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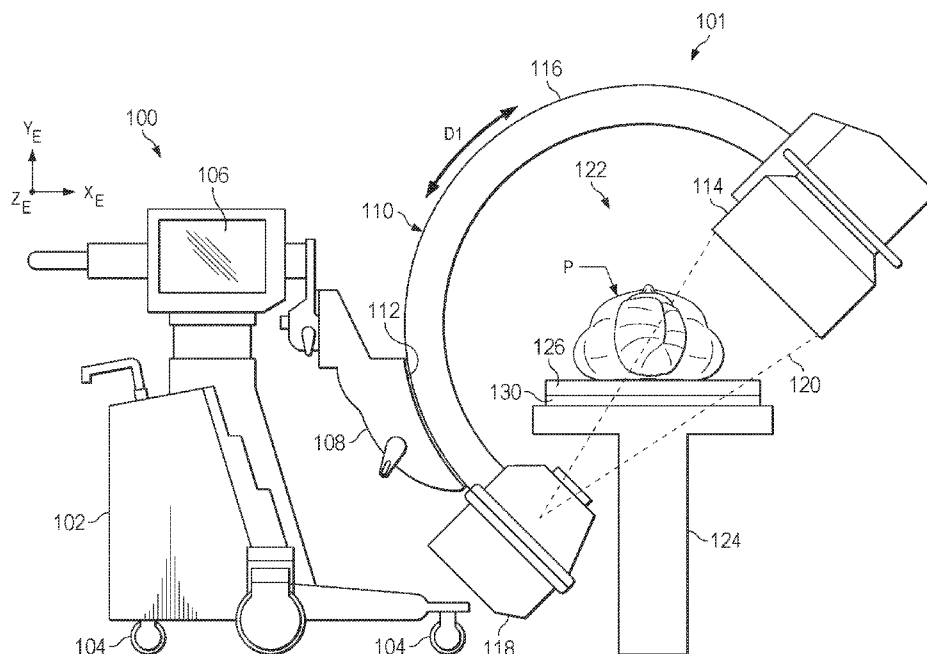


FIG. 1

(57) Abstract: A system may comprise a fiducial panel including a plurality of arrays of three dimensional, radiopaque fiducial markers. Each array of the plurality of arrays may include a plurality of a first type of the fiducial markers and a plurality of a second type of the fiducial markers. The plurality of first type fiducial markers and the plurality of second type fiducial markers may form a fiducial tag pattern. The fiducial tag pattern for at least one of the plurality of arrays may be visible in a plurality of images generated by a rotating imaging system.

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**SYSTEMS AND METHODS FOR DETERMINING IMAGING SYSTEM
LOCALIZATION PARAMETERS**

CROSS-REFERENCED APPLICATIONS

[0001] This application claims priority to and benefit of U.S. Provisional Application No. 63/509,462 filed June 21, 2023 and entitled “Systems and Methods for Determining Imaging System Localization Parameters,” which is incorporated by reference herein in its entirety.

FIELD

[0002] The present disclosure is directed to systems and methods for determining imaging system localization parameters from images that include at least a portion of a known localization pattern of three-dimensional fiducial markers.

BACKGROUND

[0003] Minimally invasive medical techniques are intended to reduce the amount of tissue that is damaged during medical procedures, thereby reducing patient recovery time, discomfort, and harmful side effects. Such minimally invasive techniques may be performed through natural orifices in a patient anatomy or through one or more surgical incisions. Through these natural orifices or incisions, an operator may insert minimally invasive medical tools to reach a target tissue location. Minimally invasive medical tools include instruments such as therapeutic, diagnostic, biopsy, and surgical instruments. Medical tools may be inserted into anatomic passageways and navigated toward a region of interest within a patient anatomy. Navigation and deployment of medical tools may be assisted using images of the anatomic passageways and surrounding anatomy, obtained intra-operatively. Intra-operative imaging, alone or in combination with pre-operative imaging, may provide improved navigational guidance and confirmation of engagement of an interventional tool with the target tissue. Improved systems and methods are needed for determining localization parameters for intra-operative imaging systems so that generated images may be used to prepare accurate anatomic models and provide accurate navigation and guidance.

SUMMARY

[0004] Consistent with some examples, a system may comprise a fiducial panel including a plurality of arrays of three dimensional, radiopaque fiducial markers. Each array of the plurality of arrays may include a plurality of a first type of the fiducial markers and a plurality of a

second type of the fiducial markers. The plurality of first type fiducial markers and the plurality of second type fiducial markers may form a fiducial tag pattern. The fiducial tag pattern for at least one of the plurality of arrays may be visible in a plurality of images generated by a rotating imaging system.

[0005] Consistent with some examples, a method may comprise receiving image data of a field of view from a rotating imaging system, detecting a plurality of fiducial markers in the image data, and identifying a localization pattern formed by the plurality of fiducial markers. The localization pattern may include a plurality of arrays comprised of the plurality of fiducial markers. Each array of the plurality of arrays includes a plurality of a first type of the fiducial markers and a plurality of a second type of the fiducial markers. The first and second types of fiducial markers in each array of the plurality of arrays may form a fiducial tag pattern. The method may further comprise determining a set of localization parameters for the rotating imaging system from the localization pattern.

[0006] Other embodiments include corresponding computer systems, apparatus, and computer programs recorded on one or more computer storage devices, each configured to perform the actions of the methods.

[0007] It is to be understood that both the foregoing general description and the following detailed description are illustrative and explanatory in nature and are intended to provide an understanding of the present disclosure without limiting the scope of the present disclosure. In that regard, additional aspects, features, and advantages of the present disclosure will be apparent to one skilled in the art from the following detailed description.

BRIEF DESCRIPTIONS OF THE DRAWINGS

[0008] FIG. 1 illustrates an imaging system with a medical environment, according to some examples.

[0009] FIG. 2 illustrates a top view of the patient on a table with a fiducial panel, according to some examples.

[0010] FIG. 3A illustrates a top view of a fiducial panel, according to some examples.

[0011] FIG. 3B illustrates a partial cross-sectional view of the fiducial panel of FIG. 3A, according to some examples.

[0012] FIG. 4A illustrates a cross-sectional view of a fiducial panel, according to some examples.

[0013] FIG. 4B illustrates a cross-sectional view of a fiducial panel, according to some examples.

[0014] FIG. 4C illustrates a cross-sectional view of a fiducial panel, according to some examples.

[0015] FIG. 4D illustrates a square fiducial array, according to some examples.

[0016] FIG. 4E illustrates a rectangular fiducial array, according to some examples.

[0017] FIG. 5 illustrates an image generated by an imaging system with a portion of a fiducial panel within the field of view of the imaging system, according to some examples.

[0018] FIG. 6 illustrates reference localization patterns, according to some examples.

[0019] FIG. 7 is a flowchart illustrating a method for determining localization parameters for an imaging system, according to some examples.

[0020] FIG. 8 is a flowchart illustrating an example of a method for identifying at least a portion of the localization pattern in an image, according to some examples.

[0021] FIG. 9A illustrates a cross-sectional portion of a fiducial panel including a fiducial marker of a first type and a fiducial marker of a second type aligned along a plane, according to some examples.

[0022] FIG. 9B illustrates a cross-sectional portion of a fiducial panel including a fiducial marker of a first type and a fiducial marker of a second type aligned along a plane, according to some examples.

[0023] FIG. 10 illustrates a fiducial panel assembly that includes an auxiliary fiducial panel detachably coupled to a main fiducial panel, according to some examples.

[0024] FIGS. 11 and 12 illustrate the fiducial panel assembly of FIG. 10 in use with an imaging system, according to some examples.

[0025] FIGS. 13A and 13B illustrate perspective views of a curved fiducial panel, according to some examples.

[0026] FIGS. 14 and 15 illustrate the fiducial panel assembly of FIGS. 13A and 13B in use with an imaging system, according to some examples.

[0027] FIGS. 16 and 17 illustrate an imaging system used with a planar fiducial panel that is angled relative to a patient table, according to some examples.

[0028] FIG. 18 illustrates a robot-assisted medical system, according to some examples. Embodiments of the present disclosure and their advantages are best understood by referring to the detailed description that follows. It should be appreciated that like reference numerals are used to identify like elements illustrated in one or more of the figures, wherein showings therein are for purposes of illustrating embodiments of the present disclosure and not for purposes of limiting the same.

DETAILED DESCRIPTION

[0029] The techniques disclosed in this document may be used with movable intra-operative imaging systems, for example, during minimally invasive procedures. In some examples, two-dimensional images received from a movable intraoperative imaging system may be used to generate a three-dimensional model reconstruction and/or update pre-operative planning and navigation models. Localization of the movable intra-operative imaging system allows the resulting two-dimensional images to be registered to each other and/or to pre-existing models or interventional plans. Although some of the movable intra-operative imaging systems described herein are C-arm X-ray imaging systems, it is contemplated that the systems and methods described herein may be applied to other imaging modalities, such as C-arm cone-beam CT, without departing from the scope of the present disclosure. The systems and techniques described in this document may be used in a variety of medical procedures that may improve accuracy and outcomes through use of intra-operative imaging. The medical procedures may be performed using hand-held or otherwise manually controlled imaging probes and tools (e.g., a bronchoscope). In other examples, the described imaging probes and tools may be manipulated with a robot-assisted medical system.

