208***a* to a first corner **1210***a*, a second edge **1208***b* to a second corner **1210***b*, and a third edge **1208***c* to a third corner **1210***c* of the target object.

The edge crawling algorithm of the volume dimensioning system **100** may include one or more inputs, such as, the depth map **1202**, the origin point **1204**, a step vector **1212**, and a test vector **1214**. The checkpoint is initially the origin point **1204** and is updated upon detecting minimum depth values which correspond to a minimum distance away from the camera. The step vector **1212** may refer to a direction in the depth map **1202** in which to step from a checkpoint **1216**. The test vector **1214** may refer to a direction in the depth map **1202** in which to examine for minimum depth values. The step vector **1212** and test vector **1214** may include one or more step vectors depending upon which of the edges **1208** is being evaluated. For example, the step vector **1212** may include a step left value (−1, 0) to evaluate the edge **1208***a*, a step right value (1, 0) to evaluate the edge **1208***b*, or a step vertically down value (0, −1) to evaluate the edge **1208***c*. By way of another example, the test vector **1214** may include a test up vector (0, 1) to evaluate the edge **1208***a* and/or the edge **1208***b*, test left vector (−1, 0) to evaluate the edge **1208***c*, and/or a test right vector (1, 0) to evaluate the edge **1208***c*. As may be understood, the specific values for the step vector **1212** and the test vector **1214** are not intended to be limiting and are merely exemplary.

The edge crawling algorithm determines the checkpoints **1216**. The checkpoints **1216** may also be referred to as edge points. The checkpoints **1216** define the edges **1208** and the corners **1210**.

The volume dimensioning system **100** may iteratively perform one or more steps using the edge crawling algorithm. In a step **1132**, the one or more processors step from a checkpoint according to a step vector and examine depth values along a test vector for a change in depth value to find a minimum depth value. In a step **1134**, the checkpoint **1216** is moved to the minimum depth value. The edge crawling algorithm implement crawling logic according to the step vector **1212** and the test vector **1214**. The edge crawling algorithm steps in the direction of the step vector **1212**. The edge crawling algorithm then steps in the direction of the test vector **1214** to determine if the next value is less than or equal to the current cell value. If the next value is less than or equal to the current cell value, continue moving in the direction of the test vector **1214**. If the next value is greater than the current cell value not, move in the direction of the step vector then iterate. The edge crawling algorithm may be generic to either of the three directions/dimensions-left, right, or vertical (down) from the origin point **1204** depending upon the values of the step vector **1212** and the test vector **1214**.

The step **1132** and step **1134** are iteratively repeated to determine the checkpoints **1216** defining the edges **1208**. The number of the checkpoints **1216** may be based on a resolution of the depth map **1202** and a size of the target object within the depth map **1202**. It is contemplated that each of the edges **1208** may be defined by several hundred or thousands of the checkpoints **1216**.

For example, FIG. **12**D depicts a portion of the depth map **1202**. In this example, the origin point **1204** is 700 mm from the image sensor. As depicted, the depth value is measured in millimeters, although this is not intended to be limiting. The step vector **1212** is set to a value of (−1,0) and the test vector **1214** is set to a value of (0, 1). In this regard, the checkpoint **1216** is stepped one to the left and then each point above the stepped value in the depth map **1202** is examined for the change in depth value. Multiple checkpoints **1216** are determined. In this example, nine of the checkpoints are determined from the origin point **1204**. This example is not intended to be limiting.

The step **1132** and step **1134** may be iteratively repeated until one or more conditions are met. The conditions may include a detecting a directional change and/or detecting a continuous segment of empty depth values.

The volume dimensioning system **100** may be iteratively repeat the edge crawling algorithm until a directional change is detected. For example, FIG. **12**E depicts a portion of the depth map **1202**. In this example, the corner **1210***a* is 929 mm from the image sensor. The volume dimensioning system **100** has detected the corner **1210***a* by detecting a directional change **1218**. The directional change **1218** may be due to a second target object adjacent to the first target object (e.g., multiple boxes on a pallet). The last point of the vector before the point of the origin of the directional change **1218** may be set as the corner **1210***a* (illustrated as 929 mm) of the **1208***a*.

The volume dimensioning system **100** may iteratively repeat the edge crawling algorithm until continuous segments of empty depth values are detected. Zeros in the depth values may cause the method **1100** to erroneously stop crawling. In some embodiments, the method **1100** may skip over one or more empty or null depth values when crawling the edges. The number of holes which are skipped over before determining the change in distance may be configured as a maximum empty threshold or the like. The edge crawling algorithm includes the maximum empty threshold as a number of the empty matrix entries to skip over when crawling the edges **1208**. The edge crawling algorithm ignores empty depth values in the depth map **1202** until the maximum empty threshold is exceeded in a row. The method **1100** may stop crawling when the maximum empty threshold is exceeded.

In a step **1140**, the depth map **1202** is deprojected into three-dimensional points **1201**. The depth map **1202** is deprojected into the three-dimensional points **1201** using the depth values of the pixels and intrinsic parameters of the image sensor used to generate the depth map **1202**. Deprojection is the process of transforming 2D depth coordinates into 3D space. Deprojecting simulates a 3D image from the depth values. A deprojection module may take the two-dimensional pixel location and the depth, and map to the three-dimensional point location. The three-dimensional points **1201** may include three-dimensional points associated with the origin point **1204** and/or the corner **1210** which are in the depth map **1202**. For example, the three-dimensional points **1201** include a three-dimensional origin point associated with the origin point **1204**, a first three-dimensional corner point associated with corner **1210***a*, a second three-dimensional corner point associated with corner **1210***b*, and a third three-dimensional corner point associated with corner **1210***c*.

In a step **1150**, edge vectors are constructed from the three-dimensional points **1201**. The 3D points are used to construct edge vectors **1220** representing the edges **1208** of the target object. A first edge vector **1220***a* may represent the left edge **1208***a* between the origin point **1204** and the corner **1210***a*, a second edge vector **1220***b* may represent the right edge **1208***b* between the origin point **1204** and the corner **1210***b*, and a third edge vector **1220***c* may represent the vertical edge **1208***c* between the origin point **1204** and the corner **1210***c*. The edge vectors **1220** are directional from the three-dimensional origin point. The edge vectors **1220** may be determined from the three-dimensional origin point to each of the three-dimensional corner points. For example, the first, second, and third three-dimensional corner points may each be subtracted from the three-dimensional origin point to find the respective first, second, and third edge vectors.

