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(54) **SYSTEM AND METHOD FOR THREE-DIMENSIONAL BOX SEGMENTATION AND MEASUREMENT**

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(22) Filed: **Dec. 7, 2020**

Related U.S. Application Data

(63) Continuation-in-part of application No. 16/786,268, filed on Feb. 10, 2020, now abandoned.

(60) Provisional application No. 63/113,658, filed on Nov. 13, 2020.

(51) **Int. Cl.**

G06T 7/62	(2017.01)
G06T 7/593	(2017.01)
G06T 7/12	(2017.01)
G01B 11/24	(2006.01)
G06T 7/11	(2017.01)
H04N 13/204	(2018.01)

(52) **U.S. Cl.**
CPC ***G06T 7/62*** (2017.01); ***G01B 11/24*** (2013.01); ***G06T 7/11*** (2017.01); ***G06T 7/12*** (2017.01); ***G06T 7/593*** (2017.01); *G06T 2207/10021* (2013.01); *G06T 2207/10028* (2013.01); *H04N 13/204* (2018.05)

(58) **Field of Classification Search**
CPC G06T 7/62; G06T 7/12; G06T 7/11; G06T 7/593; G06T 2207/10021; G06T 2207/10028; G01B 11/24; H04N 13/204
See application file for complete search history.

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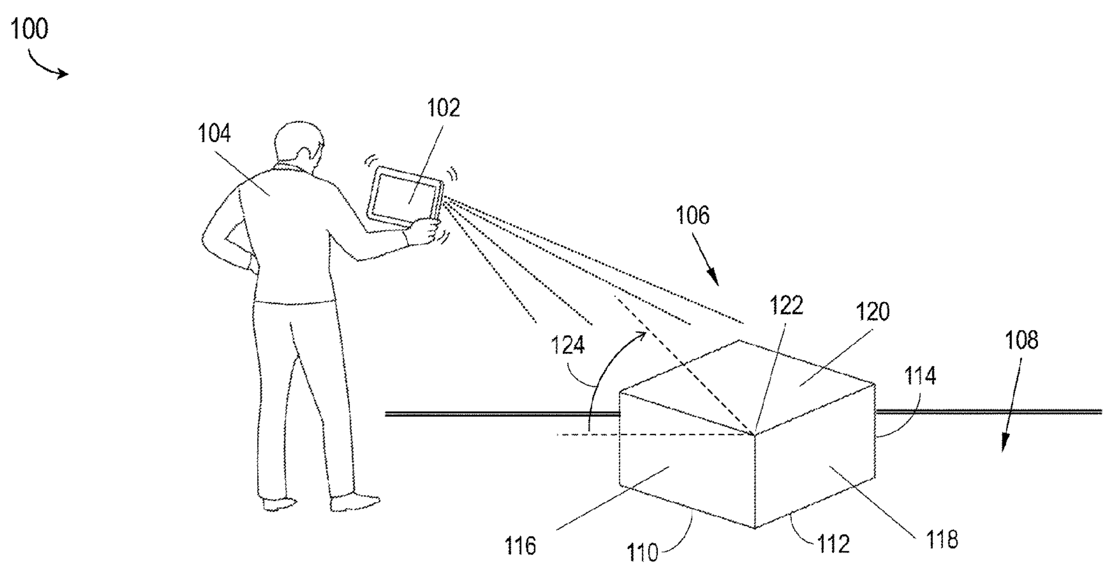
(74) *Attorney, Agent, or Firm* — Suiter Swantz pc llo

(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.

20 Claims, 29 Drawing Sheets



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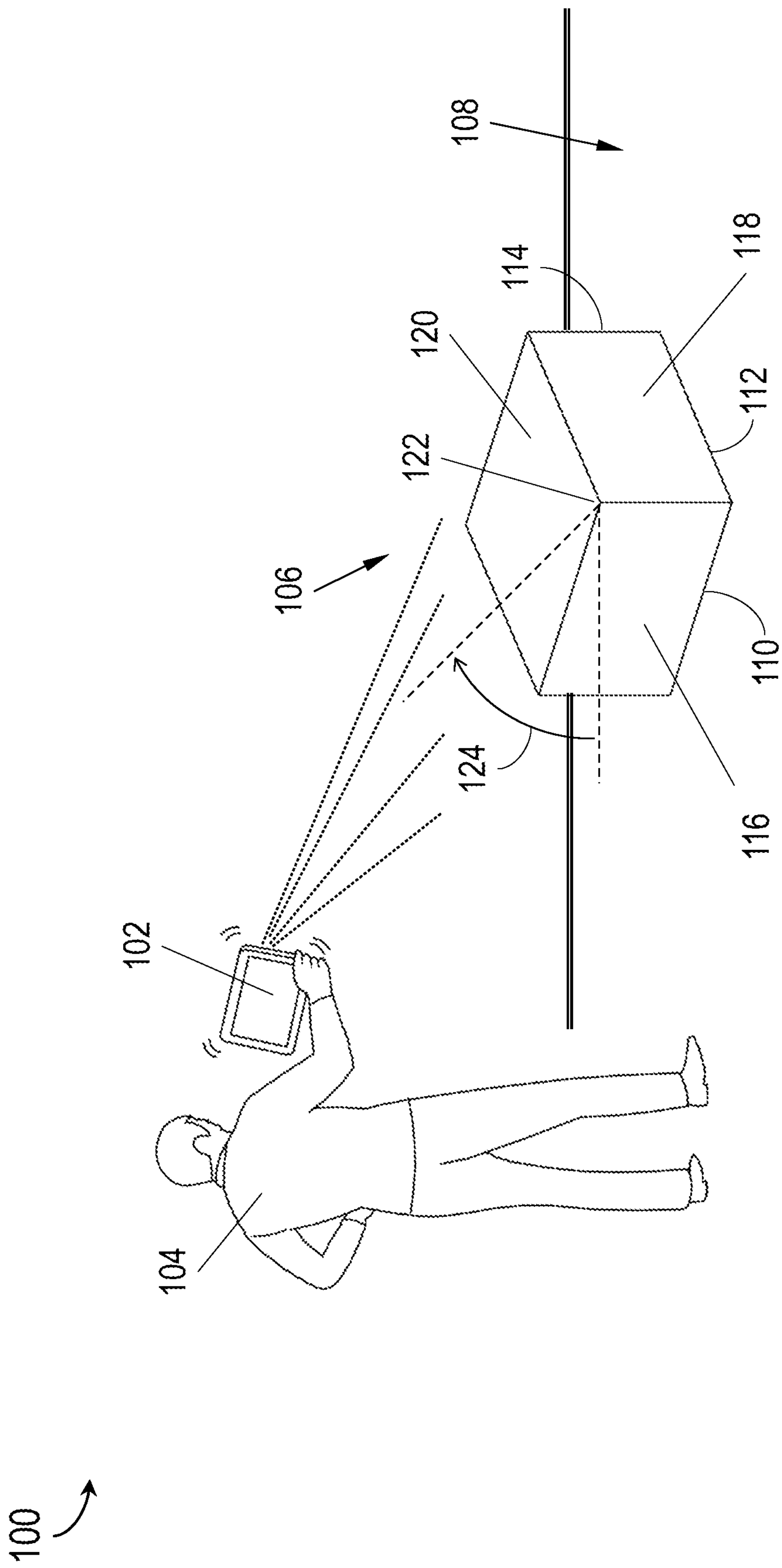
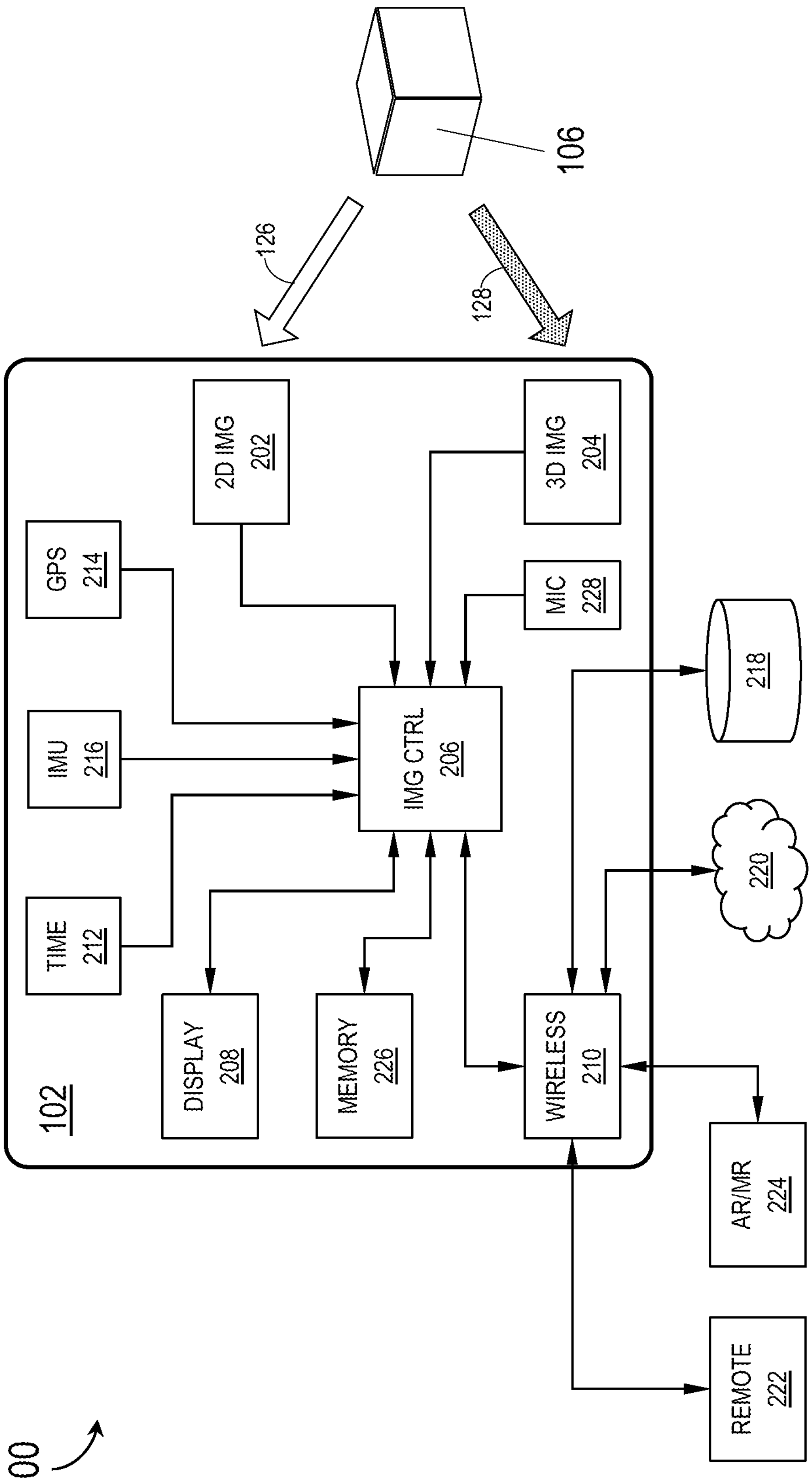