[0030] FIG. 1 illustrates an imaging system 100 within a medical environment 101 that has an environment frame of reference (X_E , Y_E , Z_E). The imaging system 100 may include a cart 102 including wheels 104 that facilitate movement of the cart within the medical environment 101. The cart 102 may include a display panel 106 that may include image display windows and control interfaces. The imaging system 100 may also include an extension arm 108 extending from the cart 102 and a C-arm mechanism 110 coupled to the extension arm 108 by a rotational or orbital joint 112. The extension arm 108 may be movable relative to the cart 102 in any of the translational directions X_E , Y_E , Z_E or in rotational degrees of freedom about the axes X_E , Y_E , Z_E . The C-arm mechanism 110 may include an imaging detector 114 coupled to one end of an arc-shaped arm 116 and an imaging source 118 coupled to an opposite end of the arc-shaped arm 116. The imaging source 118 may include an X-ray source (e.g., an X-ray tube) and a collimator that determines the size and shape of the X-ray beam. The imaging detector 114 may include an image intensifier that captures the X-ray from the X-ray source and an optical coupler that distributes light from the image intensifier to a camera or other image recording device. In some examples, a silicon flat panel detector may be used as an alternative to an image intensifier. The arc-shaped arm 116 may rotate in the direction D1 about the rotational joint 112. A field of view 120 of the imaging source 118 may extend through a free space 122 between the imaging source 118 and the imaging detector 114. The free space

122 may be occupied by a table 124 on which a patient P may be disposed. A patient interface object 126, such as a mattress or pad may extend between the patient P and the table 124. A fiducial panel 130 may also be positioned within the free space 122. In some examples, the fiducial panel 130 may extend between the patient interface object 126 and the table 124. As shown in FIG. 1, the planar fiducial panel 130 may be generally parallel to a patient surface of the table 124. Additionally or alternatively, the fiducial panel 130 may be incorporated into the patient interface object 126, incorporated into the table 124, or otherwise extend within the free space 122 supported by the table or another support member.

[0031] The imaging system 100 may be used for intraoperative imaging during surgical, orthopedic, emergency care or other medical procedures. The imaging system 100 may, for example, perform fluoroscopic or digital photo spot imaging of the patient P in the field of view 120 of the imaging source 118. The movement of the extension arm 108 relative to the cart 102 and/or the movement of the arc-shaped arm 116 about the joint 112 relative to the extension arm 108 may allow movement of the paired imaging source 118 and imaging detector 114 in translational and rotational degrees of freedom so that images of the patient P may be produced from almost any angle, without moving the patient. In some examples, the table 124 and thus the patient P may also be movable in translational and rotational degrees of freedom to further expand the viewing capacity.

[0032] FIG. 2 illustrates a top view of the patient P lying on the table 124 with the patient interface object 126 under the patient P. In this example, the fiducial panel 130 extends beneath the patient, between the patient interface object 126 and the table 124.

[0033] FIG. 3A illustrates a top view of a fiducial panel 200 (e.g. the fiducial panel 130) according to some examples. The fiducial panel 200 may include handles 201 and orientation icon 203 and/or other features that may assist personnel with arranging the fiducial panel in the medical environment 101. The fiducial panel 200 has a longitudinal axis L1 that extends in a superior to inferior direction relative to a patient anatomy. The width and length of the fiducial panel 200 may be based on sweep of the imaging system 100 so that image field of view 120 includes a portion of a localization pattern of the fiducial panel 200, without the need to reposition the fiducial panel during the procedure. In some examples, the fiducial panel may have a width of approximately 50 cm and a length of approximately 50 cm.

[0034] FIG. 3B illustrates a partial cross-sectional view of the fiducial panel 200. The fiducial panel 200 may include a cover 202 spaced apart from a cover 204 by a plurality of cells 206A, 206B, 206C. Fiducial markers may occupy a plurality of the cells of a fiducial panel, forming a localization pattern. In some examples, the fiducial markers for a fiducial

panel may be binary markers having either a distinct first type or a distinct second type. For example, the fiducial markers may be three-dimensional, radiopaque, spherical metal balls with a first type of metal ball having a large diameter, distinguishable from a second type of metal ball having a smaller diameter. The metal balls may be hollow or solid. In some examples, one or more types of the fiducial markers may be formed from a dense metal such as steel or tungsten. In some examples, the fiducial marker of a first type may be a spherical metal ball and a fiducial marker of a second type may be an empty cell. In some examples, the fiducial marker of a first type may be a 3D printed metal marker of a large size and a fiducial marker of a second type may be a 3D printed metal marker of a smaller size than the fiducial marker of the first type. In the example of FIG. 3B, a first type of fiducial marker may be a three-dimensional radiopaque marker such as a spherical metal ball having a diameter D1. Fiducial markers 208, 210 may be markers of the first type. A second type of fiducial marker may be a three-dimensional radiopaque marker such as a spherical metal ball having a diameter D2 that is smaller than the diameter D1. Fiducial marker 212 may be a marker of the second type. In some examples, the diameter D1 may be approximately 5/32 inch, and the diameter D2 may be approximately 3/32 inch. In alternative examples, the sizes of the fiducial markers may be larger or smaller, but the two types of fiducial markers may remain visually or measurably distinguishable. The fiducial markers 208, 210, 212 may engage one or more fiducial support surfaces 211 of the covers 202 and/or 204. The fiducial support surfaces 211 may be indented, molded, or otherwise shaped to isolate and maintain the fiducial markers 208, 210 in the separated cells. Fiducial support surfaces 211 may support the fiducial markers 208, 210, 212 along a planar surface. In some examples, the covers 202, 204 may be formed of a radiolucent material, such as a plastic material, and the outer surfaces of the covers 202, 204 may be generally planar.

[0035] FIG. 4A illustrates a cross-sectional view of a fiducial panel 300 (e.g., the panel 130, 200). The cross-sectional view may be, for example, with a top cover (e.g. cover 202) removed. The fiducial panel 300 has a longitudinal axis L2 that extends from a superior side 302 to an inferior side 304. In this example, the fiducial panel 300 includes twenty-five fiducial arrays 306 with each fiducial array 306 including a grid of 25 cells 308 (e.g. cells 206A-C). Each of the cells 308 may include either a fiducial marker 310 of a first type (e.g., fiducial marker 208, 210) such as a larger spherical metal ball or a fiducial marker 312 of a second type (e.g. fiducial marker 212) such as a smaller spherical metal ball. Each fiducial array 306 of the fiducial panel 300 may have a unique 5 by 5 fiducial tag pattern 314 of fiducial markers. When one or more arrays are visible in images generated by an imaging system, the unique fiducial

tag patterns may be used to determine localization parameters such as a position and orientation in three-dimensional space of features identifiable in the imaging field of view. The visible portion of the array may serve as a known three-dimensional model that may allow position and orientation of the imaging system to be determined from a single frame. Without a known three-dimensional model, features, such as anatomical features, may require at least two frames with a common reference point to triangulate in three-dimensional space. A localization pattern 316 is formed by the assembly of the unique fiducial tag patterns 314 (e.g., an assembly of the twenty-five fiducial tag patterns). In this example the fiducial arrays 306 may be arranged in columns A-E from a patient-right side 320 of the fiducial panel 300 to a patient-left side 322 of the fiducial panel 300 and in lateral bands a-e from the superior side 302 to the inferior side 304. Each array 306 (i.e., arrays Aa-Ee) of the fiducial panel 300 may include a fiducial tag pattern 314 that is different from every other fiducial tag pattern (e.g., the other 24 fiducial tag patterns) in the localization pattern 316. Thus the localization pattern 316 may be non-repeating. The localization pattern 316 may also be rotation-invariant in that the localization pattern is independent of the viewing angle of the imaging system. In some examples an array of the fiducial panel may be distinguishable based on a feature or marker other than the fiducial tag pattern, and in such an example, one or more fiducial tag patterns may be repeated in a given fiducial panel.

[0036] In this example, each column 330 of fiducial markers may be linearly arranged generally parallel to the axis L2, and each row 332 of fiducial markers may be linearly arranged at an oblique or non-orthogonal angle A1 relative to the axis L2. In this example, the row 332 may be skewed approximately 5 degrees from the orthogonal direction to the axis L2 (e.g., A1 angled approximately 95 degrees from the axis L2). In other examples, a skew angle from the orthogonal direction may be, for example, in a range between zero and 15 degrees. In some examples, larger skew angles from the orthogonal may also be suitable. The non-orthogonal rows may reduce marker occlusion and imaging artifacts as the imaging system 100 moves relative to the fiducial panel 300. The columns 330 and rows 332 of fiducial markers may be evenly spaced. In some examples, the grid may have a 1.5 cm spacing between the columns and rows, although larger or smaller spacings may also be suitable. Thus, the fiducial markers 310, 312, and accordingly the fiducial tag patterns 314, may have a known location and orientation within the fiducial panel 300.

[0037] In the example of fiducial panel 300, the fiducial tag patterns 314 may include an outer frame of cells with fiducial markers 312 of the second type (e.g., small metal balls) and an inner 3x3 matrix of cells that includes a predetermined quantity of fiducial markers 310 of

the first type (e.g., larger metal balls). For example, the predetermined quantity of fiducial markers of the first type may be 3, 4, 5, 6, 7, or 8 for each fiducial tag pattern. In other examples, fewer or more first type fiducial markers may be found in each fiducial tag pattern. In some examples, each fiducial tag pattern may include at least one first type fiducial marker in a corner of the fiducial tag pattern and at least one first type fiducial marker in an outer row or column of the fiducial tag pattern. In some examples, fiducial tag patterns that are identical when rotated 90 degrees or 180 degrees may be avoided or may be invalid because they may not be useful in unambiguously determining the pattern's position relative to the imaging system. In the localization pattern 316, the predetermined quantity of fiducial markers 310 of the first type is either five or six for each fiducial tag pattern. In some examples, the first type of fiducial markers may be considered the primary pattern type, and each array of twenty-five fiducial markers may include fewer fiducials of the first or primary pattern type than of the second type so that fiducial tag patterns may be more easily distinguished among the plurality of fiducial markers. In some examples, fiducial arrays may include a cell matrix of any of a variety of sizes or shapes. For example, a fiducial array may include a fiducial tag pattern having a square pattern (e.g., 3x3, 4x4 or 5x5) or a rectangular pattern (e.g. 3x4 or 4x3), or any other predetermined pattern. In some examples, the spacing (lateral and/or longitudinal) between fiducial arrays in a fiducial panel may be varied while still providing spacing sufficient to distinguish the arrays.