Advantageously, the edge vectors **1220** are determined without having to perform a crawling method in three-dimensional space. Rather, the crawling is performed on the depth map in two-dimensional space. Performing the computations in two-dimensional space may be require significantly less processing power than performing the computations in three-dimensional or higher space. The various points in two-dimensional space may then be deprojected back into three-dimensional space for one or more subsequent steps of validation and determining the lengths of the edge vectors.

In a step **1160**, angles between the edge vectors are compared to determine the target object is a cuboid, e.g., a box or like hexahedral solid having three opposing pairs of quadrilateral faces. Angles **1222** between the vectors **1220** may be determined. For example, the angle **1222** include angle **1222***a* between the vector **1220***a* and the vector **1220***b*, angle **1222***b* between the vector **1220***a* and the vector **1220***c*, and angle **1222***c* between vector **1220***b* and vector **1220***c*. The angles **1222** may be determined using any suitable technique, such as, but not limited to, by a dot product or the like. The angles **1222** are then examined to determine whether the target object resembles a cuboid. For example, examining the angle **1222** may include determining the angle are within tolerance of ninety degrees. The angles **1222** being within tolerance of ninety indicates the angles **1222** are orthogonal and the target object is cuboid. The tolerance may include an angular tolerance, such as, but not limited to within one degree.

In a step **1160**, distances of the edges **1208** are estimated using the vectors **1222**. For example, the distance of edge **1208***a* from the origin point **1204** to the corner **1210***a* is estimated using the edge vector **1220***a*, the distance of edge **1208***b* from the origin point **1204** to the corner **1210***b* is estimated using the edge vector **1220***b*, and the distance of edge **1208***c* from the origin point **1204** to the corner **1210***c* is estimated using the edge vector **1220***c*. The distances are estimated using the lengths of the vectors **1222**. The lengths of the vectors may be determined using any suitable approach, such as, but not limited to by the Pythagorean theorem. The lengths may then be maintained in memory, displayed on the mobile device **102**, and the like as discussed previously herein.

It is contemplated that the method **1100** performed on frame-by-frame basis or combination of frames, may accurately estimate the lengths within some variation and tolerance. For example, the length of the edges **1208** may be estimated within 20 mm from actual physical length of the edge.

In some embodiments, the size of the cursor **1206**, the angular tolerance of the angles **1222**, the maximum empty threshold, a minimum size of the target object to be recognized and measured, and the like may be considered one or more hyperparameters of the method **1100**. The hyperparameters may be adjusted to adjust a speed of the method **1100** and/or adjust an accuracy of the length estimation for the edges **1208**.

In some embodiments, the method **1100** may be iteratively performed on subsequent frames, or on a combination of subsequent frames, to further improve the estimation of the length. For example, the method **1100** may be performed for each frame to determine the dimensions of the target object across multiple of the frames. In a final step, the edge lengths for each dimension from multiple frames are received and statistical methods are applied to reduce the mean error between each of the frames to produce a final and confident result.

In some embodiments, the method **1100** may include one or more additional steps wherein the measured dimensional values are corrected or adjusted (**1225**) to mitigate or eliminate error relative to the actual physical values of each dimension. For example, the end result of the method **1100** with statistical methods applied may still include error relative to the actual physical value, where the "actual physical value" is the length that is present in the target object (which length may also be measured using traditional physical methods such as a tape measure). For example, the error relative to actual physical value length may be predictable due to one or more of a variety of contributing factors, e.g., camera functionality, algorithms, length of dimensional vectors left **1220***a*, right **1220***b*, vertical **1220***c*, angle of attack (e.g., of the camera relative to the target object), box material, color, lighting condition, and/or object quality. By way of a non-limiting example, machine learning or otherwise statistical trendline algorithms may also be applied to adjust (**1225**) the resulting measurements **1220***a*-**1220***c* achieved via method **1100** to reduce the error relative to actual physical value. In embodiments, subsequent algorithms may take the resulting value **1220***a*-**1220***c* of each dimension as achieved via method **1100** and enter said resulting values into an adjustment algorithm **1225** with input and output, which may include, but is not limited to, a lookup table, a formula, or a machine learning produced model. For example, adjustment input may include the measured values **1220***a*, **1220***b*, and **1220***c* (e.g., achieved via method **1100**), together or separately. Similarly, adjustment output may include one or more adjusted values **1230***a*, **1230***b*, and **1230***c* (e.g., also together or separately, depending upon the adjustment input). Further, the adjustment output may include a second value indicating the applied adjustment itself (e.g., positive adjustment, negative adjustment, zero adjustment) In embodiments, the adjusted value/s **1230***a*-**1230***c* may provide a final estimated length of the corresponding dimension/s. In some embodiments, adjustment calculations **1225** may be based on predictable error levels determined via testing of a broad variety of possible target objects.

Referring now to FIG. **12**H, a sample trendline relationship **1240** is shown representing measured lengths **1220** (see, e.g., **1220***a*-**1220***c*, FIG. **12**G) compared to observed and/or predictable errors in testing. In embodiments, the observed/predictable error trendline (**1240**, broken line) relative to measured dimensional length (**1220**, solid line) may be based on observed, tested errors (e.g., with respect to a broad variety of potential target objects of various dimensions) and may include a straight linear representation, logarithmic representation, or polynomial representation of any of a number of possible orders. For example, the error trendline **1240** may be represented by a formula, data table lookup values, machine learning model, and/or other algorithm. Further, the error trendline **1240** may be representative of an adjustment value depending upon the observed length **1220** (e.g., via data entries, via calculation). In embodiments, with respect to the adjustment calculations **1225** shown above by FIG. **12**G, measured values **1220** may be provided as input, and the resulting output used as adjustment to reduce trending error to zero (see, e.g., **1230***a*-**1230***c*, FIG. **12**G).