FIG. 1


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

FIG. 2

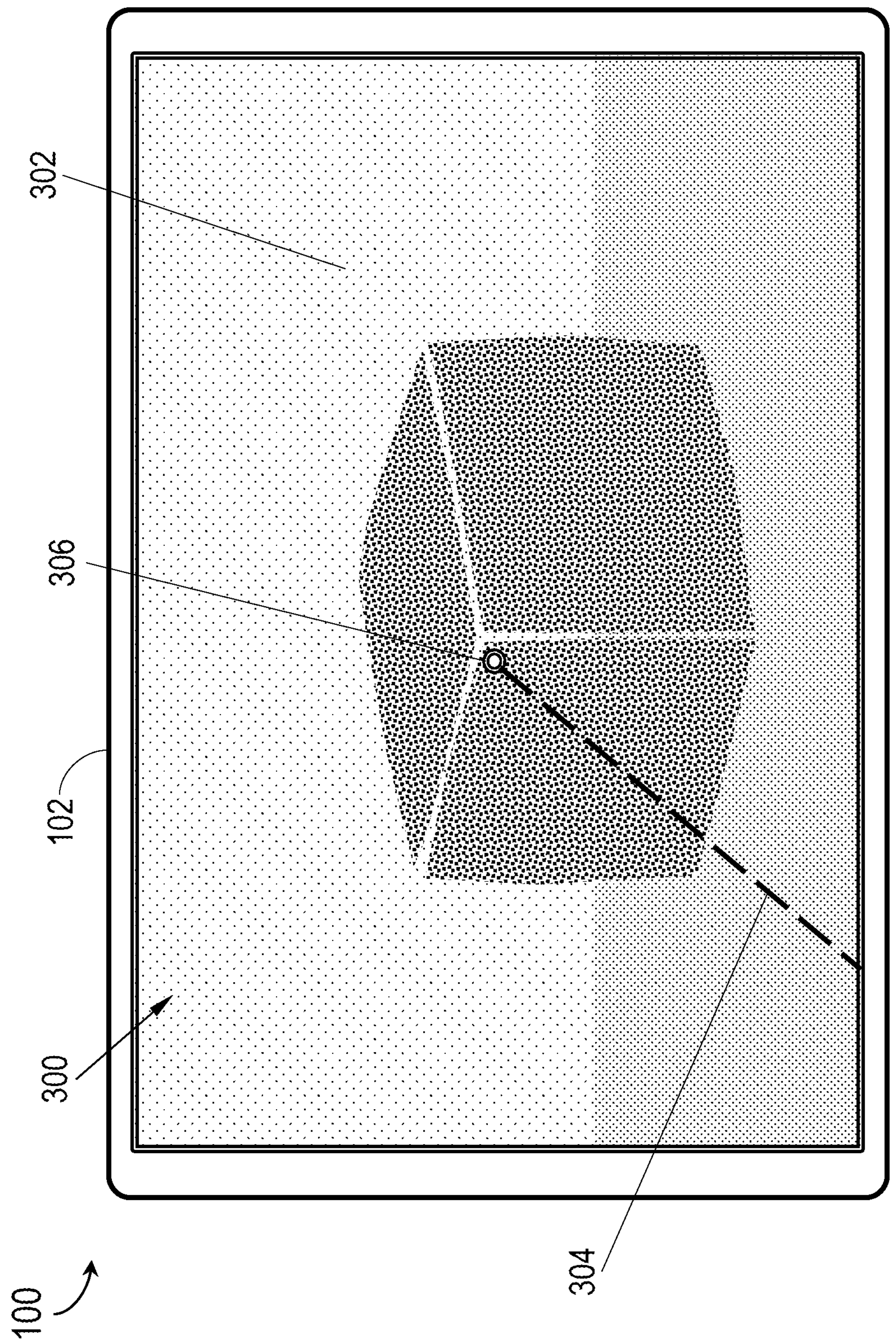

FIG. 3A

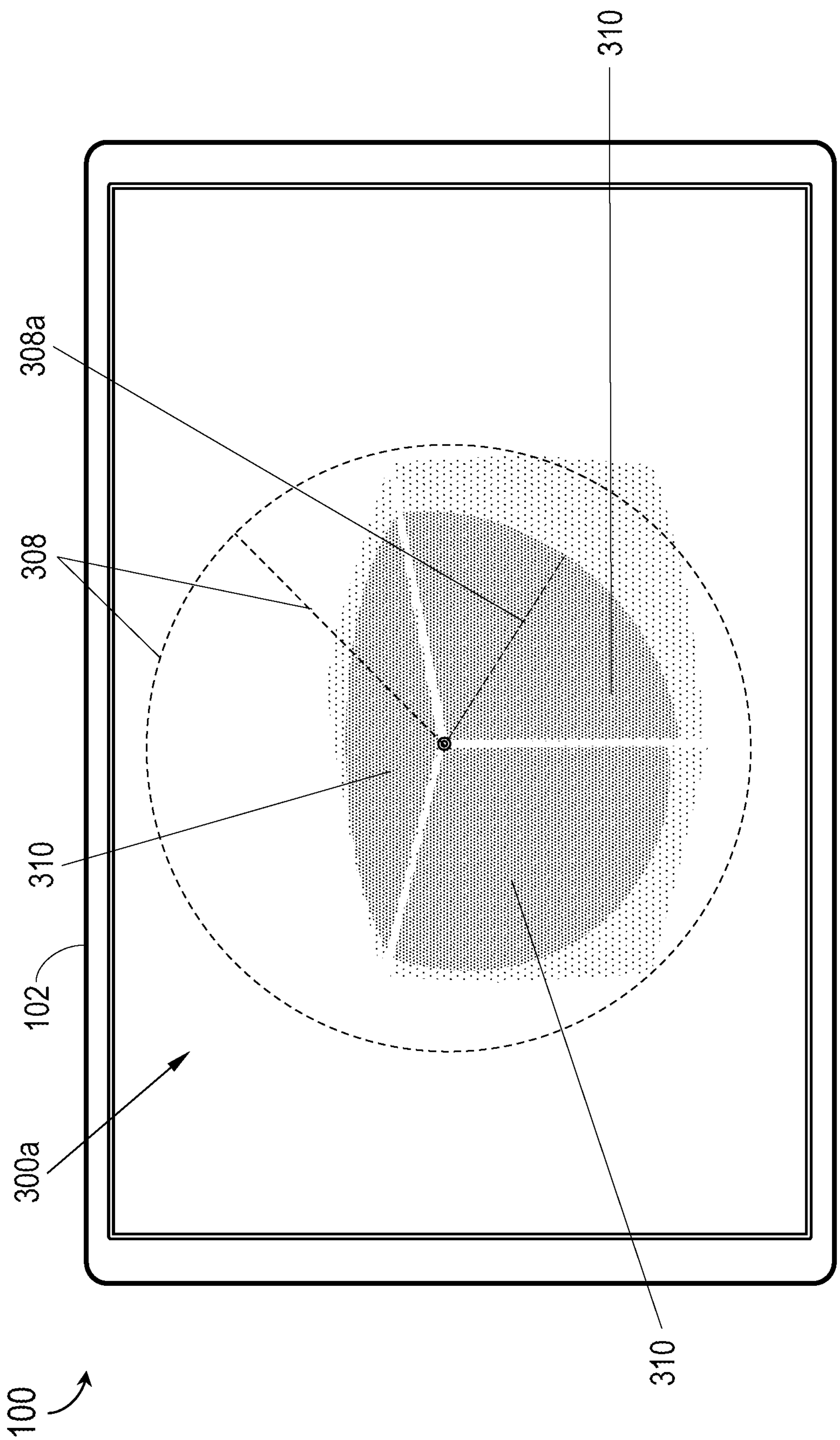

FIG. 3B

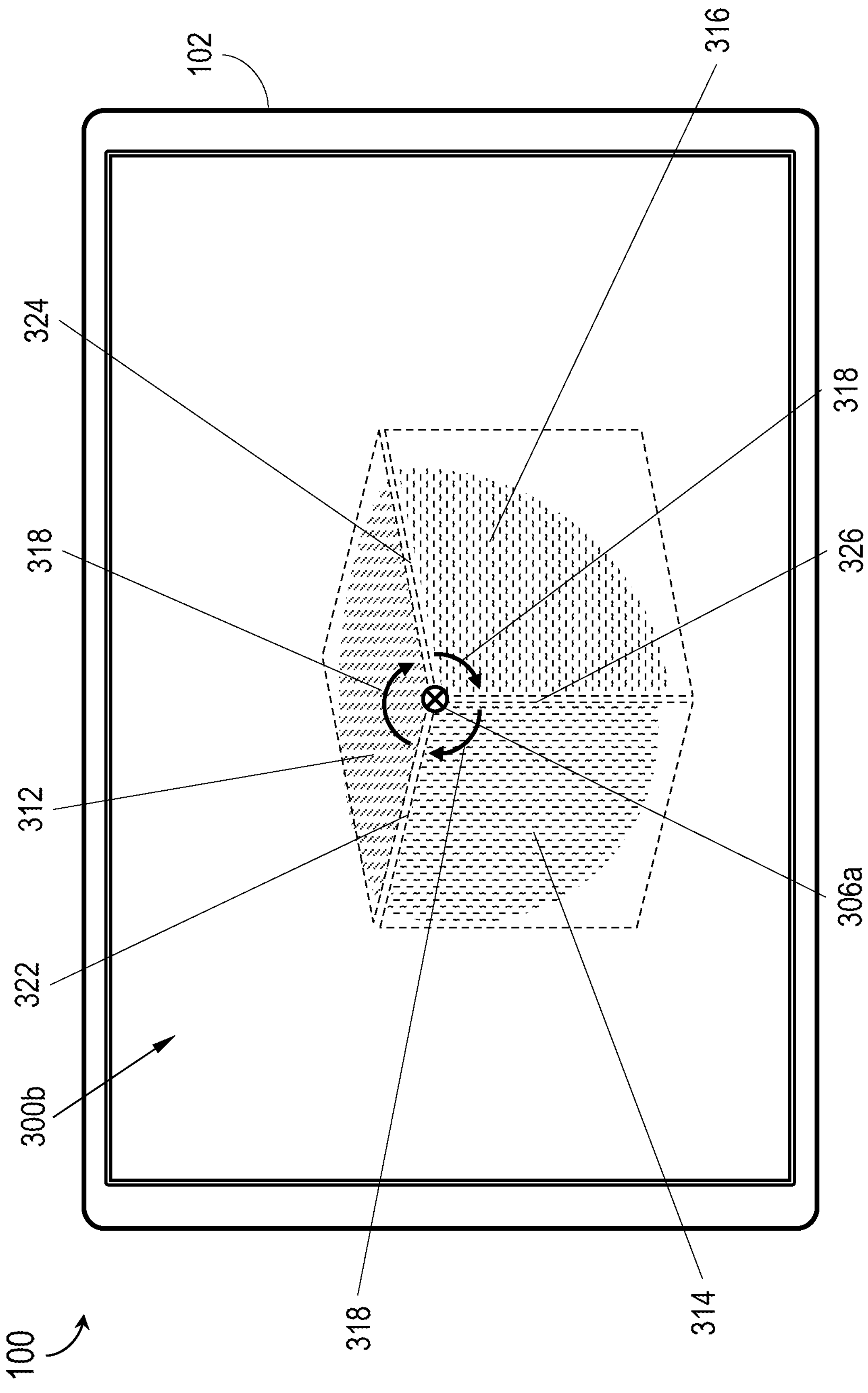

FIG. 3C

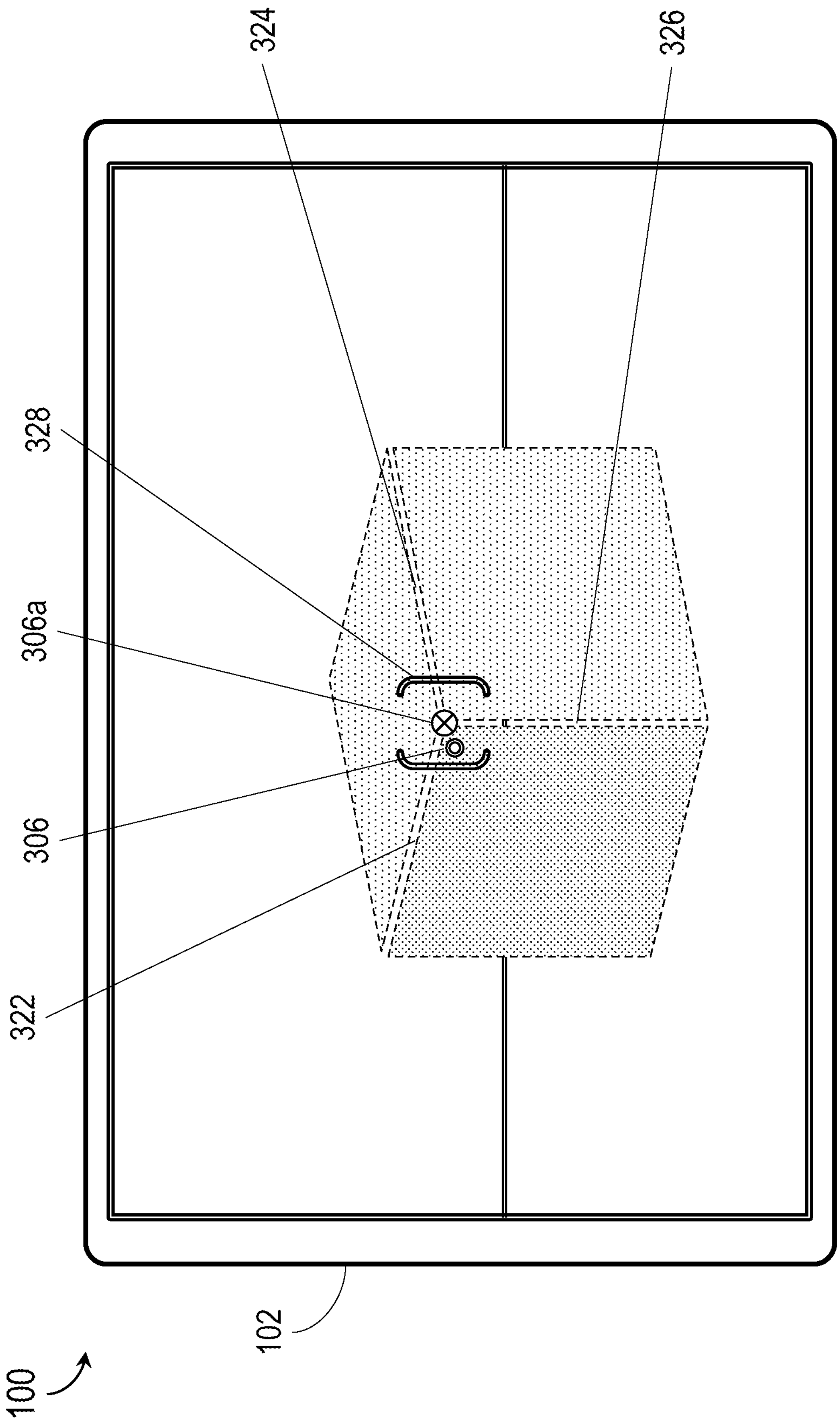

FIG. 3D

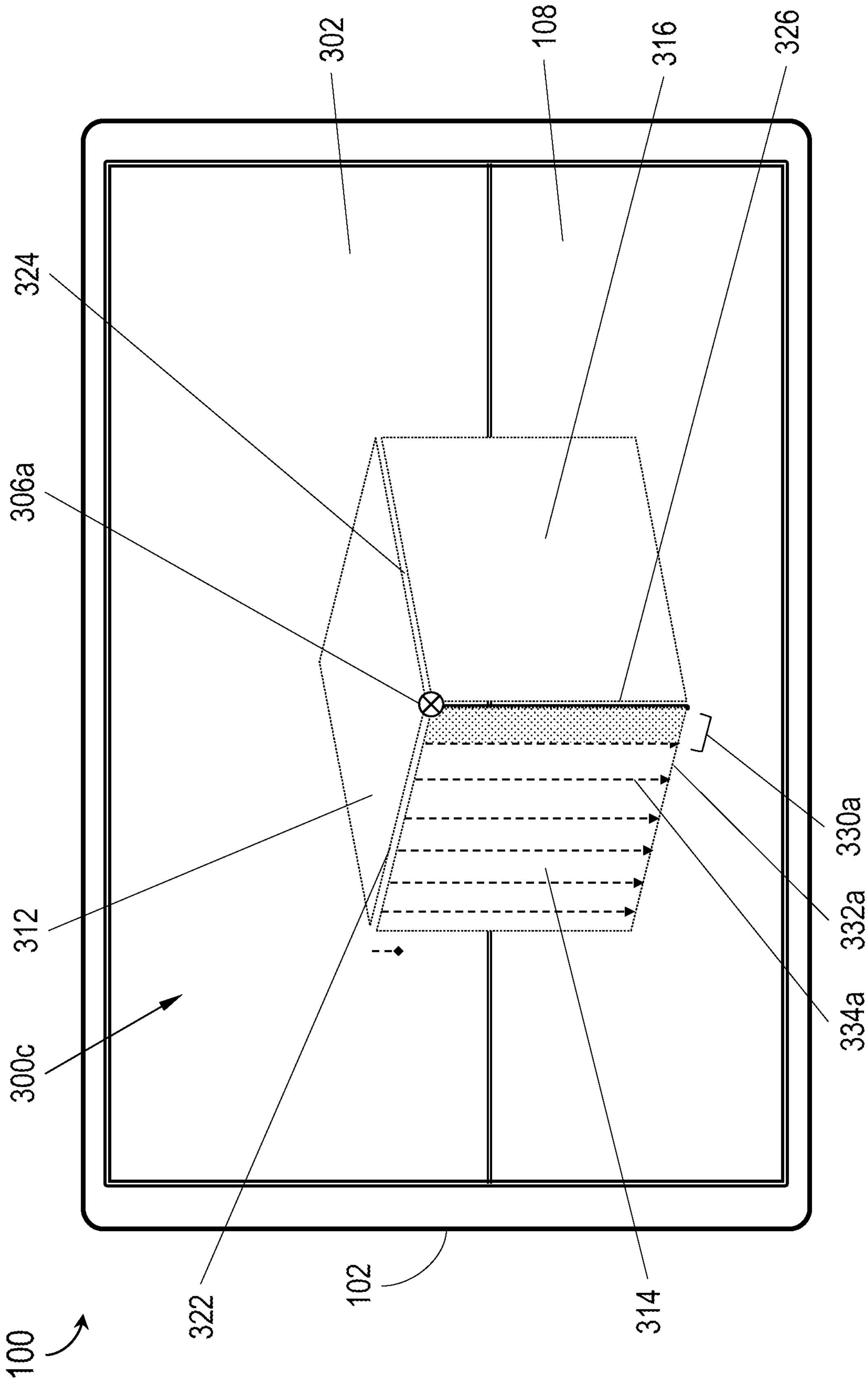
302
108
316
326
324
306a
312
300c
322
102
314
100
330a
332a
334a