[0038] When used with the imaging system 100, at least a portion of the localization pattern 316 the fiducial panel 300 may be visible in the field of view 120 of the imaging system. The three-dimensional fiducial markers may be visible and non-obstructed at most or all imaging angles of the imaging system 100. In various examples, fiducial panels may have any number of arrays in any of various arrangements that allow the three-dimensional fiducial markers to be visible and non-obstructed in all or most configurations of the imaging system 100.

[0039] FIG. 4B illustrates a cross-sectional view of a fiducial panel 400 (e.g., the panel 130, 200). The fiducial panel 400 may be substantially the same as the fiducial panel 300, with differences as described. In this example, the density of fiducial markers may be higher. For example the spacing between the rows and columns may be approximately 1.75cm. In this example, the fiducial panel 400 includes thirty-three fiducial arrays 406 with a corresponding localization pattern of thirty-three unique fiducial tag patterns 414. In this example, the fiducial panel 400 includes six columns, with successive columns alternating between five and six arrays (and corresponding unique fiducial tag patterns) in each column. This arrangement may

allow for easier localization pattern identification as the imaging field of view 120 moves horizontally (e.g., from patient right to patient left or in reverse) across the board.

[0040] In this example, the fiducial panel 400 includes thirty-three fiducial arrays 406 with each fiducial array 406 including a grid of twenty-five cells 408. Each fiducial array 406 of the fiducial panel 400 may have a unique 5 by 5 fiducial tag pattern 414 of fiducial markers. A localization pattern 416 is formed by the assembly of the unique fiducial tag patterns 414 (e.g., an assembly of the thirty-three fiducial tag patterns). In this example, the fiducial arrays 406 may be arranged in columns A-E. Columns A, C, and E may include six arrays and corresponding fiducial tag patterns, and columns B, D, and F may include five arrays and corresponding fiducial tag patterns. Each array 406 of the fiducial panel 400 may include a fiducial tag pattern 414 that is different from every other fiducial tag pattern (e.g., the other 32 fiducial tag patterns) in the localization pattern 416. Thus, the localization pattern 416 may be non-repeating. The localization pattern 416 may also be rotation-invariant in that the localization pattern is independent of the viewing angle of the imaging system.

[0041] FIG. 4C illustrates a cross-sectional view of a fiducial panel 450 (e.g., the panel 130, 200). The fiducial panel 450 may be substantially the same as the fiducial panel 300, with differences as described. In this example, the density of fiducial markers may be greater and may include seven columns of fiducial arrays (as compared to five in fiducial panel 300 and six in fiducial panel 400). In this example, the fiducial panel 450 includes forty-five fiducial arrays 456 with a corresponding localization pattern of forty-five unique fiducial tag patterns 464 (labeled A1-G6). In this example, the fiducial panel 450 includes seven columns of arrays (e.g., columns A-G), with successive columns alternating between six and seven arrays in each column. This arrangement may allow for clear localization pattern identification as the imaging field of view 120 moves horizontally (e.g., from patient right to patient left or in reverse) across the board.

[0042] In this example, each fiducial array 456 including a grid of nine cells. Each fiducial array 456 of the fiducial panel 450 may have a unique 3 by 3 fiducial tag pattern 464 of fiducial markers. In other examples, the arrays may be larger or smaller square arrays of cells or the arrays may be rectangular. The fiducial tag patterns 464 may include fiducial markers 460 of the first type (e.g. large metal balls) and fiducials 462 of the second type (e.g. small metal balls). Each fiducial tag pattern 464 may include, for example, between 3 and 8 fiducial markers 460 of the first type. In some examples, each of the fiducial tag patterns may include the same number of fiducial markers 460 of the first type. In some examples, the fiducial tag patterns may include differing quantities of fiducial markers 460 of the first type.

[0043] In this example, a column of arrays (e.g. column with fiducial tag patterns labeled A1-A6) may be separated from an adjacent column of arrays (e.g. column with fiducial tag patterns labeled A1-A6) by a predetermined spacing sufficient to distinguish the arrays in the generated images. For example, the columns of arrays be separated by two columns of cells that are empty or contain fiducial markers 462 of the second type. In other examples, the separation between the columns of arrays may have a different number of columns of cells or may include no fiducial markers at all. In this example, each array in a column is separated from an adjacent array in the same column by a predetermined spacing sufficient to distinguish the arrays. For example, the arrays may be separated by two rows of cells that are empty or contain fiducial markers 462 of the second type. In other examples, the separation between the arrays in a column may have a different number of rows of cells or may include no fiducial markers at all.

[0044] A localization pattern 466 is formed by the assembly of the unique fiducial tag patterns 464 (e.g., an assembly of the forty-five fiducial tag patterns). Each array 456 of the fiducial panel 450 may include a fiducial tag pattern 464 that is different from every other fiducial tag pattern (e.g., the other 44 fiducial tag patterns) in the localization pattern 466. Thus, the localization pattern 466 may be non-repeating. As previously described, the rows of cells in the fiducial panel 450 may be skewed at an angle between approximately 0 and 15 degrees. The localization pattern 466 may also be rotation-invariant in that the localization pattern is independent of the viewing angle of the imaging system. FIG. 4D illustrates a square fiducial array 470 (e.g. array 456) including the same numbers of rows and columns of fiducial markers. In this example, the array 470 includes three columns of fiducial markers and three rows of fiducial markers. The array 470 includes five fiducial markers 472 of a first type. In other examples, between three and eight fiducial markers of the first type may be used in a 3x3 array.

[0045] FIG. 4E illustrates a rectangular fiducial array 480 including an unequal number of rows and columns of fiducial markers. In this example, the array 480 includes three columns of fiducial markers and four rows of fiducial markers. The array 480 includes seven fiducial markers 482 of a first type, but more or fewer fiducial markers of the first type may be used.

[0046] FIG. 5 illustrates an image 500 generated by an imaging system (e.g., the imaging system 100) with a portion of the fiducial panel 300 within the field of view of the imaging system. FIG. 6 illustrates a reference localization pattern 550 which may be referenced to determine localization parameters for the imaging system from the generated image 500 from the portion of the fiducial panel 300 visible in the image 500. The reference localization pattern 550 corresponds to the localization pattern 316 and includes twenty-five arrays 556 that

correspond to the twenty-five fiducial arrays 306 of the fiducial panel 300. Each of the arrays 556 includes a grid of cells with light cells corresponding to the fiducial markers 310 of the fiducial panel 300 and the dark cells corresponding to the fiducial markers 312 of the fiducial panel 300. The reference localization pattern 550 may be analyzed, including being rotated or flipped, to identify the portion of the reference localization pattern 550 that corresponds to the portion of the fiducial panel 300 in the image 500. In this example, the reference localization pattern 550 may be flipped vertically to match portions to the image 500. In the image 500, the larger fiducial markers 310 of the first type may be distinguishable from the smaller fiducial markers 312 of the second type. In this example, the unique fiducial tag pattern of array Bd from the reference localization pattern 550 is located in the portion 560 of the image 500. The unique fiducial tag pattern of array Bc from the reference localization pattern 550 is located in the portion 562 of the image 500. The unique fiducial tag pattern of array Cd from the reference localization pattern 550 is located in the portion 564 of the image 500. Localization parameters for the imaging system 100, and more specifically the rotated imaging source 118, when the image 500 was captured may be determined from the position and orientation of the recognized fiducial tag patterns visible in the captured image. Localization parameters may include position and orientation parameters for the imaging source 118. The reference localization pattern 550 may be stored in a computer memory (e.g. memory 1016) or otherwise referenced when determining localization parameters associated with an image from the imaging system 100.

[0047] FIG. 7 is a flowchart illustrating a method 600 for determining localization parameters for a moving imaging system. In some examples the method may be performed, for example, at a control system (e.g., control system 1012) of a robot-assisted medical system. At a process 602, an image may be received with at least a portion of a fiducial panel in the field of view. For example, an image 500 of the patient P with a portion of the fiducial panel 300 in the field of view 120 may be captured. In some examples, the fiducial panel 300 may be located under a patient P positioned in the free space 122 of a C-arm imaging system 100. In other examples, a fiducial panel may be located adjacent to a side of the patient or over the patient, as described in alternative examples below. At a process 604, fiducial markers may be detected in the image. For example, image processing techniques may be used to analyze the image 500 to detect the presence and size of fiducial markers 310, 312. In other examples, image processing techniques may be used to determine a shape or the presence/absence of fiducial markers in the cells.

[0048] At a process 606, at least a portion of a localization pattern may be identified in the image of the portion of the fiducial panel. For example, at least a portion of localization pattern 316 may be identified in the image 500 of the portion of the fiducial panel 300. FIG. 8 is a flowchart illustrating an example of a process 606 for identifying at least a portion of the localization pattern in the image. At a process 610, a fiducial type is determined for each fiducial marker visible in the image. For example the fiducial markers visible in the image may be recognized as having one of at least two types (e.g., large/small; present/empty). One of the fiducial marker types may be considered a primary pattern type (e.g. the larger fiducial marker or the present fiducial marker). For the example of image 500, the fiducial markers that have the known characteristics of the three-dimensional spherical metal balls with the larger size may be identified as fiducial markers 310 of the first type that form a primary pattern. The fiducial markers that have the known characteristics of the three-dimensional spherical balls with the smaller size may be identified as fiducial markers 312 of the second type.