In embodiments, the adjustment calculations **1225** may apply the error trendline (**1240**) value for each measured length **1220** may be applied as a negative to offset error in the measured length. For example, a positive value on the error trendline **1240** may represent an overmeasure error with respect to the measured value **1220**, so an adjustment **1225** would subtract the trendline value from the measured value to achieve an adjusted measurement value (**1230***a*-**1230***c*) which may better approximate zero error relative to the actual physical length of said dimension. Similarly, if the error trendline value **1240** is negative, the measured value **1220** may be associated with an undermeasure error; accordingly, the adjustment **1225** would effectively subtract the negative trendline value (which double negative would amount to adding the error value to the measured value **1220** to achieve the adjusted measured value (**1230***a*-**1230***c*) more closely approximating zero error relative to the actual physical length. By way of a non-limiting example, and as shown by FIG. **12**H, a measured value **1220** of 575 mm would be associated with a predicted trendline error **1240** of +8 mm. Accordingly, adjustment **1225** to the measured value **1220** would subtract 8 mm from the measured value of 575 mm, resulting in an adjusted value (**1230***a*-**1230***c*) of 567 mm.

In some embodiments, the depth map **1202** may be scaled to estimate the primary box corner based on recent measurements. Scaling the depth map **1202** may make the method **1100** more tolerant aim of the origin point **1204** off-center from the cursor **1206**.

In some embodiments, a downscaled depth map may be generated from the depth map **1202**. Downscaling may refer to reducing the size of the depth map **1202**. The downscaled depth map may then be crawled to estimate the length of the edges. Downscaling the depth map before crawling may be advantageous to reduce a processing time of the crawling. Progressively higher resolution downscaled depth maps may then be crawled to reduce overall steps.

In some embodiments, a temporal filter may be implemented within the method **1100**. In some embodiments, one or more convolutional filters may be used to accentuate the edges **1208** and/or corners **1210**. Accentuating the edges **1208** and/or corners **1210** may improve the accuracy when crawling the edges **1208**.

Referring to FIGS. **13**A through **13**D, a system **1300** for 3D box segmentation and measurement is disclosed. The system **1300** may also be referred to as a volume dimensioning system. The discussion of the system **100** is incorporated herein by reference in the entirety as to the system **1300**. The system **1300** may include a cart **1302**. The cart **1302** may include one or more of the image and control processors **206**, touch-sensitive display surface **208**, and wireless transceiver **210**. The system **1300** may also include a boom **1304**. The boom **1304** may be pivotably coupled to the cart **1302**. The boom **1304** may include the 2D image sensors **202** (e.g., a visible-light camera) and/or the 3D image sensors **204** (e.g., a 3D imager).

In embodiments, the boom **1304** is aimed at a target object **106** (e.g., a rectangular cuboid solid ("target box") or like object the user wishes to measure in three dimensions. The target item may be a target box or another object, such as an envelope or irregular shaped item. The target object **106** may also be in the hands of an operator, being carried from one location to another location. The operator's body, arms, hands, head, or clothing may obstruct the view of cameras. In this case, the obstruction may require one or multiple cameras that may move to see unobstructed views of the target object **106** behind held by the operator (e.g., as shown below by FIG. **13**D). The system may be used to determine dimensions of the target object **106** and compare it to the pre-filled existing information of the dimensions in the logistics or shipping system. For example, the system **1300** may return dimensional information of the target object **106**, e.g., a length **110**, width **112**, and depth **114** of the target object. In some embodiments, the system **1300** will characterize the greatest of the length **110**, width **112**, and depth **114** as the length of the target object **106**; in some embodiments, the system **100** may derive additional information corresponding to the target object **106** based on the determined length **110**, width **112**, and depth **114** (or as disclosed in greater detail below).

In embodiments, the boom **1304** includes a head **1306**. The head **1306** may include one or more of the 2D image sensors **202** and/or the 3D image sensors **204**. The head **1306** may be considered to include an overhead camera that provides a top view of the target object **106**. The head **1306** may also include lights illuminating an area below the head (e.g., illuminating the target object **106** when the target object **106** is disposed below the head **1306**).

In embodiments, the boom **1304** may include an arm **1308**. The arm **1308** may be configured to translate along the boom **1304** relative to the head **1306**. The arm **1308** may include one or more image sensors **1310**. The image sensors **1310** may include the 2D image sensors **202** and/or the 3D image sensors **204**. In this regard, each of the image sensors **1310** may generate image data **1312** (e.g., 2D imaging data **126** and/or 3D imaging data **128**).

In embodiments, the boom **1304** and/or image sensors **1310** may be optimally oriented to the target object **106** such that three mutually intersecting planes of the target object, e.g., a left-side plane **116**, a right-side plane **118**, and a top plane **120**, are clearly visible within the image data **1312**. The image sensor **1310** may be positioned nearest a top corner **122** of the target object (e.g., where the three planes **116**, **118**, **120** intersect) at an angle **124** (e.g., a 45-degree angle). In embodiments, the system **1300** may prompt the user **104** to reposition or reorient the boom **1304** and/or the target object **106** to achieve the optimal orientation described above. For example, the system **1300** may provide an audio tone or visual alert to reposition the target object **106**. The system **1300** may also provide an audio tone or visual alert in response to dimensioning the target object **106**.

In embodiments, the arm **1308** includes several of the image sensors **1310**. For example, the arm **1308** may include three image sensors **1310**. The image sensors **1310** provide stereo vision. In embodiments, the image sensors **1310** may be oriented toward the target object **106** in such a way that the image data **1312** includes separate field-of-view of the target object **106** (e.g., the stereo vision). The orientation of the image sensors **1310** may be individually calibrated by rotating (**1310***a*) the image sensor/s **1310** relative to the arm **1308**. In embodiments, rotation and movement of the cameras may be controlled by mechanical means or robotic arms, to move the cameras to a more ideal view of the target object **106**. For example, control can be provided by a system that estimates the optimal view and subsequent movement to improve the field of view of the image sensors **1310**/cameras (e.g., to mitigate or evade obstructions, as described below). The cameras and/or camera positions (**1310***b*, **1310***c*) may be spaced apart with an angle defined between the image sensors **1310**. In some embodiments, the angle between evenly spaced image sensors **1310** may be up to 15 degrees, up to 22.5 degrees, or more.