FIG. 3E

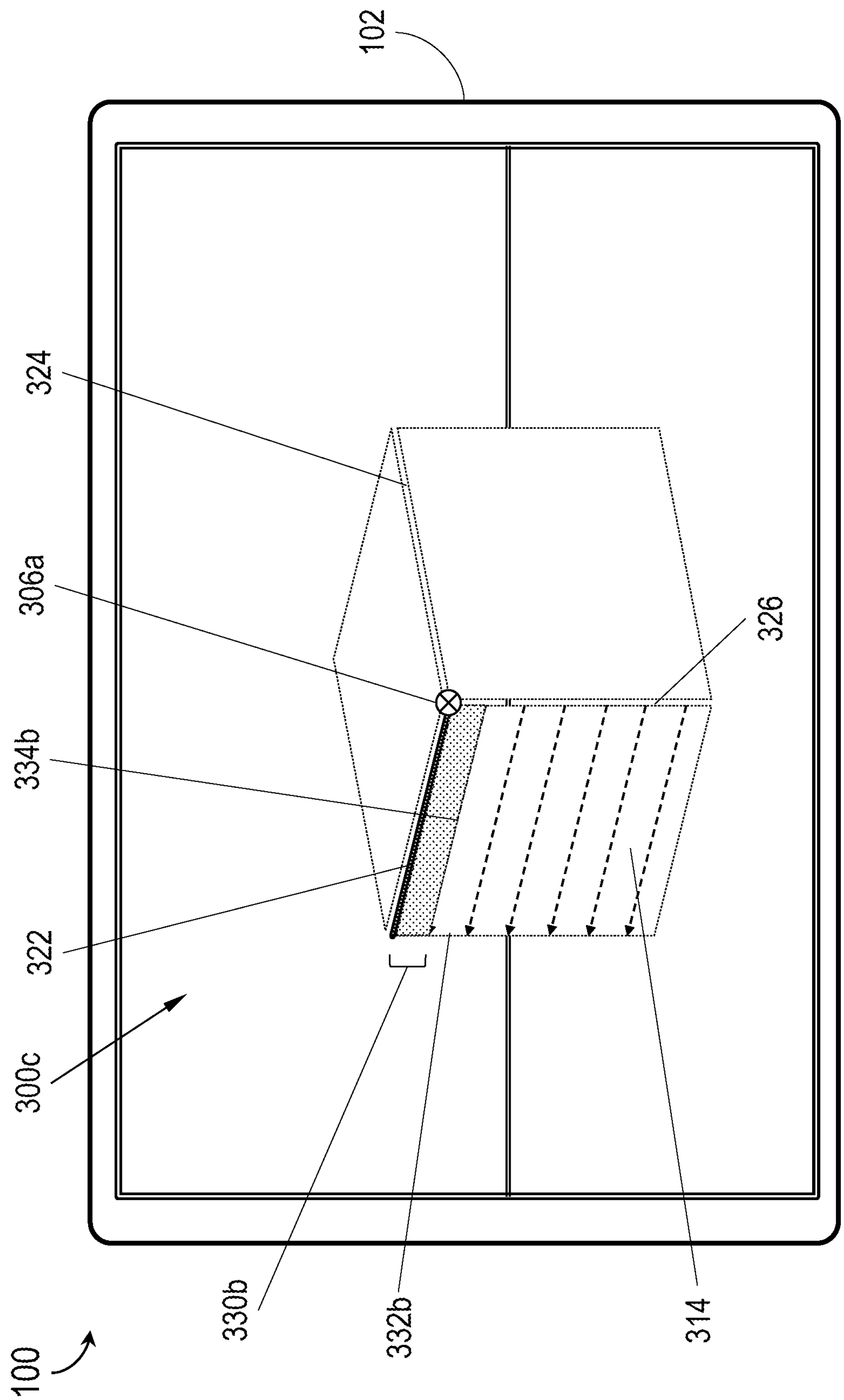

FIG. 3F

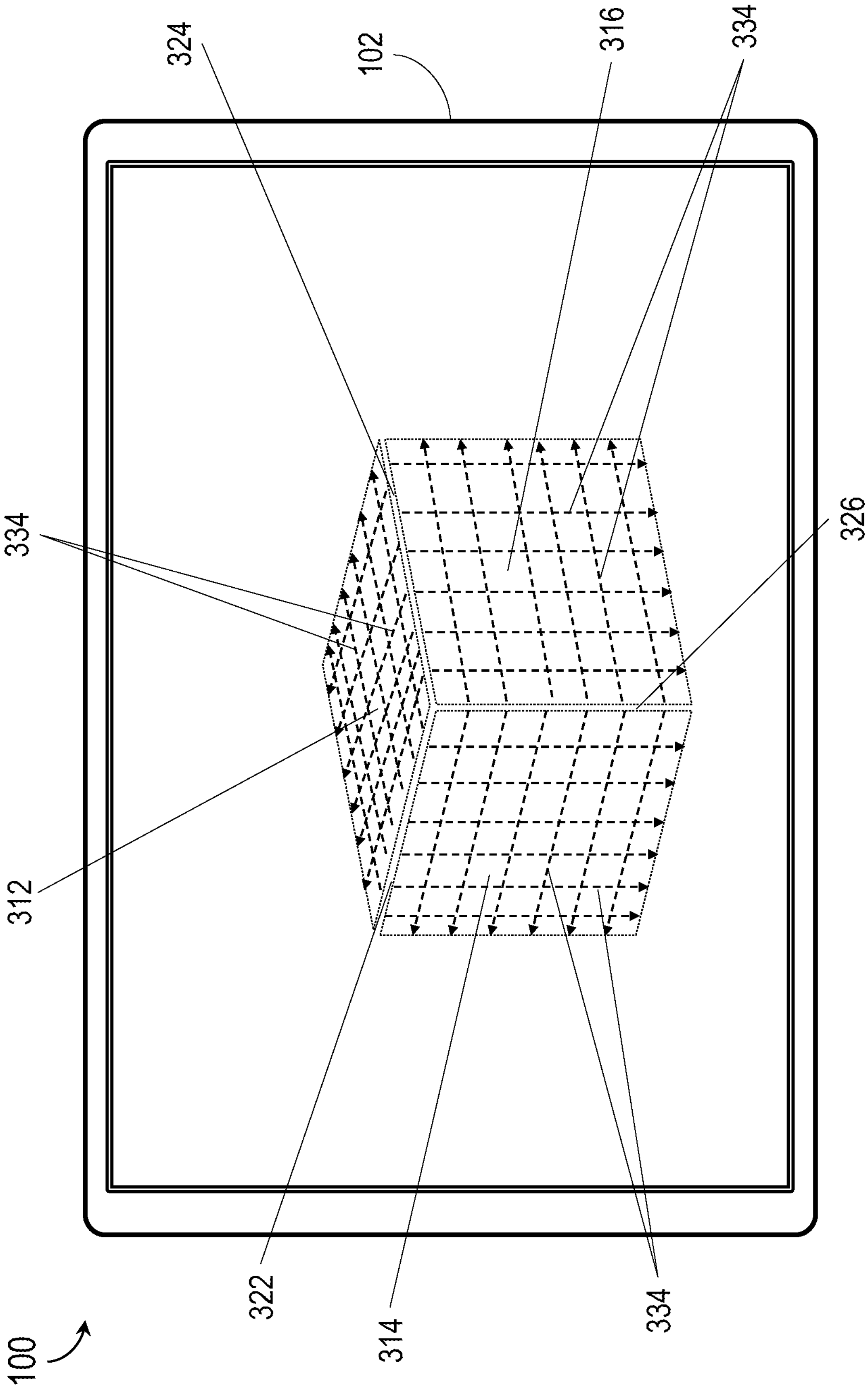

FIG. 3G

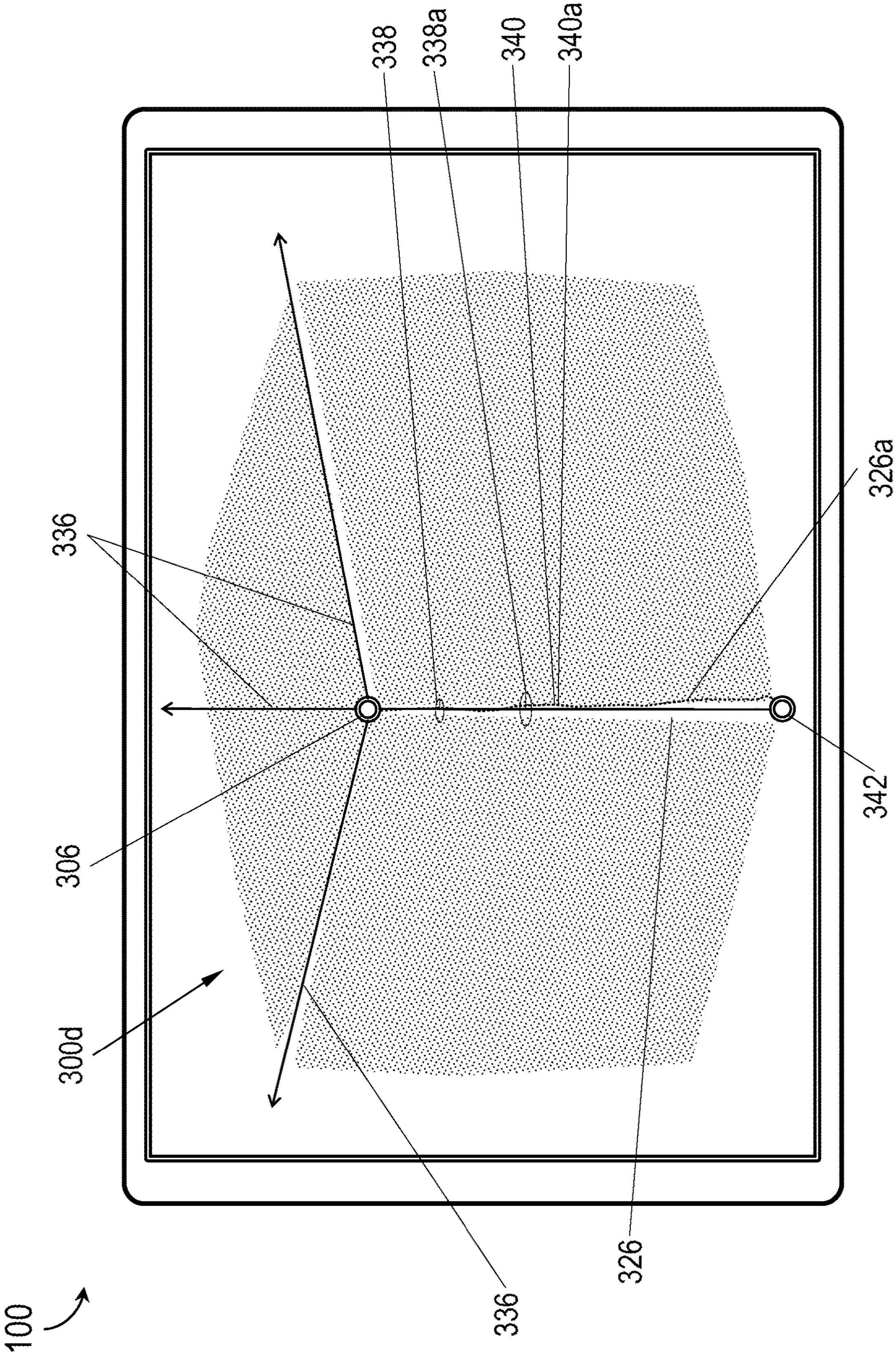

FIG. 3H

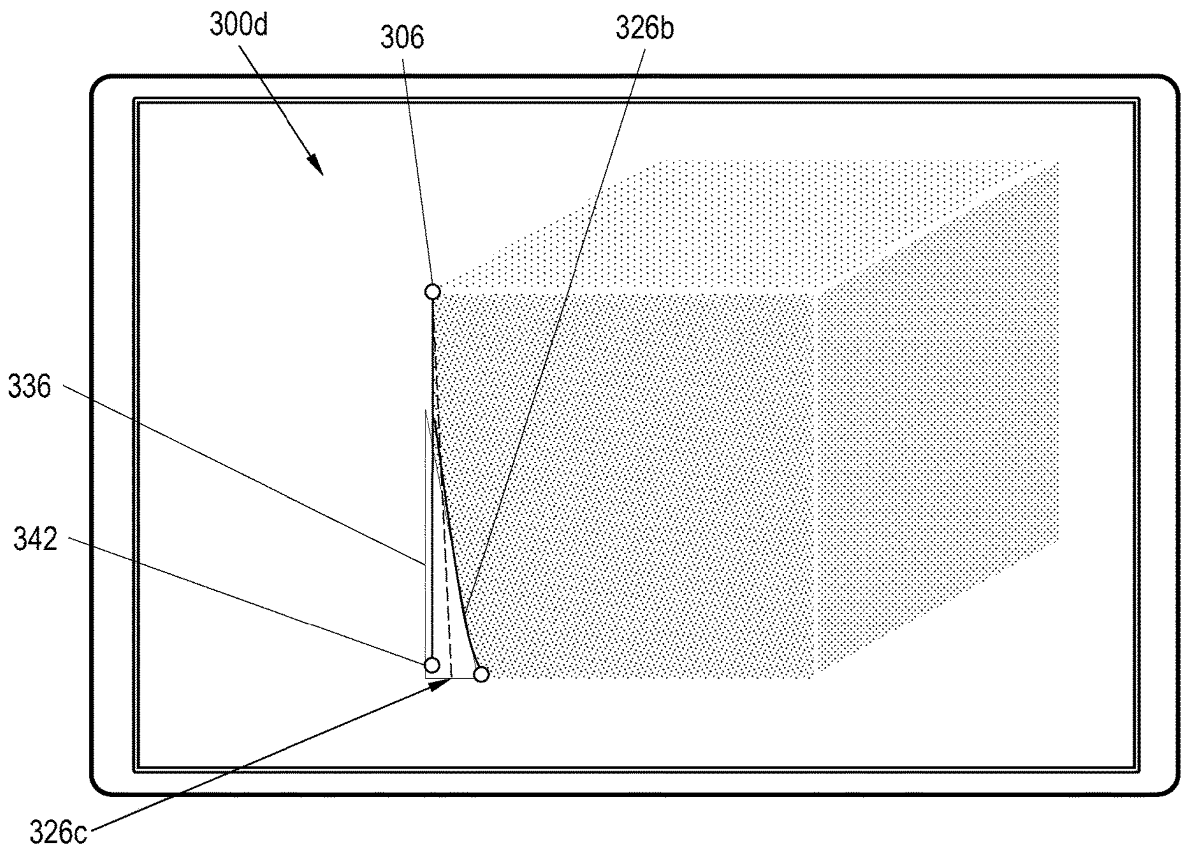

FIG. 3I

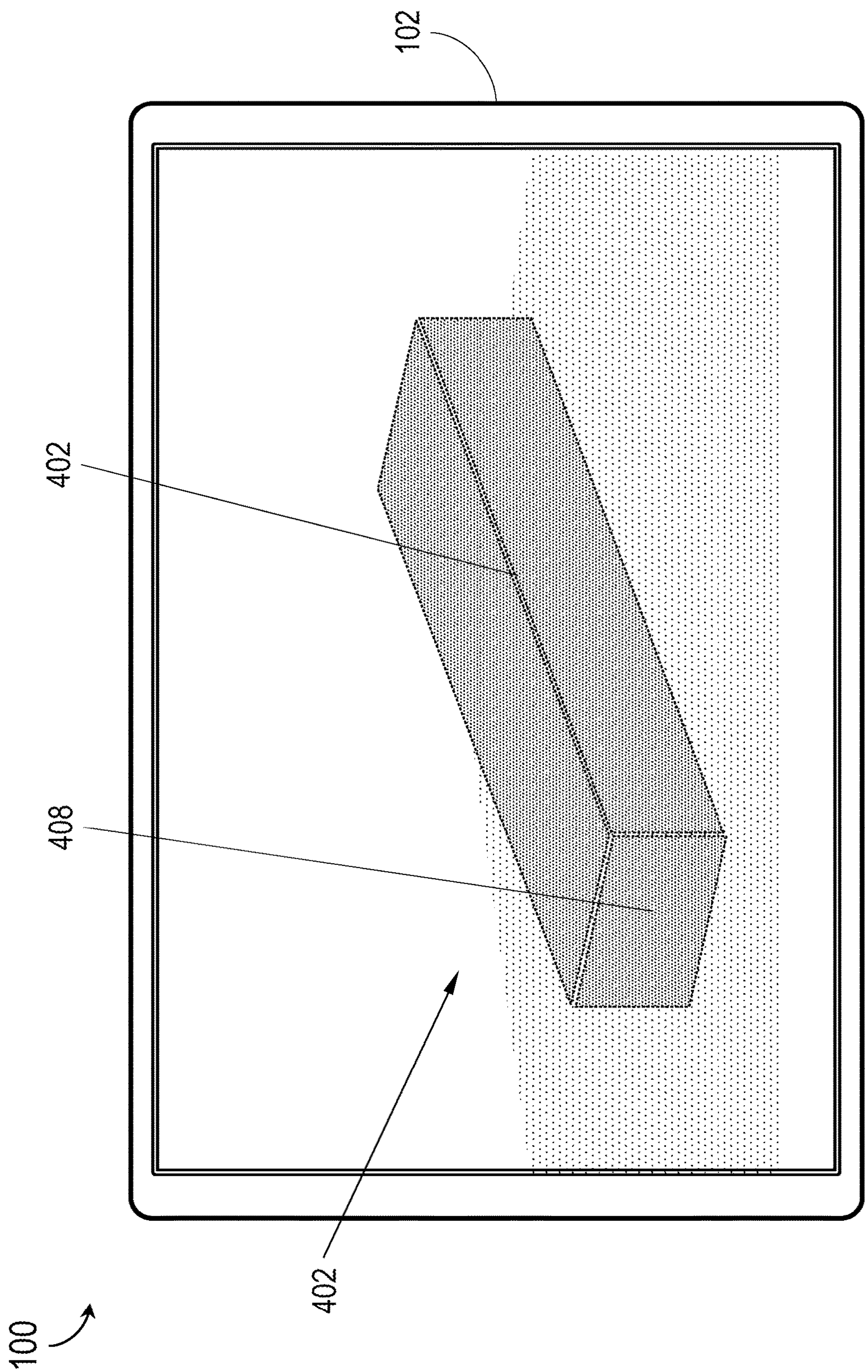

FIG. 4A

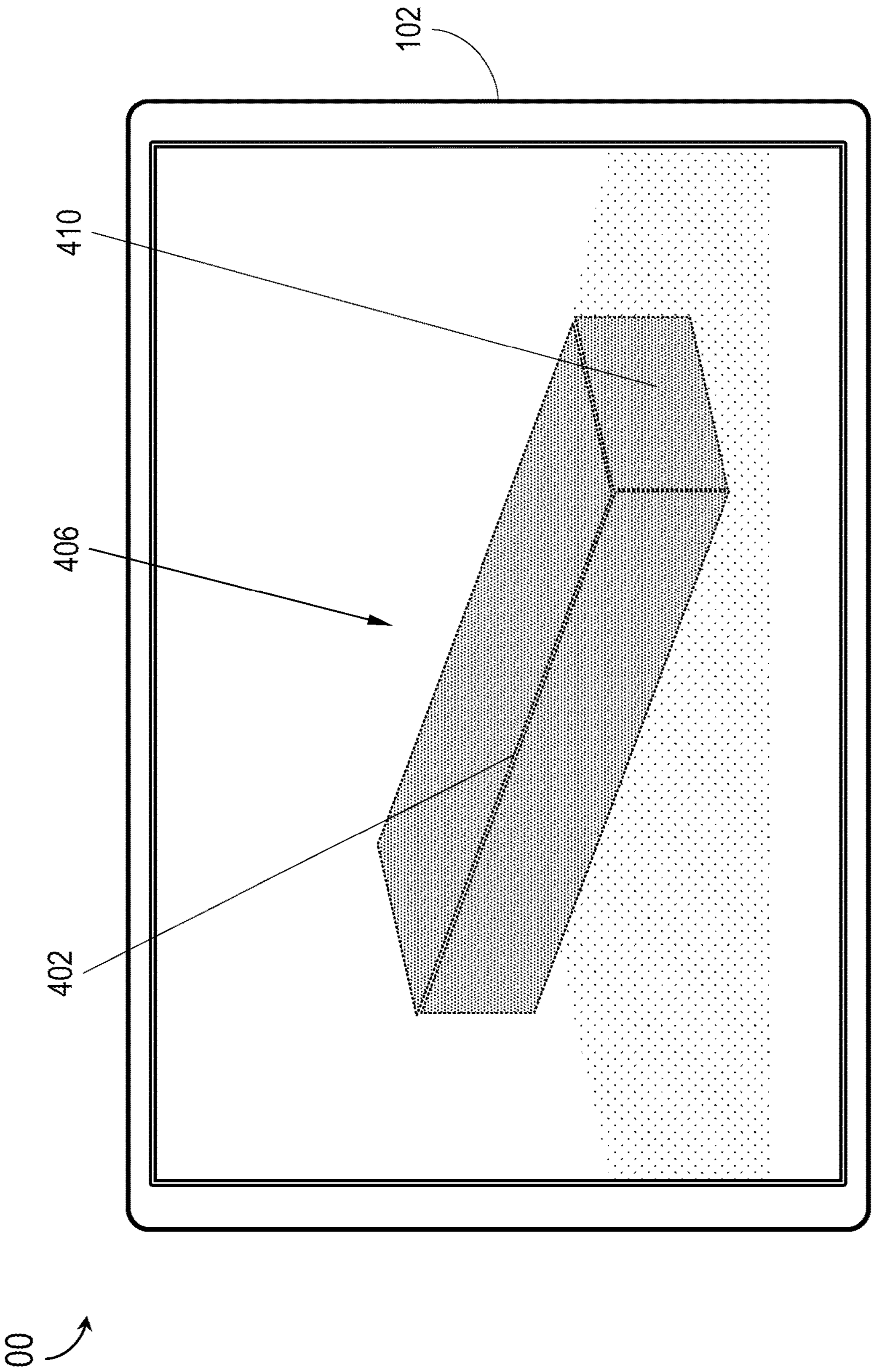

FIG. 4B

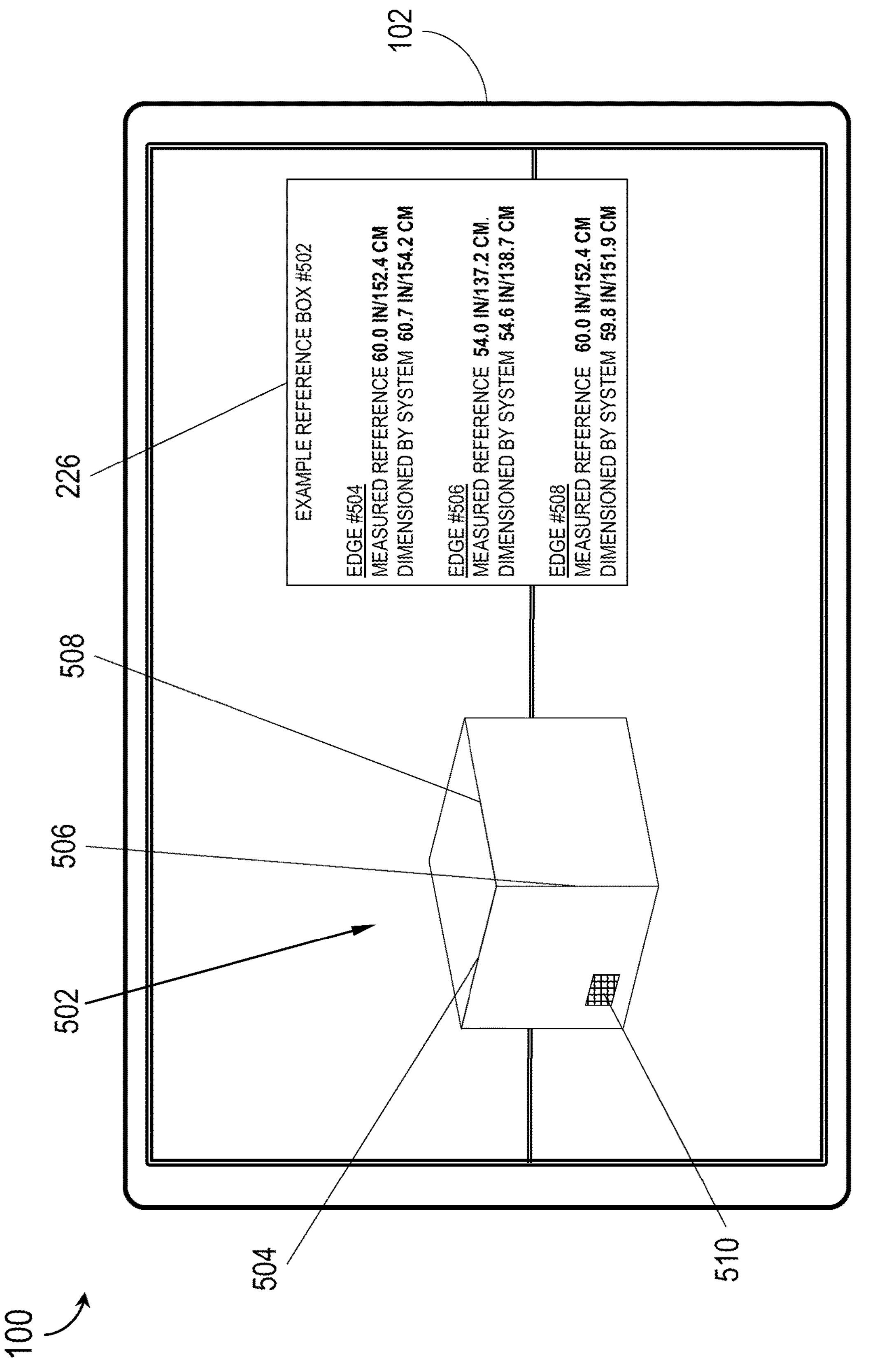
102
226
508
506
502
504
510
100
EXAMPLE REFERENCE BOX #502
EDGE #504
MEASURED REFERENCE 60.0 IN/152.4 CM
DIMENSIONED BY SYSTEM 60.7 IN/154.2 CM