[0049] At a process 612, fiducial markers of a first type may be associated into groups. The groups may each have a predetermined number of a primary pattern type (e.g. first type) fiducial markers. The predetermined number of fiducial markers may be based on the number of the first type fiducial markers in the fiducial tag patterns for the known localization pattern. In some examples the groups may have 4, 5, 6, or 7 fiducial markers of the first type. For example, for the known localization pattern 316, each fiducial tag pattern has either five or six fiducial markers of the first type, so the identified fiducial markers may be associated or subdivided into groups that include a predetermined number of first type fiducial markers. In some examples, the groups may include four, five, six, seven, or eight first type fiducial markers. For the example of image 500, groupings of 5 fiducial markers of the first type (as in portion 560) and/or groupings of 6 fiducial markers (as in portions 562 and 564) may be identified.

[0050] At a process 614, a two-dimensional fiducial array may be identified for each discrete grouping of first type fiducial markers. Each two-dimensional fiducial array may include a grouping of the primary pattern type (e.g., first type) fiducial markers. For example, each array 306 of the fiducial panel 300 is known to include a 5 by 5 array of fiducial markers with each array including a frame of second type (e.g. non-primary pattern) fiducial markers 312 enclosing a 3 by 3 array that includes the grouping of primary pattern (e.g. first type) fiducial markers 312. For the example of image 500, the two-dimensional arrays of portions 560, 562, 564 may be identified, with each portion including one of the groupings of five or six fiducial markers of the first type surrounded by a frame of second type fiducial markers.

[0051] At a process 616, the two-dimensional fiducial arrays including first type fiducial markers may be compared to the predetermined localization pattern. For example, at least one of the fiducial arrays may be compared to a reference localization pattern. The reference localization pattern or the image may be rotated or flipped to compare and match the at least a portion of the reference localization pattern with the two-dimensional fiducial arrays of the image. For example, the reference localization pattern 550 may be analyzed, including being rotated or flipped, to identify the portion of the localization pattern 550 that corresponds to the portion of the fiducial panel 300 in the image 500. In this example, the reference localization pattern 550 may be flipped vertically to match portions to the image 500. In the image 500, the larger fiducial markers 310 of the first type may be distinguishable from the smaller fiducial markers 312 of the second type. In this example, the unique fiducial tag pattern of array Bd from the reference localization pattern 550 is matched to the portion 560 of the image 500. The unique fiducial tag pattern of array Bc from the reference localization pattern 550 is matched to the portion 562 of the image 500. The unique fiducial tag pattern of array Cd from the reference localization pattern 550 is matched to the portion 564 of the image 500. In some examples, the comparison between the reference localization pattern 550 and the image 500 may be performed using a perspective-n-point computation (e.g., solvePnP).

[0052] Referring again to FIG. 7, at a process 608, localization parameters may be determined for the imaging system from the identified portion of the localization pattern. For example, localization parameters including the 3D position, orientation, and/or pose for the imaging source 118 and/or the imaging detector 114 may be determined from the patterns of three-dimensional fiducial markers 310, 312 in the portions 560, 562, 564 of the image 500 that correspond to arrays Bd, Bc, and Cd, respectively of the localization pattern 316.

[0053] In some examples, based on the determined localization parameters for a plurality of successive images, the motion of imaging system 100 may be tracked. In some examples, an intraoperative three-dimensional volumetric model may be generated based on the successive images and the determined localization parameters for each successive image. Various tomosynthesis techniques may be used for volumetric reconstruction. In some examples, filtered back projection may be used to perform tomosynthesis from the images and the respective localization parameters. In some examples, preoperative three-dimensional volumes may be registered to the generated intraoperative three-dimensional volumetric model. The registration may allow planning and navigation to be adjusted based on the intraoperative model.

[0054] In various examples, the fiducial markers of a fiducial panel may be supported along a common plane, such as a planar surface extending along a surface of the fiducial markers or a planar surface extending through centers of the fiducial markers. FIG. 9A illustrates a cross-sectional portion of a fiducial panel 700 including a fiducial marker 702 of a first type and a fiducial marker 704 of a second type. The fiducial marker 702 has a larger diameter than the fiducial marker 704. The fiducial markers 702, 704 may engage coplanar fiducial support surfaces 706 such that the bases of the fiducial markers are aligned along a plane 708. FIG. 9B illustrates a cross-sectional portion of a fiducial panel 710 including the fiducial markers 702, 704. In this example, the fiducial markers 702, 704 may engage non-coplanar fiducial support surfaces 712 such that the centers of the fiducial markers are aligned along a plane 714 through approximately the centers of the fiducial markers 702, 704.

[0055] To determine the localization parameters for an imaging system using the methods described, at least a portion of the fiducial markers and fiducial tag patterns should be visible in the generated images. Thus, motion of the C-arm mechanism 110 may be constrained by both the physical range of motion of the C-arm mechanism and by the number of fiducial markers that may be viewed from poses at oblique angles. In some examples, using a single planar fiducial panel, the rotational range of motion of the C-arm mechanism 110 may be constrained to approximately 60-80 degrees of rotation. In alternative examples, to permit a greater range of motion for the C-arm mechanism 110, additional planar fiducial panels or curved fiducial panels may be used.

[0056] FIG. 10 illustrates a fiducial panel assembly 800 that includes an auxiliary fiducial panel 802 that may be detachably coupled to a main fiducial panel 804. The main fiducial panel 804 may be, for example the fiducial panel 300 or 400. The auxiliary fiducial panel 802 may extend fiducial markers into the C-arm mechanism 110 field of view 120 at imaging angles, such as lateral angles, where the main fiducial panel is outside or substantially outside the field of view 120, as shown in FIGS. 11 and 12. The auxiliary panel 802 may connect to the main fiducial panel 804 with one or more kinematic mounting devices 806 that prevent displacement of the auxiliary panel relative to the main panel. The kinematic mounting devices 806 may also maintain known and fixed positions and orientations between fiducial markers on both panels. In various examples, the kinematic mounting devices 806 may include bolts, screws, anchors, clamps, magnets, and/or other coupling devices. The mounting devices 806 may be formed entirely or substantially of a radiolucent material or may be located outside of the field of view 120 to prevent obscuring of the patient anatomy or the fiducial markers. The auxiliary fiducial panel 802 may be formed of similar radiolucent substrate material as panel 300. In the example

of FIGS. 10-12, the auxiliary panel 802 may be attached to the main fiducial panel 804 at approximately 90 degrees, although other attachment angles may be suitable. The auxiliary panel 802 may extend parallel to an axis L3 of the main fiducial panel 804 and may flank the right or left side of the patient. As shown in FIGS. 11 and 12, as the C-arm mechanism 110 rotates about the patient P, the auxiliary fiducial panel 802 may be in the field of view 120 at imaging angles where little or none of the fiducial panel 804 may be visible. Thus, the auxiliary fiducial panel 802 may be used to determine localization parameters for the imaging system 100 at an extended range of imaging angles.

[0057] In this example, the auxiliary fiducial panel 802 may include a grid of cells 808 that may be arranged in fiducial arrays 810. Each of the cells may include either a fiducial marker 812 of a first type such as a larger spherical metal ball or a fiducial marker 814 of a second type such as a smaller spherical metal ball. Each fiducial array 810 of the auxiliary fiducial panel 802 may have a unique fiducial tag pattern of the fiducial markers. The fiducial tag patterns of the auxiliary fiducial panel 802 may be unique to each other and to the fiducial tag patterns of the main fiducial panel 804. Alternatively or additionally, the auxiliary fiducial panel 802 may include an indicator to distinguish between fiducial markers of the main fiducial panel 804 and fiducial markers of the auxiliary fiducial panel 802. In some examples, the indicator may be, for example, a cell grid spacing of the auxiliary fiducial panel that is different from (e.g. larger, smaller, or different angle) from the cell grid spacing of the main fiducial panel. In some examples, the indicator may be, for example, the quantity of fiducial markers of the first type (e.g. the pattern type) used in the fiducial tag patterns. For example the auxiliary fiducial panel 802 may include seven fiducial markers of the first type per array whereas the main fiducial panel 804 may include five fiducial markers of the first type per array. The fiducial markers 812, 814 may be arranged to reduce the risk of occluding other fiducial markers in the auxiliary or main fiducial panel. For example, the fiducial markers may have a helical arrangement to reduce the risk of occlusion in lateral imaging. In some examples, the selection of the auxiliary fiducial panel may be based on the location of the auxiliary fiducial panel to the imaging source. For example, if the auxiliary fiducial panel will be located farther from imaging source than main fiducial panel, an auxiliary fiducial panel with a grid spacing larger than main fiducial panel may be selected to attach to the main fiducial panel. However, if the auxiliary fiducial panel will be located closer to imaging source than main fiducial panel, an auxiliary fiducial panel with a grid spacing smaller than main fiducial panel may be selected. In some examples, a plurality of auxiliary panels may be attached to the main fiducial panel.

[0058] FIG. 13A and 13B illustrate perspective views of a curved or arc-shaped fiducial panel 900 that may be used as an alternative to an under-patient fiducial panel. The curved fiducial panel 900 may be fixed to the patient table 124 so that curved fiducial panel extends over the patient P and remains stationary during an imaging procedure using the imaging system 100. The curved fiducial panel 900 may be formed of similar radiolucent substrate material as panel 300. The curved fiducial panel 900 may introduce fiducial markers into the field of view 120 at all or nearly all imaging angles in the orbital range of the C-arm mechanism 110, as shown in FIGS. 14 and 15 which depict opposite ends of the imaging detector range of motion. Obtaining a greater range of images and determining the imaging system localization parameters for those images may result in improved three-dimensional model reconstructions.