Referring also to FIGS. **13**C and **13**D, an overhead view of the system **1300** for 3D box segmentation and measurement is shown. For example, as shown by FIG. **13**C, the system **1300** may include multiple image sensors **1310** or cameras fixed to arms **1308** at fixed angles and oriented toward a space where the target object **106** is presented for imaging, segmentation, and measurement. Alternatively, as shown by FIG. **13**D, the system **1300** may include one or more image sensors **1310** attached to a circular or elliptical arm **1308** and capable of articulation around the arm **1308**, such that each image sensor or camera may orient or be oriented toward the space where the target object **106** is presented from multiple angles or orientations.

In some embodiments, one or more image sensors **1310** may detect an obstruction **1314**, e.g., an arm or body part belonging to a person holding or presenting the target object **106** for scanning or otherwise disposed between the image sensor and the target object. For example, if one or more image sensors **1310** are obstructed such that the system **1300** is not receiving sufficient image data **1312** (e.g., from an advantageous orientation **1310***b*, from enough different orientations) to perform accurate volume dimensioning on the target object **106**, one or more image sensors may rotate relative to the arm **1308** to an orientation **1310***b* where the view of the target object is unobstructed and/or preferable to the prior orientation (**1310**, **1310***c*), e.g., with respect to the top corner **122** and/or mutually intersecting planes **116**, **118**, **120**. In some embodiments, more than one image sensor **1310** may rotate relative to the arm **1308**, e.g., either to evade a detected obstruction or in response to the rotation of another image sensor. For example, one or more image sensors **1310** may select one of a set of predetermined rotational orientations **1310***b*, **1310***c*; alternatively or additionally, the system **1300** may analyze image data **1312** captured by the obstructed image sensor and determine a more favorable rotational orientation wherefrom the image sensor may have an unobstructed view of the target object **106**.

Referring now to FIG. **14**, each of the image sensors **1310** may capture image data **1312** with a separate field-of-view of the target object **106**. Any of the various algorithms described herein may be performed on the image data **1312** generated by the image sensors **1310**. The multiple cameras provide algorithms with additional data to identify and measure the target object, as compared to a single of the image sensors **1310**.

In embodiments, the volume dimensioning system **1300** may independently determine a set of dimensions of the target object **106** using the image data **1312** from each of the image sensors **1310**. The set of dimensions may include dimensions of edges of the target object **106**. The edges may include any of the length **110**, width **112**, and depth **114**. The set of dimensions may include set of dimensions (x1, y1, z1), set of dimensions (x2, y2, z2), and set of dimensions (x3, y3, z3). The three sets of dimensions correspond to the respective image data generated by the three of the image sensors **1310** of the arm **1308**.

Each of the set of dimensions may be combined together to generate a combined set of dimensions (x', y', z'). The combined set of dimensions may be generated by averaging (which may include, but is not limited to, other statistical calculations or algorithms as appropriate) each of the sets of dimensions (e.g., averaging x1, x2, and x3 to get x'; averaging y1, y2, and y3 to get y'; averaging z1, z2, and z3 to get z'). The combined set of dimensions may include an accuracy or confidence level which is improved over individual of the sets of dimensions. For example, the individual sets of dimensions may include error due to misalignment of the image sensors **1310** with the corner of the target object **106**. The error is reduced in the combined set of dimensions.

In some embodiments, the set of dimensions are combined using one or more weights. The volume dimensioning system **1300** may determine that the image sensor **1310** has or does not have an ideal angle for a given edge of the target object **106**. For example, image sensors **1310** which are steeply aligned or include a sharp angle relative to the edge may be unable to accurately detect the length of the edge. The volume dimensioning system **1300** may detect the angular alignment of the image sensor **1310** relative to the edge and then weight the set of dimensions based on the alignment. In this regard, the weight may be reduced where the edge is steeply angled relative to the image sensor **1310**.

Referring to FIGS. **15**A through **15**F, the volume dimensioning system **1500** (VDS) and corresponding method may be implemented and may function similarly to previously disclosed volume dimensioning systems, except that the VDS **1500** may be trained (e.g., via machine learning algorithms) to distinguish payload objects **1502** from pallets **1504** on which the payload objects may be disposed. For example, referring in particular to FIG. **15**A, the payload object **1502** may comprise a quantity of like smaller objects (e.g., packages stacked in a cuboid array of x_1 by y_1 by z_1 packages, where each individual package **1504** likewise has a cuboid dimension of x_2 by y_2 by z_2, and therefore the payload object **1502** as a whole may be expected to have a total volume dimension approximating x_1*x_2 by y_1*y_2 by z_1*z_2. Further, the VDS **1500** may be trained to distinguish the payload object **1502** from the pallet **1504** on which the payload object sits, as well as the orientation of the pallet (e.g., whether or not the image data **1506** indicates holes **1504***b* in the pallet whereby a forklift may capture and raise the pallet). In embodiments, the VDS **1500** may additionally incorporate color and depth data from within a captured set of image data **1506** portraying the payload object **1502** and pallet **1504** (as well as, e.g., additional proximate payload objects **1502***a* and/or pallets **1504***a*).

In embodiments, the VDS **1500** may include neural networks trained (e.g., via you-only-look-once (YOLO) object detection and/or other like machine learning algorithms) to predict, based on a set of image data **1506**, instances of payload object segments **1502**, **1502***a* and/or pallet segments **1504**, **1504***a*. For example, as a first step the VDS **1500** may annotate image data **1506** to output predicted bounding boxes **1508**, class probabilities (e.g., is a given pixel or image portion part of the payload object **1502** or part of the pallet **1504**?), and/or segmentation masks corresponding to a set of instance segments, e.g., payload object segments **1502**, **1502***a* and/or pallet segments **1504**, **1504***a*. In some embodiments, the VDS **1500** may attempt to match pallet segments **1504**, **1504***a* to pallet templates and/or reference pallets (e.g., via lookup, via scanning encoded information on a pallet surface) having known dimensions and/or other attributes.