EDGE #506
MEASURED REFERENCE 54.0 IN/137.2 CM.
DIMENSIONED BY SYSTEM 54.6 IN/138.7 CM
EDGE #508
MEASURED REFERENCE 60.0 IN/152.4 CM
DIMENSIONED BY SYSTEM 59.8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

FIG. 5A

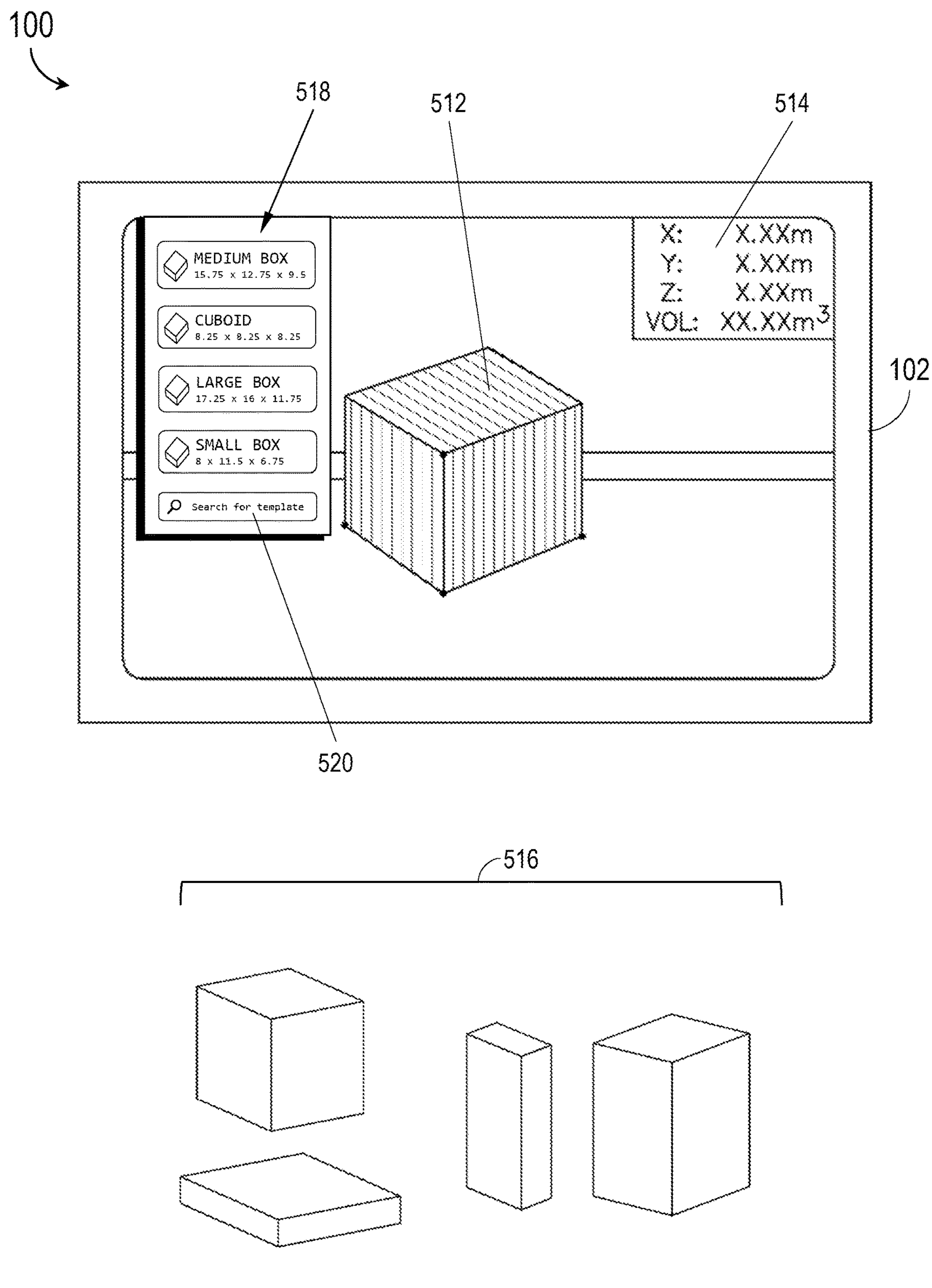
100
518
512
514
X: X.XXm
Y: X.XXm
Z: X.XXm
VOL: XX.XXm3
MEDIUM BOX
15.75 x 12.75 x 9.5
CUBOID
8.25 x 8.25 x 8.25
LARGE BOX
17.25 x 16 x 11.75
SMALL BOX
8 x 11.5 x 6.75
Search for template
102
520
516