[0059] Similar to the previously described fiducial panels, the panel 900 may include a grid of cells 902 on a curved substrate 904. The cells 902 that may be arranged in fiducial arrays. Each of the cells may include either a fiducial marker 908 of a first type such as a larger spherical metal ball or a fiducial marker 910 of a second type such as a smaller spherical metal ball. Each fiducial array of the curved fiducial panel 900 may have a unique fiducial tag pattern of the fiducial markers. In this example, the fiducial markers may be omitted from a portion 906 of the curved substrate 904 so that at lateral imaging configurations (e.g. the imaging configuration of FIG. 14) in which the field of view 120 includes two spaced apart portions of the panel 900, only a single layer of fiducial markers 908, 910 is imaged. The fiducial panel 900 may have a known configuration of fiducial markers that may be visible in the full range of the imaging system's field of view and may also correct for distortion associated with flat panel imaging. In various examples the panel 900 may be provided in various sizes, including widths large enough to extend over large patients and removable without disturbing the patient. A curved fiducial panel may place the fiducial markers closer to the imaging detector along the full range of motion of the imaging detector and may minimize distortion because the arc of the panel may be similar to the arc of the imaging system.

[0060] In some examples, a planar fiducial panel may be arranged at a non-parallel angle to a surface of the patient table to allow the C-arm mechanism 110 to rotate further while maintaining the fiducial markers within the field of view 120. Being able to generate localization parameters and images for a greater range of rotation may result in more tracked images that may be used to generate more accurate three-dimensional model reconstructions. FIG. 16 illustrates the imaging system 100 used with a planar fiducial panel 950 (e.g., the fiducial panel 130, 200, 300) that may be angled approximately 5-10 degrees relative to a patient surface of the table 124. Larger or smaller angles may also be suitable. In this example,

the fiducial panel 950 may be canted toward the C-arm mechanism 110. The canted fiducial panel 950 may allow the C-arm to rotate further (e.g., counter-clockwise) before the fiducial markers become indiscernible. Further rotation may permit more localized images that may generate more accurate reconstructions. In some examples, as shown in FIGS. 16 and 17, the planar fiducial panel 950 may be within a patient interface object 952 such as a mattress or pad. As shown in FIG. 17, in some examples a patient interface object 954 may have one or more angled patient interface surfaces 956 to accommodate an increased angle of the fiducial panel 950 without raising the height of the patient P.

[0061] In some examples, the imaging systems and methods described herein may be used during medical procedures involving hand-held or otherwise manually controlled medical instruments. In other examples, the imaging systems and methods described herein may be used during medical procedures using instruments and/or tools manipulated with a robot-assisted medical system as shown in FIG. 18. As shown in FIG. 18, a robot-assisted medical system 1000 may include a manipulator assembly 1002 for operating a medical instrument system 1004 in performing various procedures on a patient P positioned on a table T (e.g., table 124) in a surgical environment 1001. The manipulator assembly 1002 may be teleoperated, non-teleoperated, or a hybrid teleoperated and non-teleoperated assembly with select degrees of freedom of motion that may be motorized and/or teleoperated and select degrees of freedom of motion that may be non-motorized and/or non-teleoperated. A master assembly 1006, which may be inside or outside of the surgical environment 1001, generally includes one or more control devices for controlling manipulator assembly 1002. The control devices may include any number of a variety of input devices, such as joysticks, trackballs, data gloves, trigger-guns, hand-operated controllers, voice recognition devices, body motion or presence sensors, and/or the like. To provide the operator O a strong sense of directly controlling instruments 1004 the control devices may be provided with the same degrees of freedom as the associated medical instrument 1004. In this manner, the control devices provide the operator O with telepresence or the perception that the control devices are integral with medical instruments 1004.

[0062] Manipulator assembly 1002 supports medical instrument 1004 may optionally include a kinematic structure of one or more non-servo controlled links and/or one or more servo controlled links. The manipulator assembly 1002 may optionally include a plurality of actuators or motors that drive inputs on medical instrument 1004 in response to commands from a control system 1012. The actuators may optionally include transmission or drive systems that when coupled to medical instrument 1004 may advance medical instrument 1004

into a naturally or surgically created anatomic orifice. Other transmission or drive systems may move the distal end of medical instrument in multiple degrees of freedom, which may include three degrees of linear motion (e.g., linear motion along the X, Y, Z Cartesian axes) and in three degrees of rotational motion (e.g., rotation about the X, Y, Z Cartesian axes). The manipulator assembly 1002 may support various other systems for irrigation, treatment, or other purposes. Such systems may include fluid systems (including, for example, reservoirs, heating/cooling elements, pumps, and valves), generators, lasers, interrogators, and ablation components.

[0063] Robotically-assisted medical system 1000 also includes a display system 1010 for displaying an image or representation of the surgical site and medical instrument 1004 generated by an imaging system 1009 which may include an endoscopic imaging system and/or an external intra-operative imaging system (e.g., imaging system 100). Display system 1010 and master assembly 1006 may be oriented so an operator O can control medical instrument 1004 and master assembly 1006 with the perception of telepresence.

[0064] In some examples, the endoscopic imaging system components of the imaging system 1009 may be integrally or removably coupled to medical instrument system 1004. However, in some examples, a separate endoscope, attached to a separate manipulator assembly may be used with medical instrument system 1004 to image the surgical site. The imaging system 1009 may be implemented as hardware, firmware, software, or a combination thereof which interact with or are otherwise executed by one or more computer processors, which may include the processors of the control system 1012.

[0065] A sensor system 1008 may include a position/location sensor system (e.g., an actuator encoder or an electromagnetic (EM) sensor system) and/or a shape sensor system (e.g., an optical fiber shape sensor) for determining the position, orientation, speed, velocity, pose, and/or shape of the medical instrument 1004. The sensor system 1008 may also include temperature, pressure, force, or contact sensors or the like.

[0066] Robot-assisted medical system 1000 may also include control system 1012. Control system 1012 includes at least one memory 1016 and at least one computer processor 1014 for effecting control between medical instrument 1004, master assembly 1006, sensor system 1008, and display system 1010. Control system 1012 also includes programmed instructions (e.g., a non-transitory machine-readable medium storing the instructions) to implement

instrument actuation using the robot-assisted medical system including for navigation and steering.

[0067] Control system 1012 may optionally further include a virtual visualization system to provide navigation assistance to operator O when controlling medical instrument 1004 during an image-guided surgical procedure. Virtual navigation using the virtual visualization system may be based upon reference to an acquired pre-operative or intra-operative dataset of anatomic passageways. The virtual visualization system processes images of the surgical site imaged using imaging technology such as computerized tomography (CT), magnetic resonance imaging (MRI), fluoroscopy, thermography, ultrasound, optical coherence tomography (OCT), thermal imaging, impedance imaging, laser imaging, nanotube X-ray imaging, and/or the like. The control system 1012 may use pre-operative or intra-operative images or models to locate the target tissue (using vision imaging techniques and/or by receiving user input) and create an operative plan.

[0068] In the description, specific details have been set forth describing some examples. Numerous specific details are set forth in order to provide a thorough understanding of the examples. It will be apparent, however, to one skilled in the art that some examples may be practiced without some or all of these specific details. The specific examples disclosed herein are meant to be illustrative but not limiting. One skilled in the art may realize other elements that, although not specifically described here, are within the scope and the spirit of this disclosure.

[0069] Elements described in detail with reference to one example, implementation, or application optionally may be included, whenever practical, in other examples, implementations, or applications in which they are not specifically shown or described. For example, if an element is described in detail with reference to one example and is not described with reference to a second example, the element may nevertheless be claimed as included in the second example. Thus, to avoid unnecessary repetition in the following description, one or more elements shown and described in association with one example, implementation, or application may be incorporated into other examples, implementations, or aspects unless specifically described otherwise, unless the one or more elements would make an example or implementation non-functional, or unless two or more of the elements provide conflicting functions.

[0070] Any alterations and further modifications to the described devices, instruments, methods, and any further application of the principles of the present disclosure are fully contemplated as would normally occur to one skilled in the art to which the disclosure relates. In particular, it is fully contemplated that the features, components, and/or steps described with respect to one example may be combined with the features, components, and/or steps described with respect to other examples of the present disclosure. In addition, dimensions provided herein are for specific examples and it is contemplated that different sizes, dimensions, and/or ratios may be utilized to implement the concepts of the present disclosure. To avoid needless descriptive repetition, one or more components or actions described in accordance with one illustrative example can be used or omitted as applicable from other illustrative examples. For the sake of brevity, the numerous iterations of these combinations will not be described separately. For simplicity, in some instances the same reference numbers are used throughout the drawings to refer to the same or like parts.

[0071] The systems and methods described herein may be suited for imaging and treatment, via natural or surgically created connected passageways, in any of a variety of anatomic systems, including the lung, colon, the intestines, the stomach, the liver, the kidneys and kidney calices, the brain, the heart, the circulatory system including vasculature, and/or the like. While some examples are provided herein with respect to medical procedures, any reference to medical or surgical instruments and medical or surgical methods is non-limiting. For example, the instruments, systems, and methods described herein may be used for non-medical purposes including industrial uses, general robotic uses, and sensing or manipulating non-tissue work pieces. Other example applications involve cosmetic improvements, imaging of human or animal anatomy, gathering data from human or animal anatomy, and training medical or non-medical personnel. Additional example applications include use for procedures on tissue removed from human or animal anatomies (without return to a human or animal anatomy) and performing procedures on human or animal cadavers. Further, these techniques can also be used for surgical and nonsurgical medical treatment or diagnosis procedures.

[0072] The methods described herein are illustrated as a set of operations or processes. Not all the illustrated processes may be performed in all examples of the methods. Additionally, one or more processes that are not expressly illustrated or described may be included before, after, in between, or as part of the example processes. In some examples, one or more of the processes may be performed by the control system (e.g., control system 1012) or may be implemented, at least in part, in the form of executable code stored on non-transitory, tangible, machine-readable media that when run by one or more processors (e.g., the processors 1014 of

control system 1012) may cause the one or more processors to perform one or more of the processes.