In embodiments, referring also to FIG. **15**B, as a further step the VDS **1500** may select from the set **1510** the centermost payload object **1502** and corresponding payload **1504** as primary subjects for volume dimensioning. For example, the VDS **1500** may create a binary mask **1512** based on the selected centermost payload object **1502** and payload **1504**, the binary mask **1512** serving to threshold depth data corresponding to the payload object **1502** and payload **1504**.

In embodiments, referring also to FIG. **15**C, as a further step the VDS **1500** may deproject (**1514**) the depth data within the binary mask **1512** into 3D space, e.g., using camera intrinsics of the image sensors **1310**. For example, based on the deprojected depth data **1514**, the VDS **1500** may further sample points proximate to, but not part of, the payload object **1502** and pallet **1504**. In embodiments, assuming the ground plane **1516** (e.g., floor) on which the payload object **1502** and pallet **1504** are disposed is clearly visible within the deprojected depth data **1514**, three points **1518***a*-**1518***c* proximate to the pallet may be sampled to estimate the ground plane.

In embodiments, referring also to FIG. **15**D, as a further step the VDS **1500** may determine a reference plane **1520** onto which any remaining points corresponding to the payload object **1502** and pallet **1504** may be projected (**1522**). For example, the reference plane **1520** may be calculated orthogonal to the ground plane **1516** and passing through two points **1518***b*, **1518***c* near the bottom of the pallet **1504** and from which the ground plane was estimated. Further, the VDS **1500** may determine any points more than a threshold distance away from the reference plane **1520** as outliers, removing these outlying points from the point projection **1522**. The remaining projected points **1522** may be downsampled by the VDS **1500** to improve performance.

In embodiments, referring also to FIG. **15**E, as a further step the VDS **1500** may transform (**1524**) the downsampled projected points to align the ground plane **1516** to the x-axis of the VDS' global coordinate system. For example, when the ground plane **1516** is properly aligned, any bounding boxes for the payload object **1502** and/or pallet **1504** may efficiently align with the ground plane.

In embodiments, referring also to FIG. **15**F, as a further step the VDS **1500** may calculate an oriented bounding box **1526** for volume dimensioning of the payload object **1502** and/or pallet **1504**. For example, the oriented bounding box **1526** may correspond solely to the payload object **1502**, solely to the pallet **1504**, or to the payload object and pallet combined. Further, the VDS **1500** may calculate the oriented bounding box **1526** based on principal component analysis of the convex hull of the transformed downsampled projected points (**1524**). In embodiments, the axis alignment associated with the transformation **1524** may ensure that one face of the bounding box **1526** is anchored to the ground plane **1516**. In embodiments, the VDS may perform volume dimensioning of the payload object **1502** and/or pallet **1504** based on the faces, edges, and/or vertices of the bounding box **1526**.

Referring to FIGS. **16**A through **16**G, the volume dimensioning system **1600** (VDS) and corresponding method may be implemented and may function similarly to previously disclosed volume dimensioning systems, except that the VDS **1600** may perform accurate imaging-based volume dimensioning of an irregularly shaped target object **1602** is disclosed. For example, referring in particular to FIG. **16**A, the target object **1602** may include any object of interest not corresponding to a cuboid or hexahedral solid, e.g., not having three linear dimensions x, y, z or three opposing pairs of quadrilateral faces xy, xz, yz.

In embodiments, the VDS **1600** may, broadly speaking, perform volume dimensioning of the target object **1602** by identifying and measuring a minimal bounding box **1604** that fully encloses the target object but minimizes excess volume, e.g., any space within the bounding box that is not occupied by the target object.

In embodiments, as a first step the VDS **1600** may deproject depth maps (e.g., x/y/depth values) extracted from image data **1606** into three-dimensional (3D) space (e.g., based on camera intrinsics). For example, via binary thresholding, dilation, and/or blurring operations, the VDS **1600** may perform rapid segmentation of the target object **1602** from its surroundings by accentuating gaps in depth data indicative of object boundaries, e.g., where the target object meets a ground plane **1608**. Further, from a center **1610** of the thresholded depth map **1606**, the VDS **1600** may crawl along a series of directional vectors until a nearest boundary is detected, flooding boundary gaps to create a more comprehensive subject boundary. Further, referring also to FIG. **16**B, using the filled object boundaries, contours **1612** may be calculated and flooded to create a binary image mask **1614**, which may be used for segmentation of any depth data within the image data **1606** determined to contain the target object **1602**.

Referring also to FIG. **16**C, the reprojected depth map may be downsampled (e.g., for enhanced processing performance) and the dominant plane within the image data **1606** estimated (e.g., via random sample consensus (RANSAC) or any appropriate like algorithm) and assumed to be the ground plane **1608**. Further, any points determined to be within a threshold distance of the ground plane **1608** may be removed from the target object model, e.g., to emphasize the likely target object **1602**.

In embodiments, referring also to FIG. **16**D, as a further step the VDS **1600**, once the ground plane **1608** is removed from the object model of the image data **1606**, may isolate one or more point clusters **1616** corresponding to the target object **1602** (e.g., from any non-near objects remaining in the model but not to be included in volume dimensioning) via density-based spatial clustering (e.g., DBSCAN). If, for example, multiple clusters **1616** are identified, the centermost cluster **1616***a* may be assumed to correspond to the target object **1602**.

In embodiments, referring also to FIG. **16**E, as a further step the VDS **1600** may project (**1618**) point clusters **1616** (e.g., identified above as corresponding to the target object **1602**) onto the ground plane **1608** as well as the top plane **1620**. For example, the top plane **1620** may be determined by translating the calculated ground plane **1608** to a point within the point cluster **1616** having the highest y-coordinate. For example, horizontal plane projection **1618** may compensate for the limited capacity of the image sensors **1310** to capture useful depth data near edges and/or at acute angles to surfaces.

In embodiments, referring also to FIG. **16**F, as a further step the VDS **1600** may fill out obstructed areas of the target object **1602** (e.g., those parts of the target object not directly shown by the image data **1606**) by assuming the target object as generally symmetrical and rotating (**1624**) the horizontally projected point clusters **1618** 180 degrees relative to a ground plane normal axis **1622** passing through a center of the convex hull of the horizontally projected point clusters.