FIG. 5B

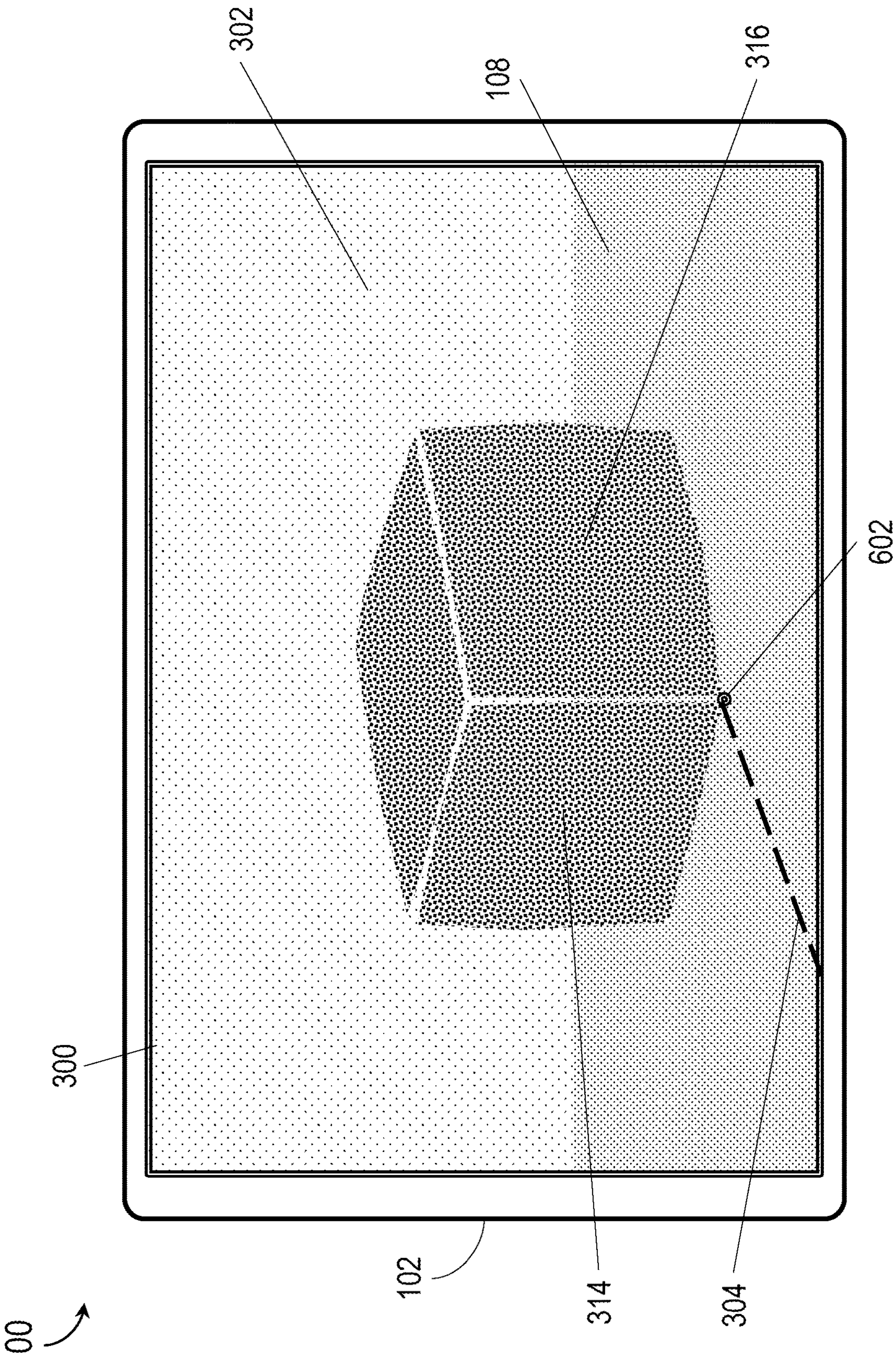

FIG. 6A

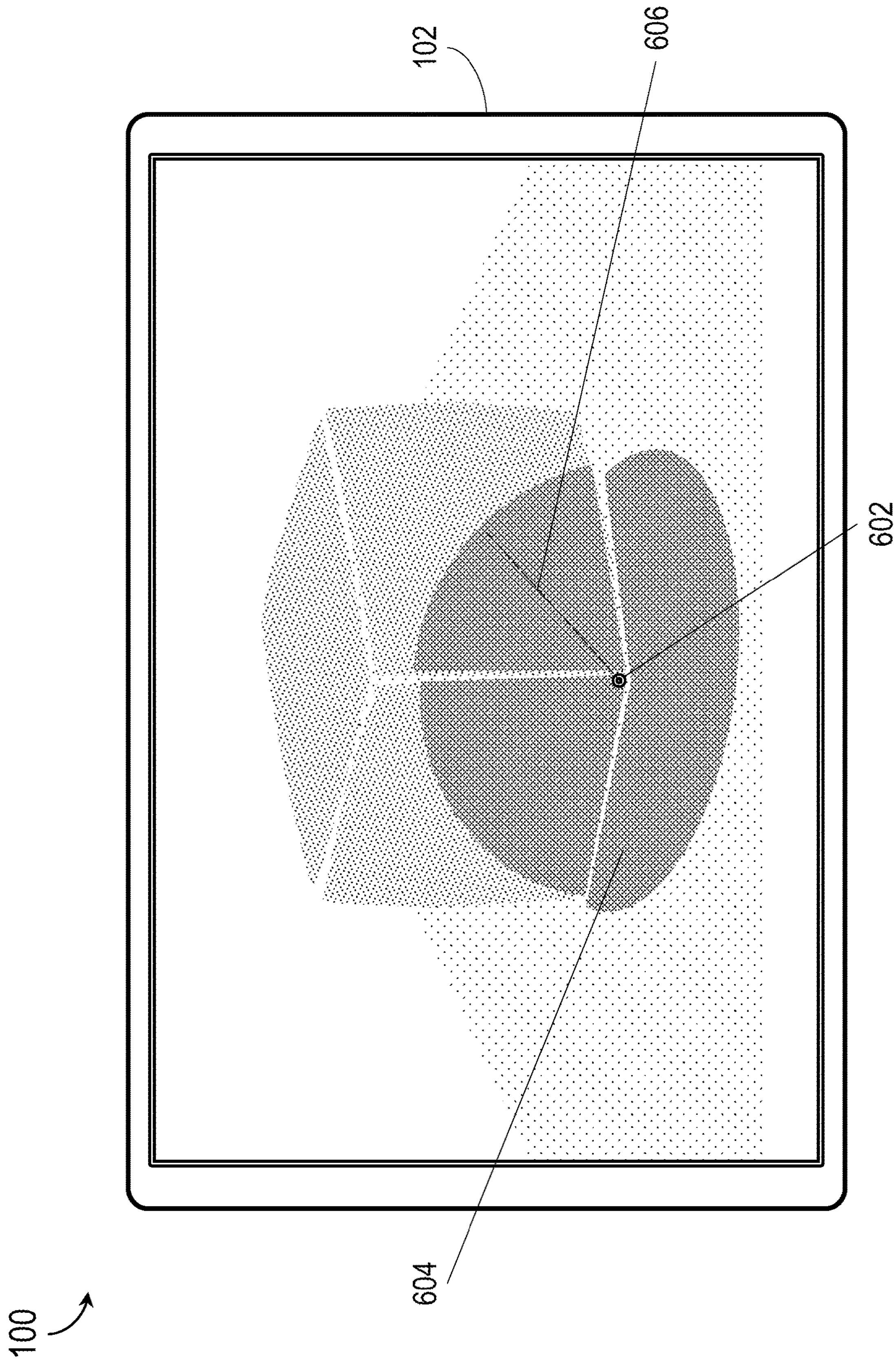

FIG. 6B

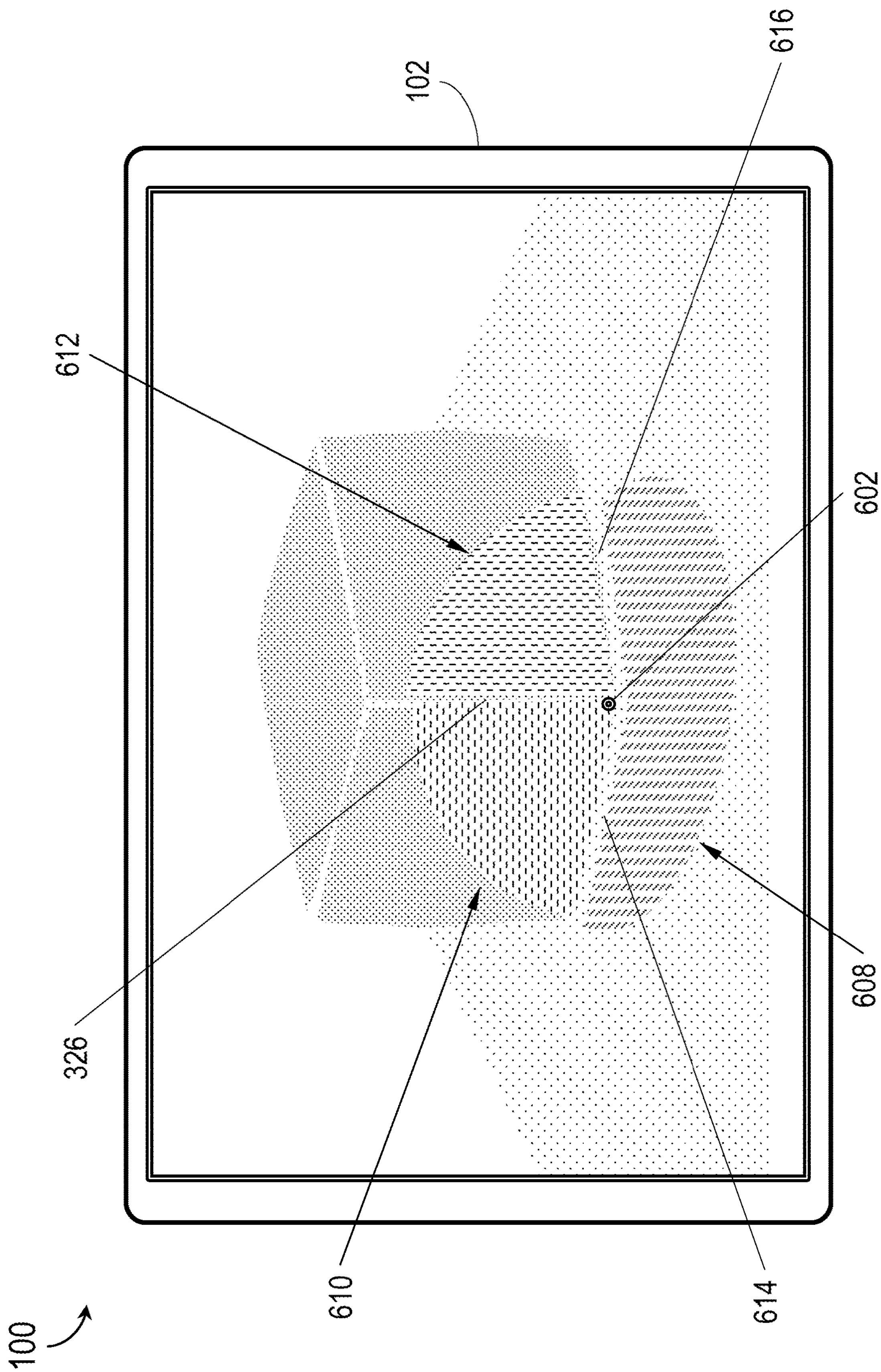

FIG. 6C

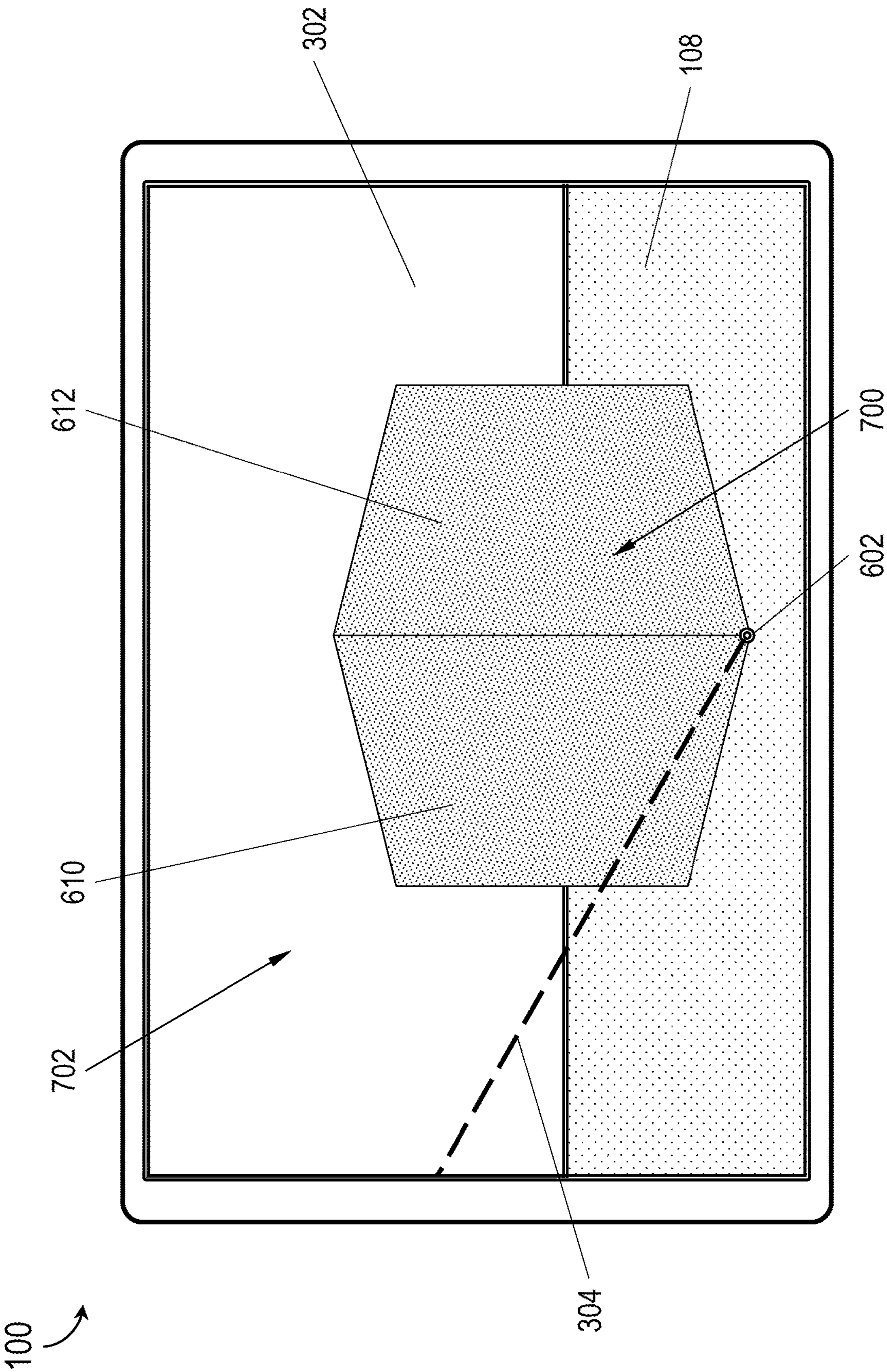

FIG. 7A

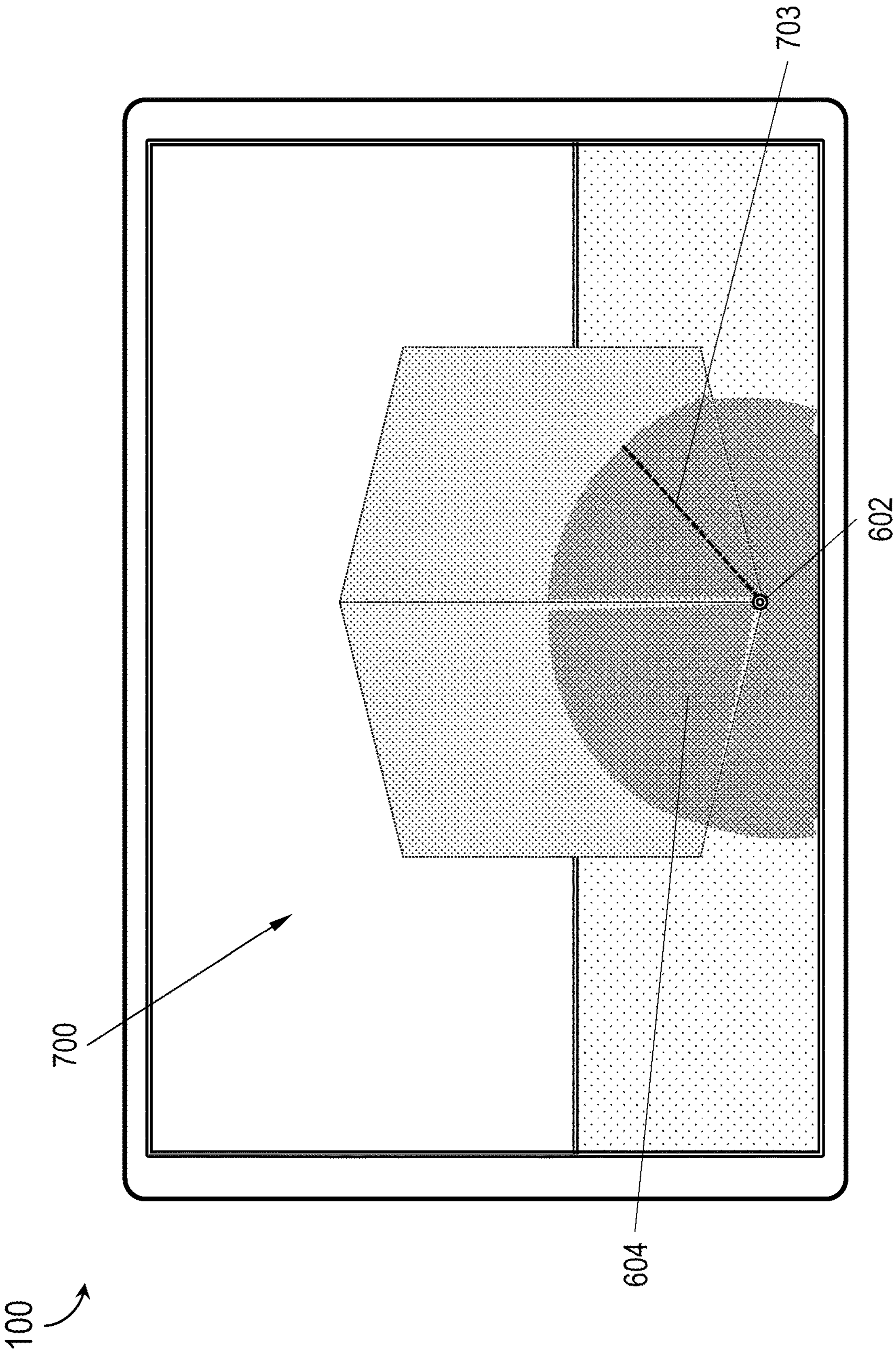

FIG. 7B

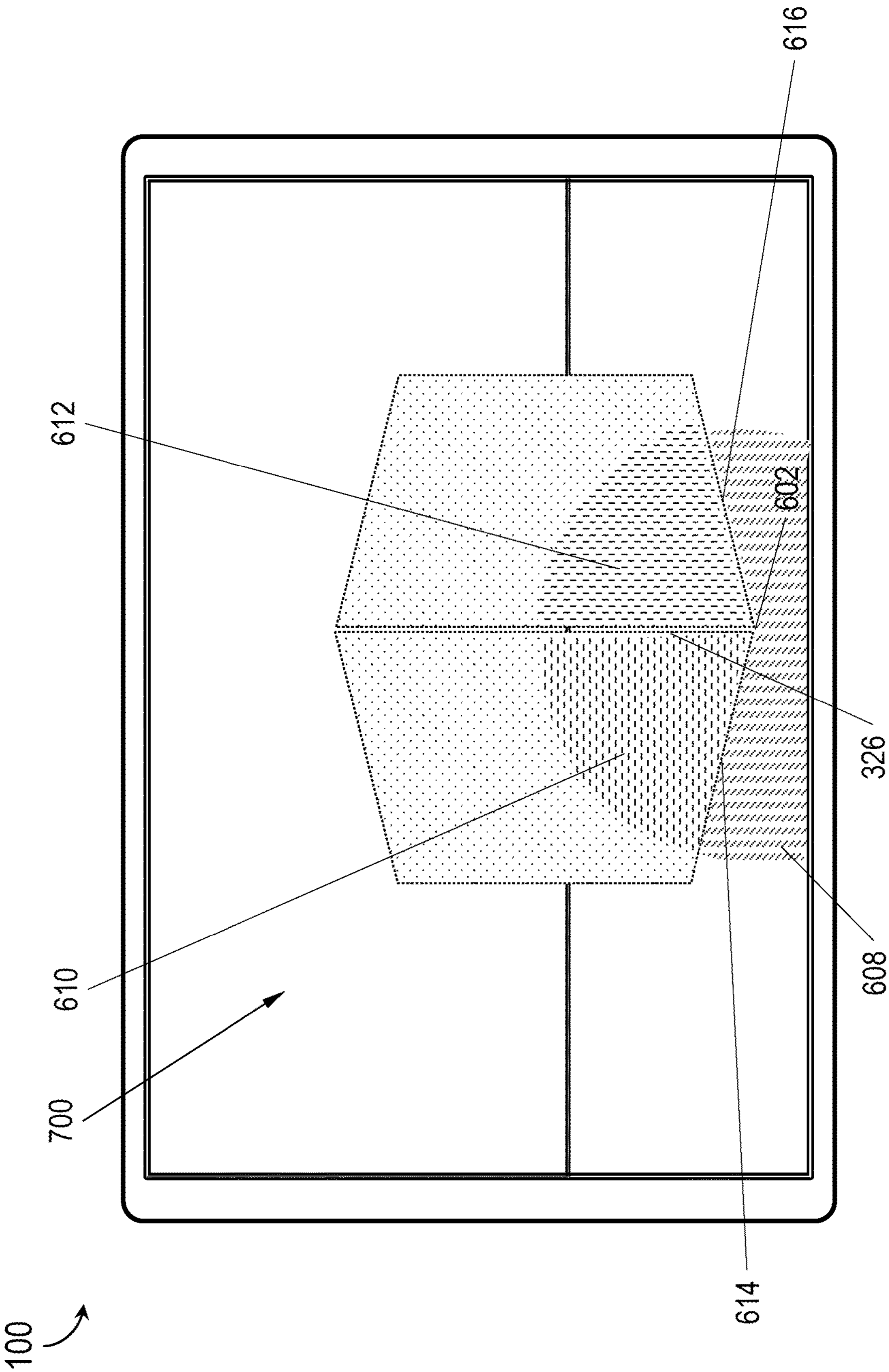

FIG. 7C

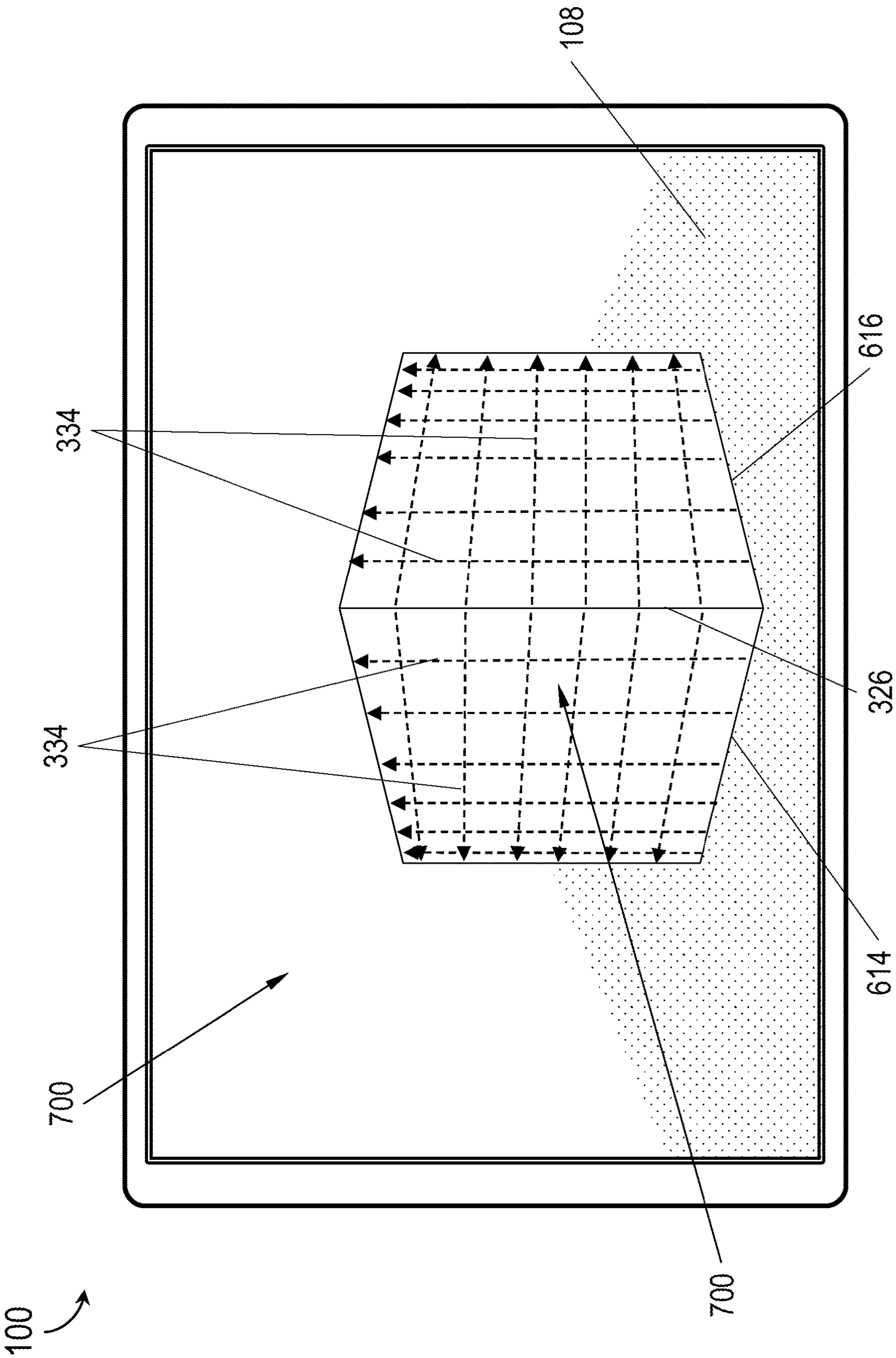

FIG. 7D

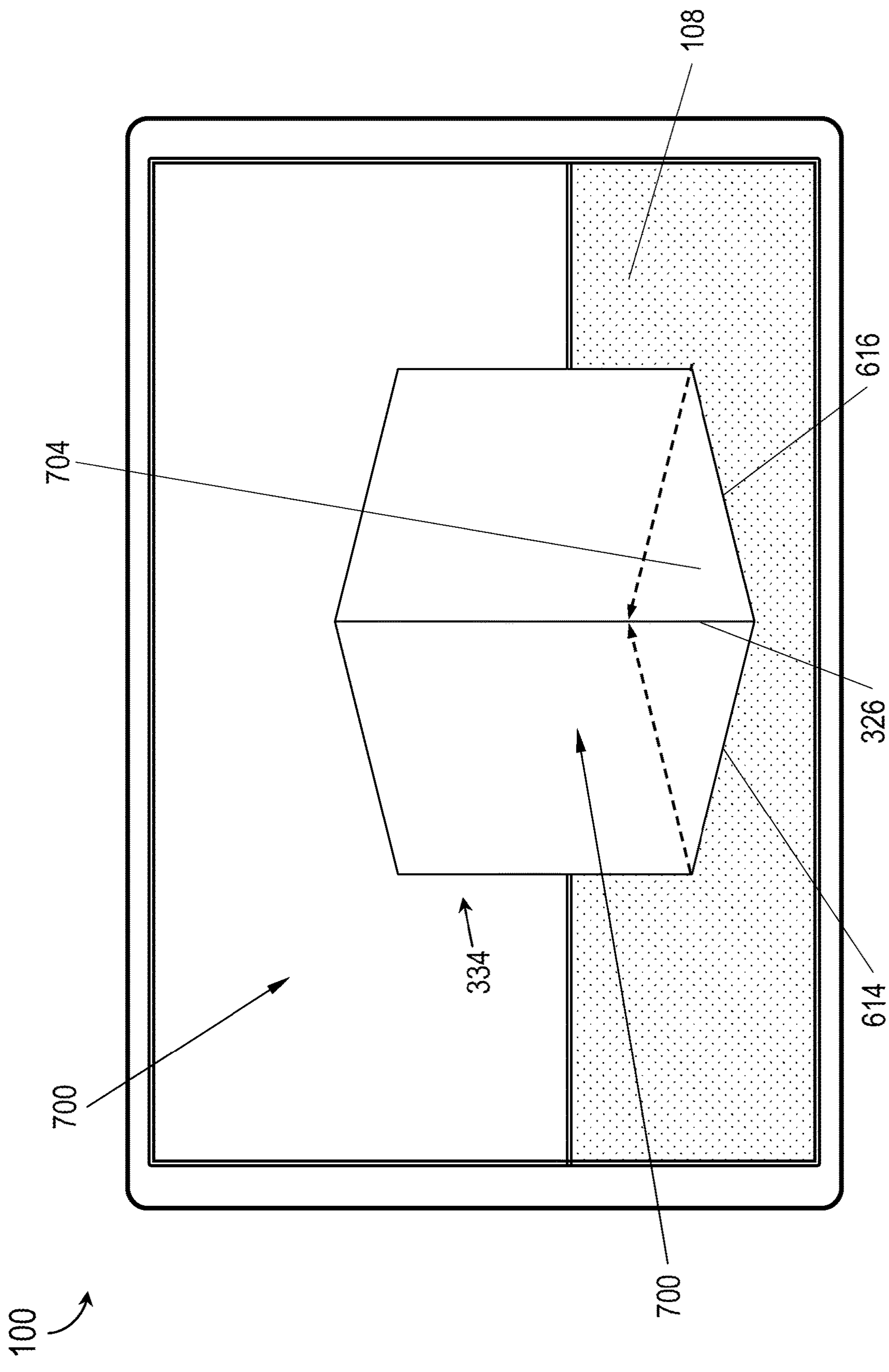

FIG. 7E

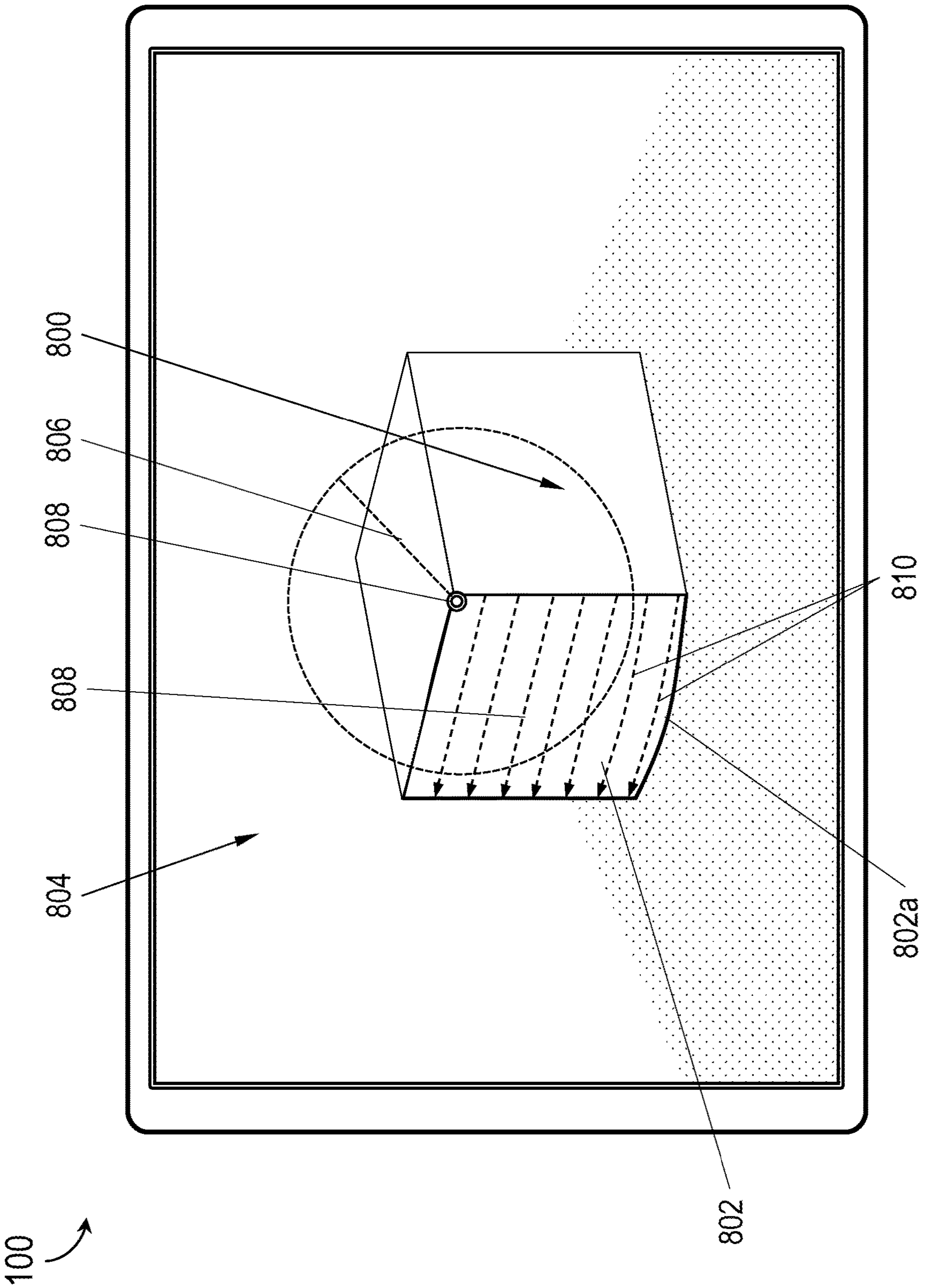

FIG. 8

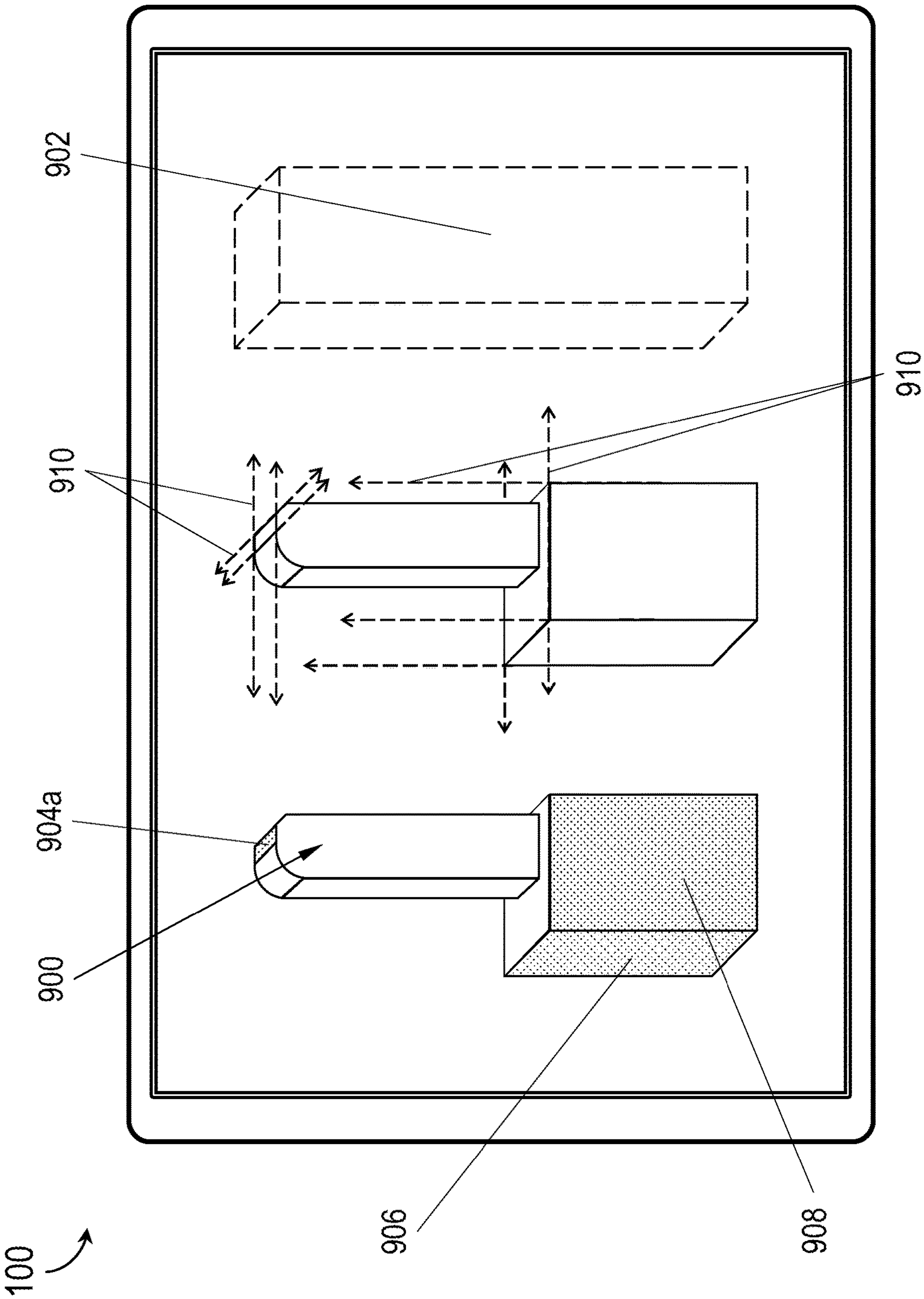

FIG. 9A

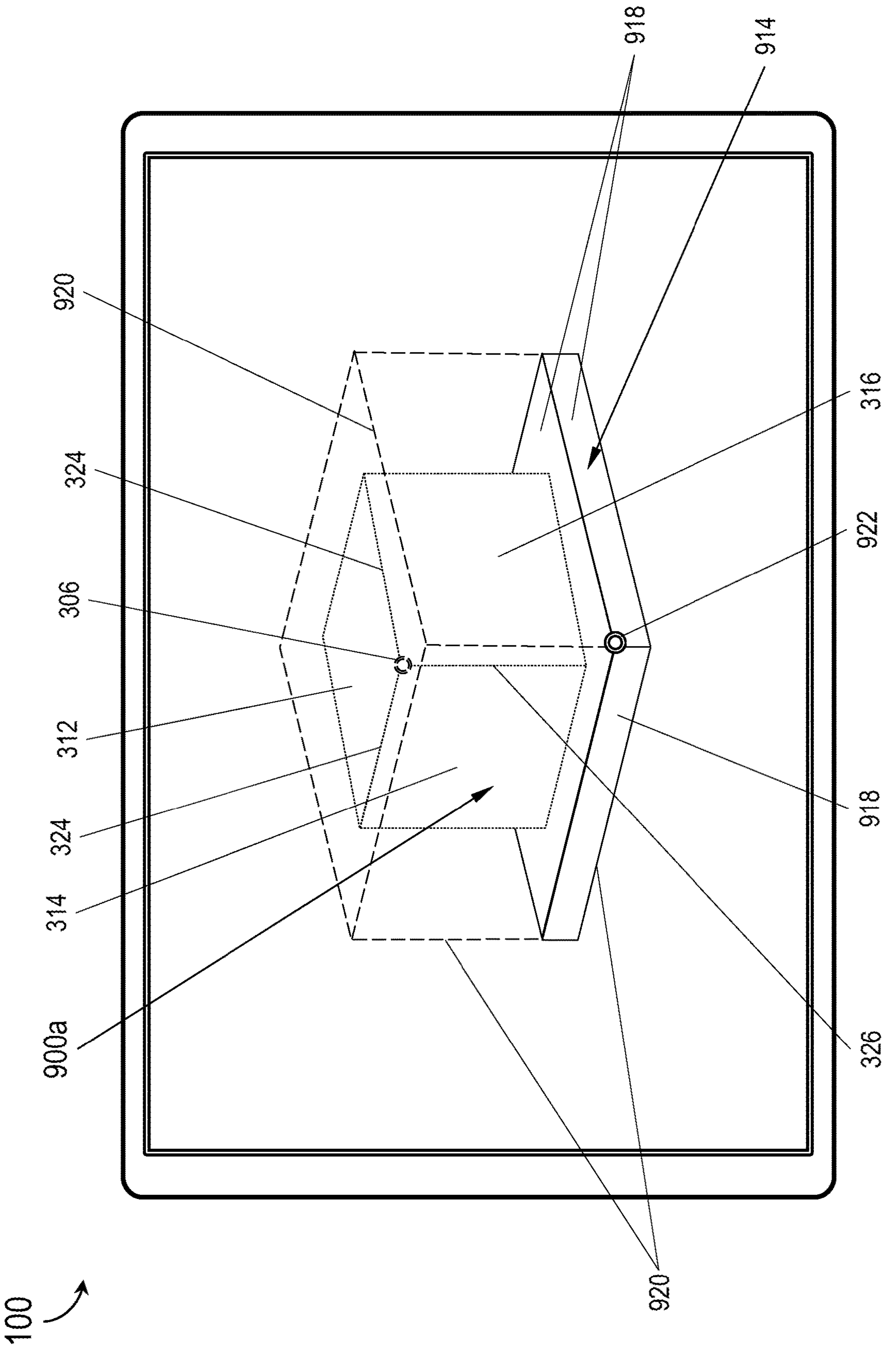

FIG. 9B

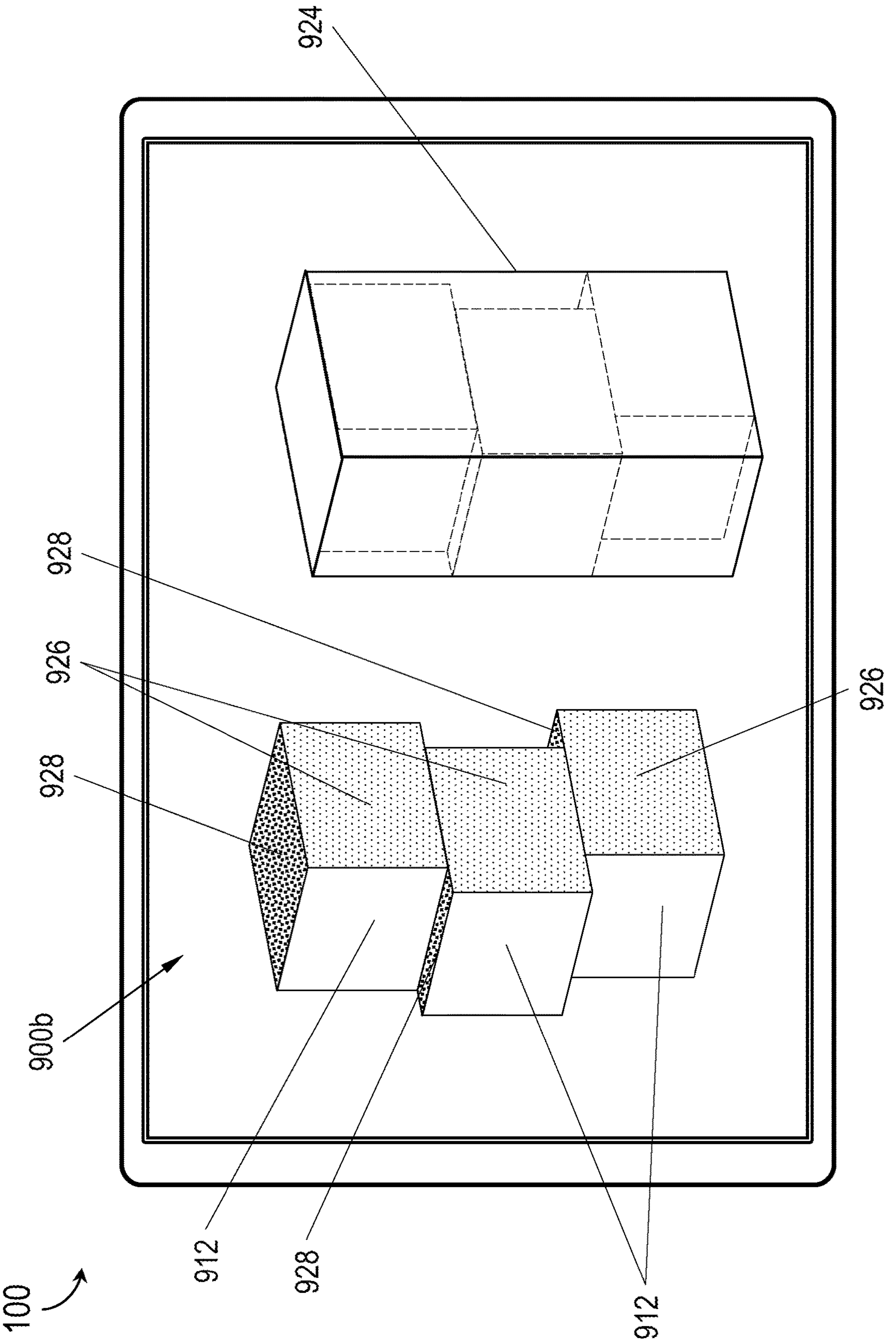

FIG. 9C

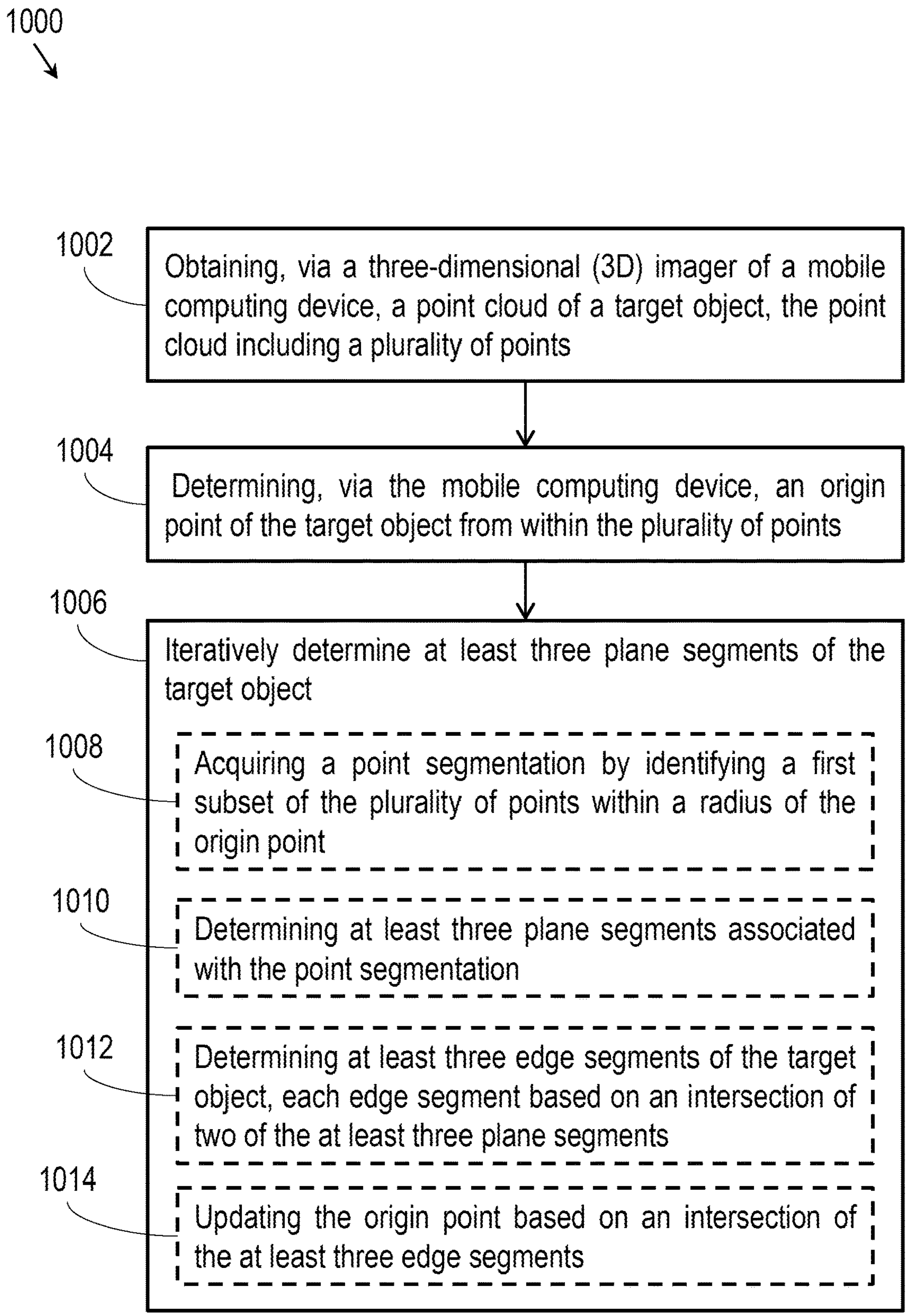
1000
1002
Obtaining, via a three-dimensional (3D) imager of a mobile computing device, a point cloud of a target object, the point cloud including a plurality of points
1004
Determining, via the mobile computing device, an origin point of the target object from within the plurality of points
1006
Iteratively determine at least three plane segments of the target object
1008
Acquiring a point segmentation by identifying a first subset of the plurality of points within a radius of the origin point
1010
Determining at least three plane segments associated with the point segmentation
1012
Determining at least three edge segments of the target object, each edge segment based on an intersection of two of the at least three plane segments
1014
Updating the origin point based on an intersection of the at least three edge segments

FIG. 10A

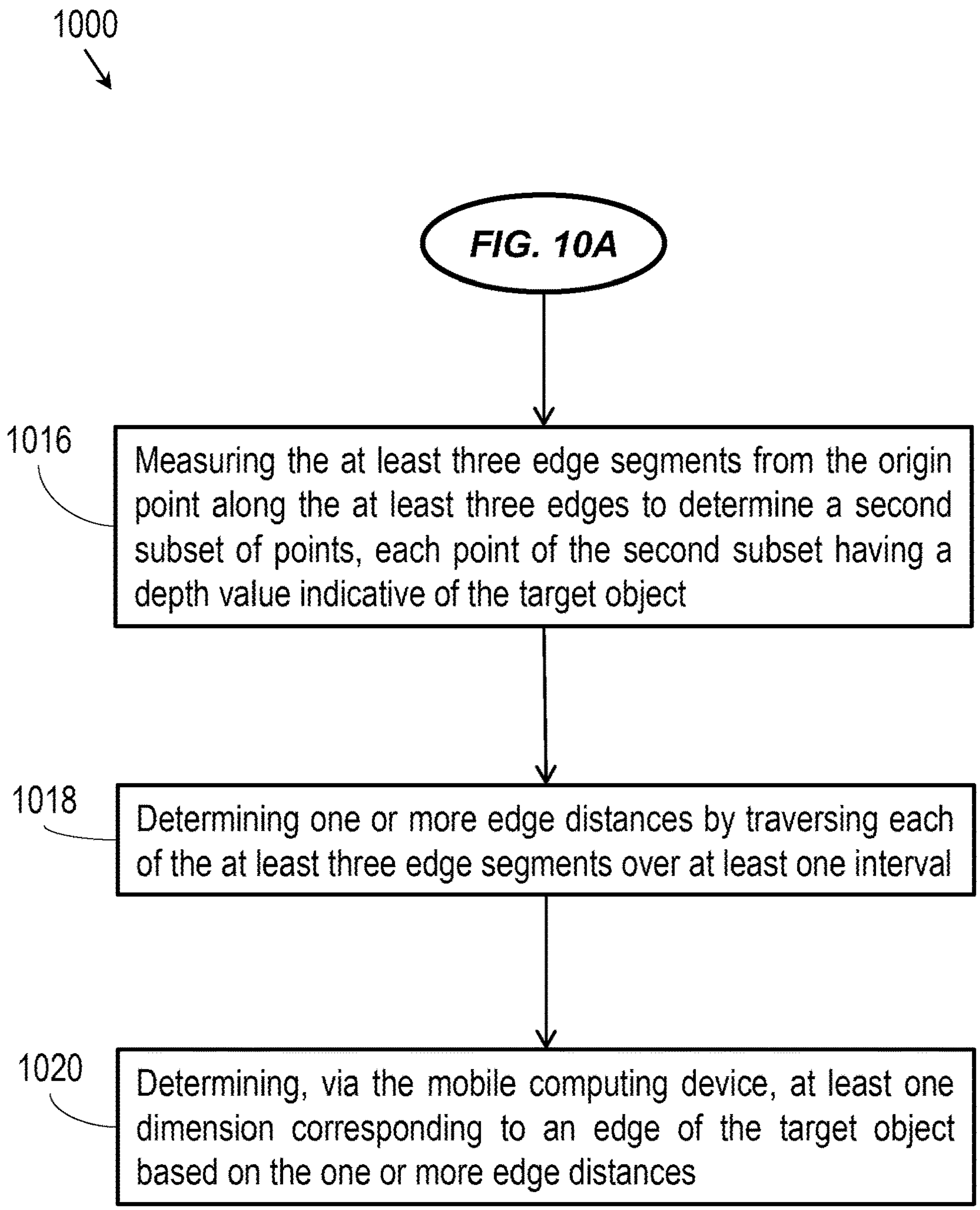
1000
FIG. 10A
1016
Measuring the at least three edge segments from the origin point along the at least three edges to determine a second subset of points, each point of the second subset having a depth value indicative of the target object
1018
Determining one or more edge distances by traversing each of the at least three edge segments over at least one interval
1020
Determining, via the mobile computing device, at least one dimension corresponding to an edge of the target object based on the one or more edge distances

FIG. 10B

SYSTEM AND METHOD FOR THREE-DIMENSIONAL 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. 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. 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.

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 mobile computing device capable of being held by a user is disclosed. The mobile computing device includes a three-dimensional (3D) imager. The 3D imager is configured to capture at least 3D imaging data associated with a target object positioned on a background surface. The 3D imaging data includes a sequence of frames, where each frame is associated with a plurality of points, where each point has an associated depth value. The mobile computing device may include one or more processors in communication with the 3D imager. The one or more processors may be configured to identify within the plurality of points, based on the depth values, at least one origin point, at least one subset of neighboring points, a plurality of plane segments, a plurality of edge segments, one or more edge distances associated with the edge segments, and one or more dimensions of the target object.