[0073] One or more elements in examples of this disclosure may be implemented in software to execute on a processor of a computer system such as control processing system. When implemented in software, the elements of the examples may be the code segments to perform the necessary tasks. The program or code segments can be stored in a processor readable storage medium or device that may have been downloaded by way of a computer data signal embodied in a carrier wave over a transmission medium or a communication link. The processor readable storage device may include any medium that can store information including an optical medium, semiconductor medium, and magnetic medium. Processor readable storage device examples include an electronic circuit; a semiconductor device, a semiconductor memory device, a read only memory (ROM), a flash memory, an erasable programmable read only memory (EPROM); a floppy diskette, a CD-ROM, an optical disk, a hard disk, or other storage device. The code segments may be downloaded via computer networks such as the Internet, Intranet, etc. Any of a wide variety of centralized or distributed data processing architectures may be employed. Programmed instructions may be implemented as a number of separate programs or subroutines, or they may be integrated into a number of other aspects of the systems described herein. In one example, the control system supports wireless communication protocols such as Bluetooth, IrDA, HomeRF, IEEE 802.11, DECT, and Wireless Telemetry.

[0074] Note that the processes and displays presented may not inherently be related to any particular computer or other apparatus. Various general-purpose systems may be used with programs in accordance with the teachings herein, or it may prove convenient to construct a more specialized apparatus to perform the operations described. The required structure for a variety of these systems will appear as elements in the claims. In addition, the examples described herein are not described with reference to any particular programming language. It will be appreciated that a variety of programming languages may be used to implement the teachings described herein.

[0075] In some instances well known methods, procedures, components, and circuits have not been described in detail so as not to unnecessarily obscure aspects of the examples. This disclosure describes various instruments, portions of instruments, and anatomic structures in terms of their state in three-dimensional space. As used herein, the term “position” refers to the location of an object or a portion of an object in a three-dimensional space (e.g., three degrees of translational freedom along Cartesian x-, y-, and z-coordinates). As used herein,

the term “orientation” refers to the rotational placement of an object or a portion of an object (three degrees of rotational freedom – e.g., roll, pitch, and yaw). As used herein, the term “pose” refers to the position of an object or a portion of an object in at least one degree of translational freedom and to the orientation of that object or portion of the object in at least one degree of rotational freedom (up to six total degrees of freedom). As used herein, the term “shape” refers to a set of poses, positions, or orientations measured along an object.

[0076] While certain illustrative examples have been described and shown in the accompanying drawings, it is to be understood that such examples are merely illustrative of and not restrictive on the broad invention, and that the examples of the invention are not limited to the specific constructions and arrangements shown and described, since various other modifications may occur to those ordinarily skilled in the art.

CLAIMS

What is claimed is:

1. A system comprising:
a fiducial panel including a plurality of arrays of three dimensional, radiopaque fiducial markers,
wherein each array of the plurality of arrays includes a plurality of a first type of the fiducial markers and a plurality of a second type of the fiducial markers,
wherein the plurality of first type fiducial markers and the plurality of second type fiducial markers form a fiducial tag pattern and
wherein the fiducial tag pattern for at least one of the plurality of arrays is visible in a plurality of images generated by a rotating imaging system.
2. The system of claim 1, wherein the plurality of arrays includes a first array and a second array, the first array including a first fiducial tag pattern and the second array including a second fiducial tag pattern, wherein the first and second fiducial tag patterns are different.
3. The system of claim 1, wherein the first type fiducial markers are larger than the second type fiducial markers.
4. The system of claim 1, wherein the second type fiducial markers include a cell empty of a first type fiducial marker.
5. The system of claim 1, wherein the fiducial tag pattern includes a square pattern of first and second type fiducial markers.
6. The system of claim 5, wherein the fiducial tag pattern includes a 3x3 pattern of first and second type fiducial markers.
7. The system of claim 5, wherein the fiducial tag pattern includes a 5x5 pattern of first and second type fiducial markers.
8. The system of claim 1, wherein the fiducial tag pattern includes a rectangular pattern of first and second type fiducial markers.

9. The system of claim 1, wherein each fiducial tag pattern includes between three and eight first type fiducial markers.
10. The system of claim 1, wherein the plurality of arrays includes a 5x5 matrix of arrays.
11. The system of claim 1, wherein each array includes a plurality of rows of the fiducial markers and wherein the plurality of rows are at an oblique angle relative to a longitudinal axis of the fiducial panel.
12. The system of claim 11, wherein the oblique angle is approximately 5 degrees relative to the longitudinal axis of the fiducial panel.
13. The system of claims 1 or 2-12, wherein the first and second type fiducial markers are spherical.
14. The system of claims 1 or 2-12, wherein the first and second type fiducial markers include a metal.
15. The system of claims 1 or 2-12, wherein the fiducial panel comprises a planar fiducial panel.
16. The system of claim 15, wherein the planar fiducial panel is configured to extend beneath a patient interface surface.
17. The system of claim 16, wherein the planar fiducial panel extends parallel to the patient interface surface.
18. The system of claim 16, wherein the planar fiducial panel is non-parallel to the patient interface surface.
19. The system of claims 1 or 2-12, wherein the first and second type fiducial markers are aligned along a plane extending through centers of the fiducial markers.

20. The system of claims 1 or 2-12, wherein the first and second type fiducial markers are supported along a planar surface.
21. The system of claim claims 1 or 2-12, wherein the fiducial panel includes a first panel portion and a second panel portion, wherein the second panel portion is removably attachable to the first panel portion.
22. The system of claim 21, wherein the second panel portion includes a second panel identifying feature.
23. The system of claim claims 1 or 2-12, wherein the fiducial panel comprises a curved fiducial panel.
24. The system of claim 23, wherein the curved fiducial panel is configured to extend over a patient table.
25. The system of claim 23, wherein the plurality of arrays extends along the curved fiducial panel across a portion of the curved fiducial panel proximate to a rotating detector of the rotating imaging system.
26. The system of claims 1 or 2-12, further comprising the rotating imaging system.
27. A method comprising:
receiving, from a rotating imaging system, image data of a field of view;
detecting a plurality of fiducial markers in the image data;
identifying a localization pattern formed by the plurality of fiducial markers, the localization pattern including a plurality of arrays comprised of the plurality of fiducial markers, wherein each array of the plurality of arrays includes a plurality of a first type of the fiducial markers and a plurality of a second type of the fiducial markers and wherein the first and second types of fiducial markers in each array of the plurality of arrays form a fiducial tag pattern; and
determining, from the localization pattern, a set of localization parameters for the rotating imaging system.

28. The method of claim 27, wherein identifying a localization pattern further includes assigning a type indicator to each of the detected fiducial markers.
29. The method of claim 27, wherein identifying a localization pattern further includes associating the first type fiducial markers into groups of a predetermined size.
30. The method of claim 27, wherein identifying a localization pattern includes comparing the plurality of arrays to a reference localization pattern.
31. The method of claim 27, wherein the fiducial tag pattern includes a square pattern of first and second type fiducial markers.
32. The method of claim 31, wherein the fiducial tag pattern includes a 3x3 pattern of the first and second type fiducial markers.
33. The method of claim 31, wherein the fiducial tag pattern includes a 5x5 pattern of the first and second type fiducial markers.
34. The method of claim 27, wherein the fiducial tag pattern includes a rectangular pattern of first and second type fiducial markers.
35. The method of claim 27 or 28-34, further comprising tracking motion of the rotating imaging system based on a plurality of received image data sets.
36. The method of claim 35, further comprising generating an intraoperative volumetric image from the plurality of received image data sets.
37. The method of claim 36, further comprising updating a preoperative anatomic model based on the intraoperative volumetric image.