In embodiments, referring also to FIG. **16**G, as a further step the VDS **1600** may calculate an oriented bounding box **1604** enclosing the updated depth model (e.g., the rotated and horizontally projected point clusters **1624** corresponding to the estimated target object **1602**) and orienting one face (**1604***a*) of the bounding box parallel to the ground plane **1608**. For example, the VDS **1600** may calculate the oriented bounding box **1604** based on principal component analysis of the convex hull of the rotated and horizontally projected point clusters **1624**, e.g., to ensure that the target object is fully enclosed within the bounding box and that unoccupied space within the bounding box is minimized. In embodiments, the VDS **1600** may proceed to volume dimensioning based on the edges, vertices, and/or faces of the bounding box **1604**.

In embodiments, referring to FIG. **17**, the VDS **1700** may be implemented and may function similarly to the VDS **1500**, **1600** of FIGS. **15**A through **16**G, except that the VDS **1700** may provide manual or automatic selection of a particular volume dimensioning mode based on the target object **1702**. For example, the VDS **1700** may first attempt to determine if the target object **1702** is a candidate for two-step-based volume dimensioning **1704** (see, e.g., FIGS. **3**A through **3**H and accompanying text above). Alternatively, a user may manually select two-step-based volume dimensioning **1704**.

In embodiments, if the VDS **1700** determines that two-step-based volume dimensioning **1704** is inoptimal for the target object **1702**, the VDS may next determine if box corner-based volume dimensioning **1706** is optimal (see, e.g., FIGS. **11** through **12**E and accompanying text above). Alternatively, the user may manually select box corner-based volume dimensioning **1706**.

In embodiments, if the VDS **1700** likewise determines that box corner-based volume dimensioning **1706** is inoptimal for the target object **1702**, the VDS may next determine if pallet segmentation and volume dimensioning **1708** is optimal (see, e.g., FIGS. **15**A through **15**F and accompanying text above). For example, if the VSD **1700** determines that the target object **1702** includes, or is disposed upon, a pallet (**1504**, FIG. **15**A), pallet segmentation and volume dimensioning **1708** may be selected. Alternatively, the user may manually select pallet segmentation and volume dimensioning **1708**.

In embodiments, if the VDS **1700** likewise determines that pallet segmentation and volume dimensioning **1708** is inoptimal for the target object **1702**, the VDS may next determine if irregular object segmentation and volume dimensioning **1710** is optimal (see, e.g., FIGS. **16**A through **16**G and accompanying text above). For example, if the VSD **1700** has difficulty identifying a cuboid or hexahedral structure with respect to the target object **1702**, irregular object segmentation and volume dimensioning **1710** may be selected. Alternatively, the user may manually select irregular object segmentation and volume dimensioning **1710**.

Referring now to FIGS. **18**A-**18**F, diagrammatic illustrations **1800** of the mobile device **102** with three-dimensional user guidance is described, in accordance with one or more embodiments of the present disclosure. The mobile device **102** may provide the three-dimensional user guidance via the display **208** or the like.

The three-dimensional user guidance may include a progress indicator **1802**. The progress indicator **1802** indicates that the target object **106** is recognized, the volume dimensioning system **100** is actively working, and a remaining percentage until the dimensions of the target object **106** have been determined. The progress indicator **1802** may be a progress indicator bar, progress indicator circle, or the like. The progress **1802** indicator indicates the percentage of completion towards detecting the dimensions of the target object **106**.

The three-dimensional user guidance may include a guidance cursor **1804**. The guidance cursor may be similar to the cursor **1206**. The guidance cursor may be a y-shaped cursor disposed in the center of the display of the mobile device **102**. The guidance cursor indicates a target for aiming the imaging sensors of the mobile device **102** at the corner point **306**. The corner point **306** may be aligned with a vertex defined by the guidance cursor. The guidance cursor **1804** includes lines that are angled at 135 degrees. The target object **106** may be aligned at 45 degrees from each plane to perfectly line up to the guidance cursor **1804**. In some embodiments, the guidance cursor **1804** may also assist a user in aligning the mobile device **102** to non-cuboid target objects, e.g., where the preferred acquisition alignment may not be obvious or apparent.

The three-dimensional user guidance may include a guidance indicator **1806**. The guidance indicator **1806** may prompt the user or operator to move the imaging sensor and/or the mobile device **102** relative to the target object **106** (e.g., as seen via the display of the mobile device) in order to optimize the capacity of the mobile device to accurately view and measure the target object. The guidance indicator **1806** may include three-dimensional guidance in any of vertical directions (downwards **1806***a*, upwards **1806***b*), horizontal directions (leftwards **1806***c*, rightwards **1806***d*), and/or longitudinal directions (backward **1806***e*, forwards **1806***f*). The guidance indicators **1806** may be a visual guidance indicator, aural guidance indicators, textual guidance indicators, and the like. As depicted, the visual guidance indicators are chevrons, although this is not intended as a limitation of the present disclosure. In embodiments, the guidance indicators **1806** may appear for at least a minimum tolerance time to allow the user/operator adequate opportunity to both recognize the need for corrective action and execute said corrective action to shift the mobile device **102** away from the tolerance edge state triggering the prompt and toward a preferred acquisition view.

Referring now to FIGS. **19A-19**C, a sensor fusion keyboard **1900** is described, in accordance with one or more embodiments of the present disclosure. The sensor fusion keyboard **1900** may also be referred to as a keyboard wedge, a keyboard interface, or the like. The sensor fusion keyboard **1900** may be implemented on the mobile device **102** and the like. The sensor fusion keyboard **1900** provides an alternate keyboard method of sensor data entry into an application. The application may include any supply chain management software applications or the like. The sensor fusion keyboard **1900** may be a pop-up keyboard. The sensor fusion keyboard **1900** may be chosen in configuration to be used all the time, for specific applications, and/or for specific data field types.

The sensor fusion keyboard **1900** simulates keyboard data entry into fields **1902**. The fields **1902** may be fields of the various applications. The data field attributes may include attributes associated with sensor data. The system keyboard will appear onscreen when the mobile device **102** detects the attribute associated with the sensor data is displayed. The sensor fusion keyboard **1900** advantageously allow for getting the sensor data into the fields **1902** with reduced touches (e.g., one-touch data entry). The fields **1902** may include an attribute associated with the sensor data.