A method for dimensioning an object is disclosed. The method includes obtaining a point cloud of a target object, the point cloud including a plurality of points. The method further includes determining an origin point of the target object from within the plurality of points. The method further includes determining at least three plane segments of the target object by an iterative loop. The iterative loop includes acquiring a point segmentation by identifying a first subset of the plurality of points within a radius of the origin point. The iterative loop further includes determining at least three plane segments associated with the point segmentation. The iterative loop further includes determining at least three edges of the target object, each edge based on an intersection of two of the at least three plane segments. The iterative loop further includes updating the origin point based on an intersection of the at least three edges. The method further includes measuring the at least three edge distances from the origin point along the at least three edges to determine a second subset of points, each point of the second subset of points having a depth value indicative of the target object. The method further includes determining one or more edge distances by traversing each of the at least three edge segments over at least one interval. The method further includes determining, via the mobile computing device, at least one dimension corresponding to an edge of the target object based on the one or more edge distances.

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**;

and 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.

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**, **1***a*, **1***b*). 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 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 or flat surface **108**. 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, gyrometer, 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, table, or other flat surface **108**; 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. **3**A, 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 flat surface (**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. **3**C, 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. **3**B) 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 flat surface **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 segments **322**, **324**, **326** (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**.

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 box **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).

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/flat surface **108** 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/flat surface **108** 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 flat surface **108**, 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 imager (**204**, FIG. **2**). This may be beneficial where imaging three planes of a target object **700** via the 3D imager **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 imagers **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 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 **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. **1**A-**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 imager **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 imager **202** and 3D imager **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 imager (**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.

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 mobile computing device capable of being held by a user, comprising:

a three-dimensional (3D) imager configured to capture at least 3D imaging data associated with a target object positioned on a surface, the 3D imaging data comprising a sequence of frames, each frame associated with a plurality of points, each point associated with a depth value;

one or more processors in communication with the 3D imager, the one or more processors configured to:

identify within the plurality of points, based on the plurality of depth values:

at least one origin point associated with a corner of the target object;

at least one set of neighboring points within a radius of the origin point;

identify, by sampling the set of neighboring points:

a plurality of plane segments, each plane segment associated with a surface of the target object; and

a plurality of edge segments, each edge segment corresponding to an edge of the target object and to an intersection of two adjacent plane segments;

determine, for each edge segment, one or more edge distances associated with the corresponding edge of the target object by sampling one or more intervals across at least one adjacent plane segment; and

determine at least one dimension of each associated edge of the target object based on the one or more edge distances;

and

at least one display operatively coupled to the one or more processors, the display configured to present to the user one or more of the 3D imaging data, the plurality of edge segments, and the determined dimensions of each associated edge of the target object.

2. The mobile computing device of claim **1**, wherein the determined dimension is based on a median value of the one or more edge distances.

3. The mobile computing device of claim **1**, wherein the one or more processors are configured to:

identify, within each frame, at least one frame dataset associated with an orientation of the mobile computing device relative to the target object, each frame dataset comprising one or more of the at least one origin point, the at least one set of neighboring points, the plurality of plane segments, and the plurality of edge segments; and

refine at least one of the one or more edge distances and the dimension based on a median value including the at least one frame dataset.

4. The mobile computing device of claim **1**, 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.

5. The mobile computing device of claim **4**, wherein the one or more processors are configured to:

compile 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.

6. The mobile computing device of claim **4**, wherein the one or more processors are configured to determine the dimension by comparing the target object to at least one reference object.

7. The mobile computing device of claim **4**, further comprising:

at least one camera configured to capture a two-dimensional (2D) image stream associated with the target object, the camera including at least one scanner configured to detect encoded information on the target object;

wherein the one or more processors are configured to:

associate the target object with at least one reference object based on the detected encoded information; and

compare the set of determined dimensions corresponding to the target object and the set of reference dimensions corresponding to the associated reference box.

8. The mobile computing device of claim **7**, wherein the one or more processors are configured to:

determine at least one difference between the set of determined dimensions and the set of reference dimensions; and

direct the display to prompt the user when the determined difference exceeds a threshold level.

9. The mobile computing device of claim **1**, wherein the one or more processors are further configured to identify, by sampling the subset of neighboring points, a surface plane corresponding to the surface, wherein the surface is selected from a floor and a wall.

10. The mobile computing device of claim **1**, further comprising:

at least one distance sensor configured to determine at least one distance of the target object from the mobile computing device;

wherein

the set of determined dimensions is based on the at least one distance.

11. The mobile computing device of claim **1**, wherein the one or more processors are configured to refine the plurality of plane segments and the plurality of edge segments by iteratively:

determining at least one refined origin point based on an intersection of the plurality of plane segments;