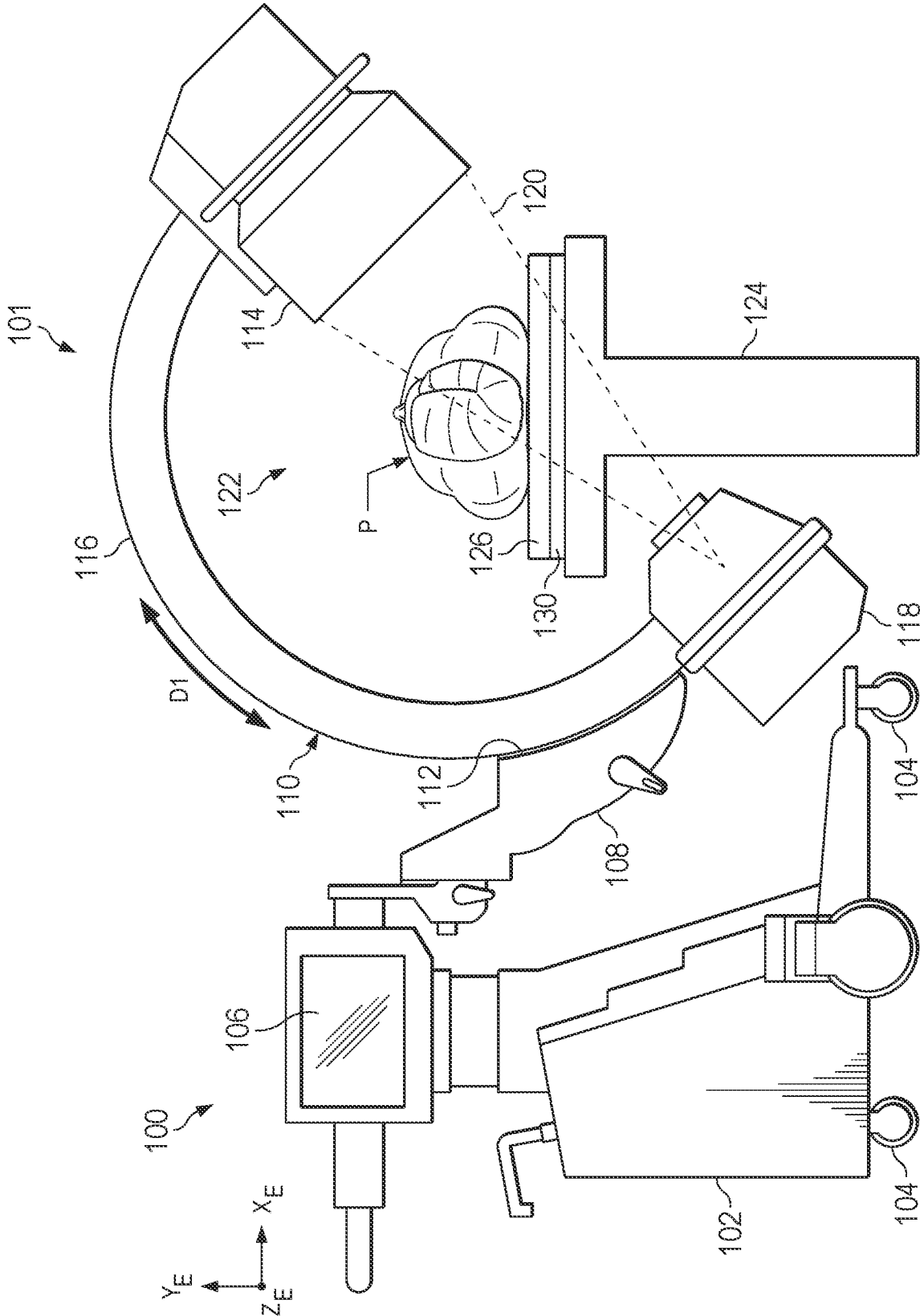


FIG. 1

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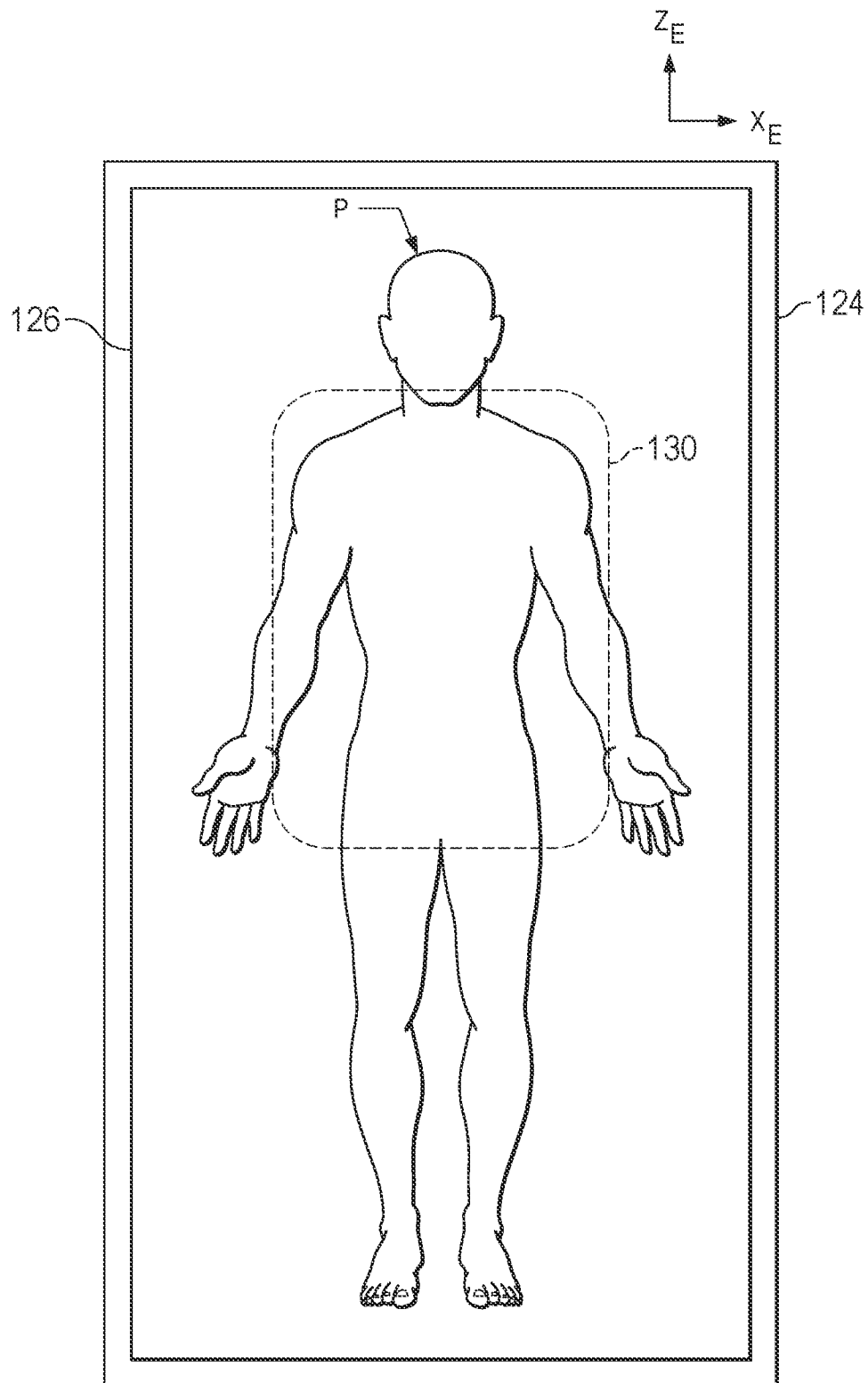