The sensor fusion keyboard **1900** may receive sensor input data from one or more sensors. The sensors may include wired or wireless sensors which are communicatively coupled to the mobile device **102**. The sensors may include, but are not limited to, imaging sensor, volume dimensioning system, scale, bar code scanner, RFID reader, temperature sensor (e.g., thermometer, thermocouple, thermal camera), blood pressure sensors, light sensor, location sensor, and the like. The sensor input data may include dimensions (e.g., length, width, height), weight, mass, scanned bar code data, scanned RFID data (interrogated/read data), temperature values (human body temp, food temperature, machinery temperature), blood pressure values, lumens, location (e.g., (geolocation, GPS, coordinates, address), and the like. The dimensions may be in the form of delimited data. For example, the dimensions may be length, delimiter, width, delimiter, height, or some variation thereof. The dimensions may be in the chosen units (imperial or metric). The dimensions may be delimited in predetermined order set by a configuration on the mobile device **102** or in cloud account settings/configuration.

In some embodiments, the sensor fusion keyboard **1900** may populate the fields **1902** with the sensor data automatically.

In some embodiments, the sensor fusion keyboard **1900** may populate the fields **1902** with the sensor data in response to the mobile device **102** receiving one or more inputs. For example, the sensor fusion keyboard **1900** may include interfaces **1904** associated with the sensors. As depicted, the interfaces **1904** includes a dimensioning interface and a scale interface. The dimensioning interface may lead to an interface using any of the various dimensioning techniques described in the present application. The dimensioning interface may determine the dimensions (e.g., length, width, height) of the target object **106**. The mobile device **102** may receive an input **1906** to confirm the dimensions. The mobile device **102** may also include an input to recalculate the dimensions.

In some embodiments, the interfaces **1904** may include an icon. In some embodiments, pressing the icon (FIG. **19**A) may bring up a separate user interface (FIG. **19**B) that may be required to capture the sensor's value. The separate user interface could be a view window that may partially or fully cover up the screen. Once data is acquired via the separate user interface, the separate user interface may automatically fill data into the fields and/or have the user press a button to "submit".

In some embodiments, the icon may include a notification indicator. The notification indicator may include a current value of a data input (FIG. **19**C). Pressing the notification indicator with the current value may populate the fields **1902**.

Another way to enter data into a data entry field is via multi-factor prompting. The application may ask for the data values upon entering the application. The sensor may send the mobile device **102** the data values via text and the like. The mobile device **102** may sense that the data value is received and also know an application is awaiting the data value for entry into the fields **1902**. The data value can be popped up into the keyboard, such as where the sensor icons reside. Subsequent pressing of that prompt will auto fill that code into the data field expecting that code (having been pressed by user with blinking cursor).

Referring now to FIG. **20**, an edge computing system **2000** is described, in accordance with one or more embodiments of the present disclosure. The edge computing system **2000** may include the mobile device **102**, a server **2002**, and a network **2004**.

The system **2000** may also include the server **2002**. The server **2002** may include one or more processors and memory. The server **2002** may also include a cloud-based architecture. For instance, it is contemplated herein that the server **2002** may include a hosted server and/or cloud computing platform including, but not limited to, Amazon Web Services (e.g., Amazon EC2, and the like). In this regard, any of the various algorithms or dimensioning methods may include a software as a service (Saas) configuration, in which various functions or steps of the present disclosure are carried out by a remote server.

The server **2002** may be communicatively coupled to the mobile device **102** by way of a network **2004**. The network **2004** may include any wireline communication protocol (e.g., DSL-based interconnection, cable-based interconnection, T9-based interconnection, and the like) or wireless communication protocol (e.g., GSM, GPRS, CDMA, EV-DO, EDGE, WIMAX, 3G, 4G, 4G LTE, 5G, Wi-Fi protocols, RF, Bluetooth, and the like) known in the art. By way of another example, the network **2004** may include communication protocols including, but not limited to, radio frequency identification (RFID) protocols, open-sourced radio frequencies, and the like. Accordingly, an interaction between the mobile device **102** and the server **2002** may be determined based on one or more characteristics including, but not limited to, cellular signatures, IP addresses, MAC addresses, Bluetooth signatures, radio frequency identification (RFID) tags, and the like.

The mobile device **102** may be considered an edge computing device. The mobile device **102** includes one or more models or algorithms saved in memory. The mobile device **102** may receive the models or algorithms from the server **2002** by way of the network **2004**. The mobile device **102** may perform generate the sensor data and perform dimensioning on target objects within the sensor data using the various models or algorithms (which may be, e.g., trained machine learning or artificial intelligence generated models).

CONCLUSION

It is to be understood that embodiments of the methods disclosed herein may include one or more of the steps described herein. Further, such steps may be carried out in any desired order and two or more of the steps may be carried out simultaneously with one another. Two or more of the steps disclosed herein may be combined in a single step, and in some embodiments, one or more of the steps may be carried out as two or more sub-steps. Further, other steps or sub-steps may be carried in addition to, or as substitutes to one or more of the steps disclosed herein.

Although inventive concepts have been described with reference to the embodiments illustrated in the attached drawing figures, equivalents may be employed and substitutions made herein without departing from the scope of the claims. Components illustrated and described herein are merely examples of a system/device and components that may be used to implement embodiments of the inventive concepts and may be replaced with other devices and components without departing from the scope of the claims. Furthermore, any dimensions, degrees, and/or numerical ranges provided herein are to be understood as non-limiting examples unless otherwise specified in the claims.