identifying at least one set of refined neighboring points within the radius of the refined origin point; and

identifying, by sampling the at least one set of refined neighboring points:

at least one plurality of refined plane segments; and

at least one plurality of refined edge segments corresponding to an intersection of two adjacent refined plane segments.

12. A method for dimensioning an object, comprising:

obtaining, via a three-dimensional (3D) imager of a mobile computing device, a point cloud of a target object, the point cloud including a plurality of points;

determining, via the mobile computing device, an origin point of the target object from within the plurality of points;

determining at least three plane segments of the target object by iteratively:

acquiring a point segmentation by identifying a first subset of the plurality of points within a radius of the origin point;

determining at least three plane segments associated with the point segmentation; and

determining at least three edge segments of the target object, each edge segment based on an intersection of two of the at least three plane segments;

measuring the at least three edge segments from the origin point along the at least three edge segments to determine a second subset of points, each point of the second subset having a depth value indicative of the target object;

determining one or more edge distances by traversing each of the at least three edge segments over at least one interval;

and

determining, via the mobile computing device, at least one dimension corresponding to an edge of the target object based on the one or more edge distances.

13. The method for dimensioning an object of claim **12**, further comprising:

updating the origin point based on an intersection of the at least three edge segments.

14. The method for dimensioning an object of claim **12**, further comprising:

updating at least one of the origin point and the radius based on based on the point segmentation of a previously obtained point cloud.

15. The method for dimensioning an object of claim **12**, wherein at least one of acquiring a point segmentation by identifying a first subset of the plurality of points within a radius of the origin point and determining one or more edge distances by traversing each of the at least three edge segments over the at least one interval includes a nearest neighbors search.

16. The method for dimensioning an object of claim **12**, wherein the radius is adjustable to a greater radius when the point segmentation does not include all points having a depth value indicative of the target object.

17. The method for dimensioning an object of claim **12**, wherein the radius is adjustable to a smaller radius when the point segmentation includes one or more points having a depth value indicative of a floor or a background.

18. The method for dimensioning an object of claim **12**, wherein determining at least three plane segments associated with the point segmentation includes:

iteratively determining the at least three plane segments associated with the point segmentation until at least one criterion is fulfilled, wherein the criterion is a number of iterations.

19. The method for dimensioning an object of claim **12**, wherein the origin point of the object is initially determined based on a nearest depth value relative to the plurality of points.

20. The method for dimensioning an object of claim **12**, wherein determining at least three edge segments of the target object, each edge segment based on an intersection of two of the at least three plane segments, includes:

correcting for at least one divergence of the plurality of points from a determined edge segment.

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