We claim:

1. A volume dimensioning system, comprising:

an image sensor configured to capture imaging data associated with a target object positioned on a surface, the imaging data comprising a sequence of frames, each frame comprising a depth map with two-dimensional (2D) pixel coordinates and a plurality of depth values; and

one or more processors in communication with the image sensor, the one or more processors configured to:

identify an origin point within the plurality of depth values; wherein the origin point is associated with a top corner of the target object; wherein the origin point is a local minimum of the depth values within a cursor of the imaging data; wherein the one or more processors are configured to examine the depth values for the local minimum to identify the origin point;

crawl from the origin point along a first edge to a first corner, along a second edge to a second corner, and along a third edge to a third corner of the target object to detect the first edge, the first corner, the second edge, the second corner, the third edge, and the third corner;

deproject the depth map into three-dimensional (3D) points;

construct a first edge vector representing the first edge from the origin point to the first corner, a second edge vector representing the second edge from the origin point to the second corner point, and a third edge vector representing the third edge from the origin point to the third corner point using the 3D points;

determine the target object is a cuboid by examining a first angle between the first edge vector and the second edge vector, a second angle between the first edge vector and the third edge vector, and a third angle between the second edge vector and the third edge vector;

and

estimate a first distance of the first edge using the first edge vector, a second distance of the second edge using the second edge vector, and a third distance of the third edge using the third edge vector.

2. The volume dimensioning system of claim **1**, wherein the cursor is disposed in a center of the imaging data.

3. The volume dimensioning system of claim **1**, wherein the crawling from the origin point along a first edge to a first corner, along a second edge to a second corner, and along a third edge to a third corner of the target object comprises iteratively:

stepping from a checkpoint according to a step vector and examining one or more of the plurality of depth values along a test vector to find a minimum depth value, wherein the test vector is perpendicular to the step vector;

and

moving the checkpoint to the minimum depth value, wherein the checkpoint detects the first edge, the second edge, and the third edge.

4. The volume dimensioning system of claim **3**, wherein the checkpoint is initially the origin point.

5. The volume dimensioning system of claim **3**, wherein crawling from the origin point along the first edge to the first corner, along the second edge to the second corner, and along the third edge to the third corner of the target object includes:

iteratively crawling along at least one of the first edge, the second edge, or the third edge until the one or more processors detect a directional change by which the first edge, the second edge, and the third edge are detected.

6. The volume dimensioning system of claim **3**, wherein crawling from the origin point along the first edge to the first corner, along the second edge to the second corner, and along the third edge to the third corner of the target object includes:

iteratively crawling along at least one of the first edge, the second edge, or the third edge until the one or more processors detect a continuous segment of empty depth data.

7. The volume dimensioning system of claim **6**, wherein the one or more processors ignore one or more zero depth values when iteratively crawling along at least one of the first edge, the second edge, or the third edge until the one or more processors.

8. The volume dimensioning system of claim **1**, wherein examining the first angle, the second angle, and the third angle comprises determining the first angle, the second angle, and the third angle are within tolerance of ninety degrees.

9. The volume dimensioning system of claim **1**, wherein the one or more processors deproject the 2D pixel coordinates into the 3D points using the two-dimensional (2D) pixel coordinates and the plurality of depth values.

10. The volume dimensioning system of claim **1**, comprising at least one display operatively coupled to the one or more processors, the display configured to display the imaging data and at least one of the first distance, the second distance, or the third distance.

11. The volume dimensioning system of claim **1**, wherein the image sensor is a 3D image sensor; wherein the image data is 3D image data; wherein the one or more processors project the 3D image data into the depth map.

12. The volume dimensioning system of claim **11**, further comprising:

at least one memory operatively coupled to the one or more processors, the memory configured for storing one or more reference objects, each reference object corresponding to a set of reference dimensions.

13. The volume dimensioning system of claim 12, wherein the first distance, the second distance, and the third distance are determined dimensions of the target object; wherein the one or more processors are configured to:

compile the one or more of the determined dimensions and the 3D imaging data corresponding to the target object;

and

store the compilation corresponding to the target object in the at least one memory as a reference object.

14. The volume dimensioning system of claim 12, wherein the one or more processors are configured to determine the dimension by comparing the target object to at least one reference object.

15. A method comprising:

obtaining, via an image sensor of a mobile device, imaging data associated with a target object positioned on a surface, the imaging data comprising a sequence of frames, each frame comprising a depth map with two-dimensional (2D) pixel coordinates and a plurality of depth values;

identifying, via a volume dimensioning system, an origin point within the plurality of depth values, wherein the origin point is associated with a top corner of the target object; wherein identifying the origin point includes identifying a local minimum of the depth values within a cursor of the imaging data; wherein the depth values are examined for the local minimum to identify the origin point;

crawling, via the volume dimensioning system, from the origin point along a first edge to a first corner, along a second edge to a second corner, and along a third edge to a third corner of the target object to detect the first edge, the first corner, the second edge, the second corner, the third edge, and the third corner;

deprojecting, via the volume dimensioning system, the depth map into three-dimensional (3D) points;

constructing, via the volume dimensioning system, a first edge vector representing the first edge from the origin point to the first corner, a second edge vector representing the second edge from the origin point to the second corner point, and a third edge vector representing the third edge from the origin point to the third corner point using the 3D points;

determining, via the volume dimensioning system, that the target object is a cuboid by examining a first angle between the first edge vector and the second edge vector, a second angle between the first edge vector and the third edge vector, and a third angle between the second edge vector and the third edge vector;

and

estimating, via the volume dimensioning system, a first distance of the first edge using the first edge vector, a second distance of the second edge using the second edge vector, and a third distance of the third edge using the third edge vector.

16. The method of claim 15, wherein crawling, via the volume dimensioning system, from the origin point along a first edge to a first corner, along a second edge to a second corner, and along a third edge to a third corner of the target object includes iteratively:

stepping from a checkpoint according to a step vector and examining one or more of the plurality of depth values along a test vector to find a minimum depth value; wherein the checkpoint is initially the origin point, wherein the test vector is perpendicular to the step vector;

and

moving the checkpoint to the minimum depth value, wherein the checkpoint detects the first edge, the second edge, and the third edge.

17. The method of claim 15, wherein crawling, via the volume dimensioning system, from the origin point along a first edge to a first corner, along a second edge to a second corner, and along a third edge to a third corner of the target object includes:

iteratively crawling along at least one of the first edge, the second edge, or the third edge until the volume dimensioning system detects at least one of a directional change or a continuous segment of empty depth data.

18. The method of claim 15, wherein examining the first angle, the second angle, and the third angle comprises determining the first angle, the second angle, and the third angle are within tolerance of ninety degrees.

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