FIG. 2

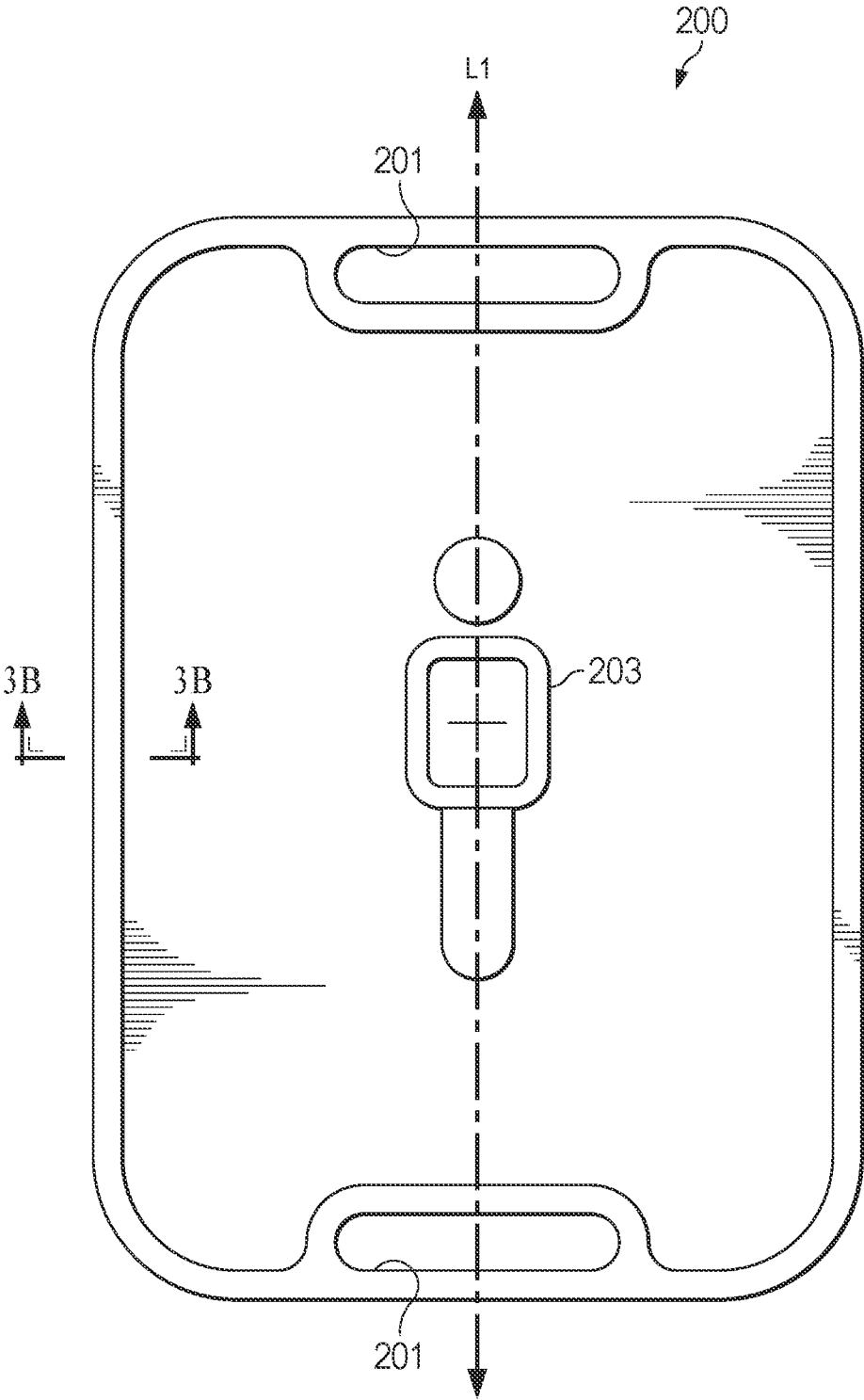


FIG. 3A

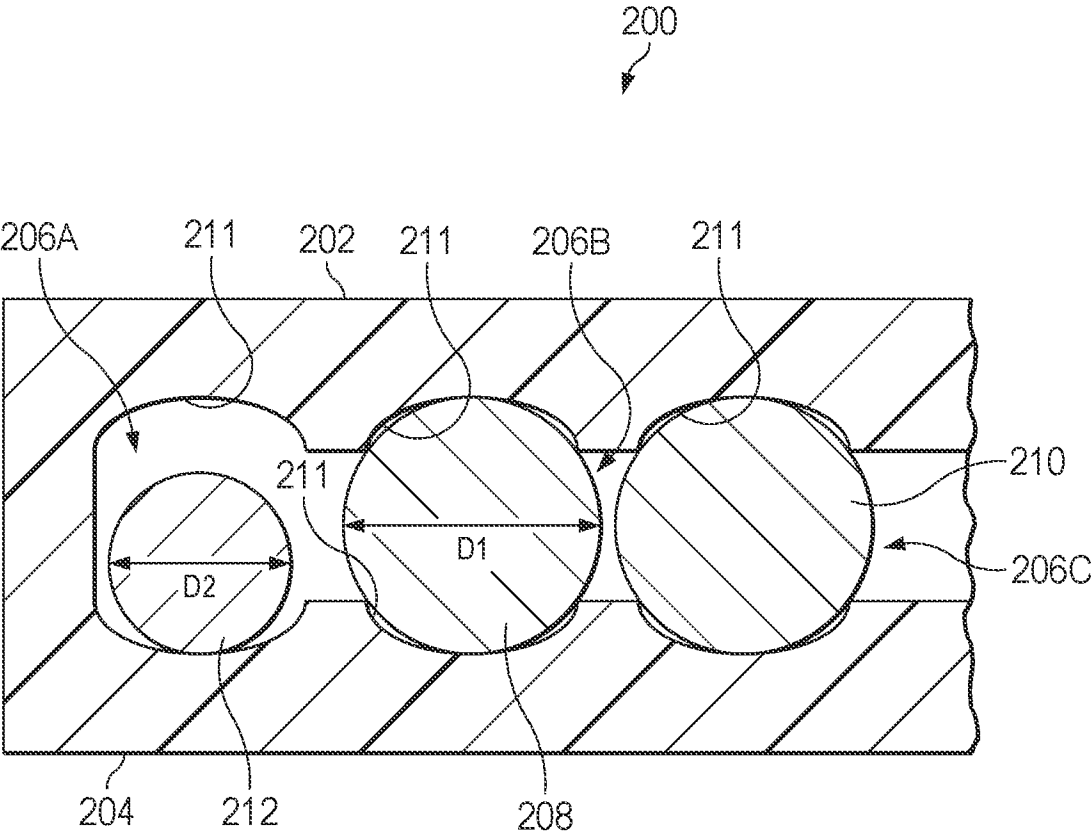


FIG. 3B

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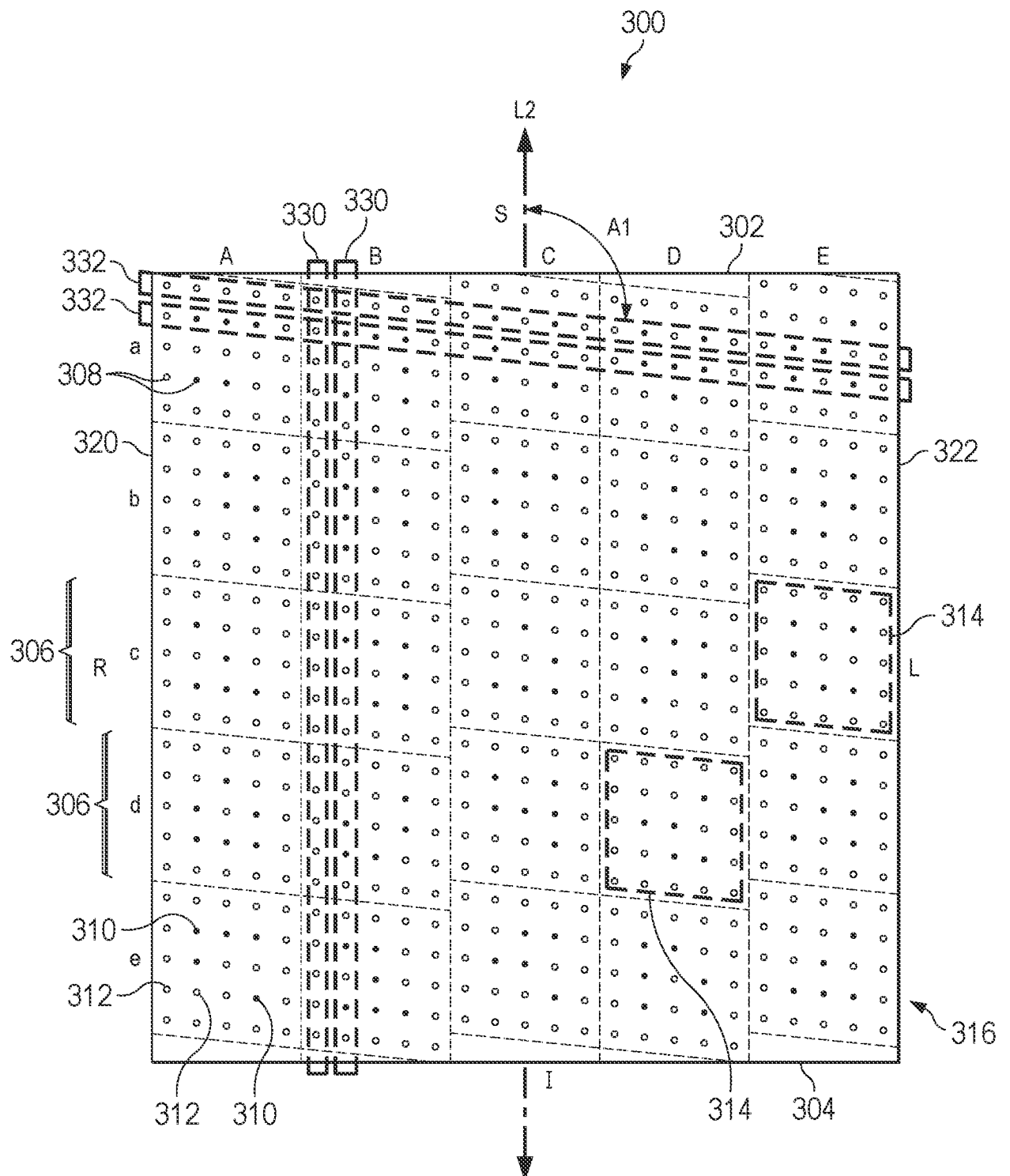


FIG. 4A

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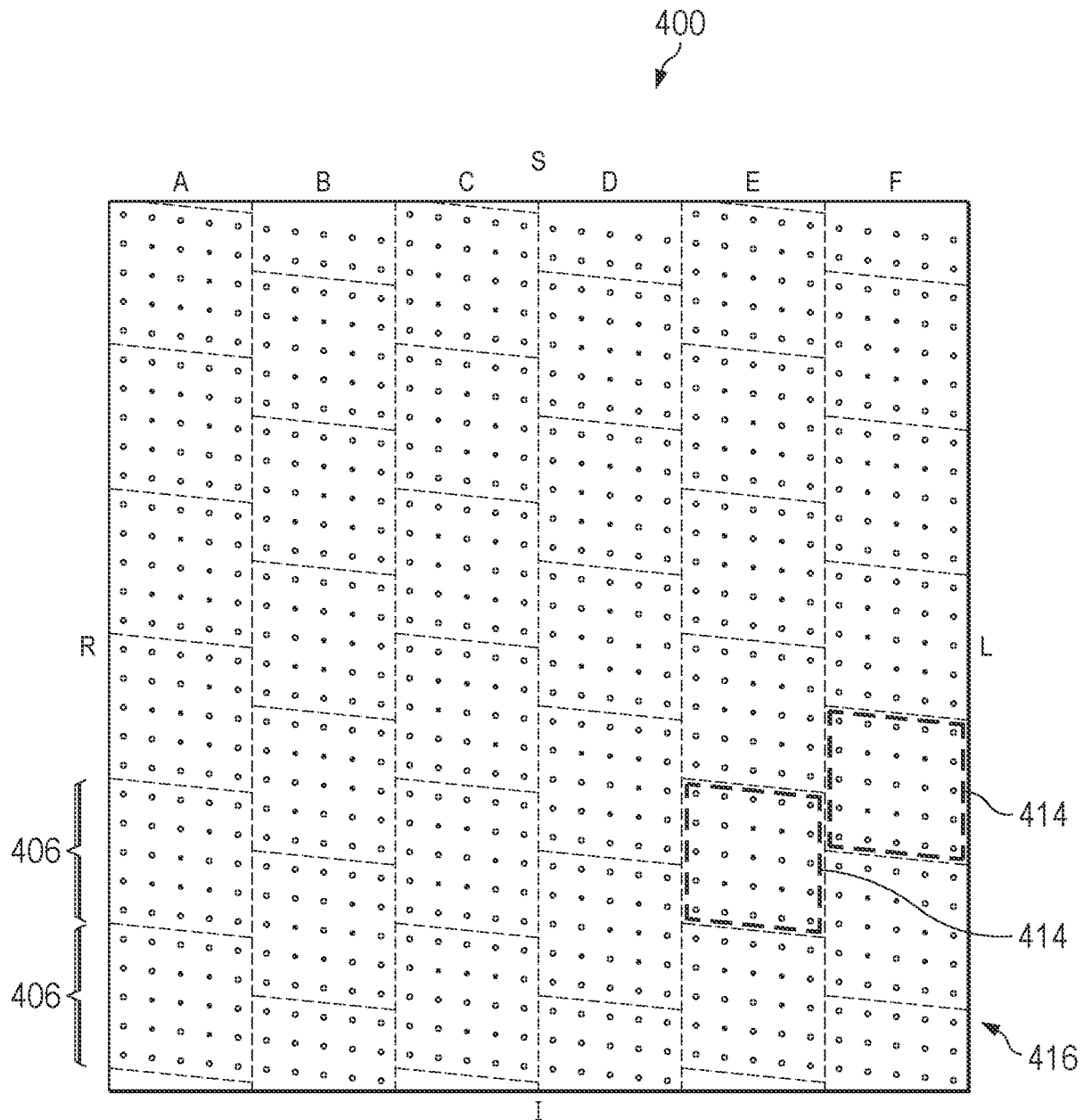
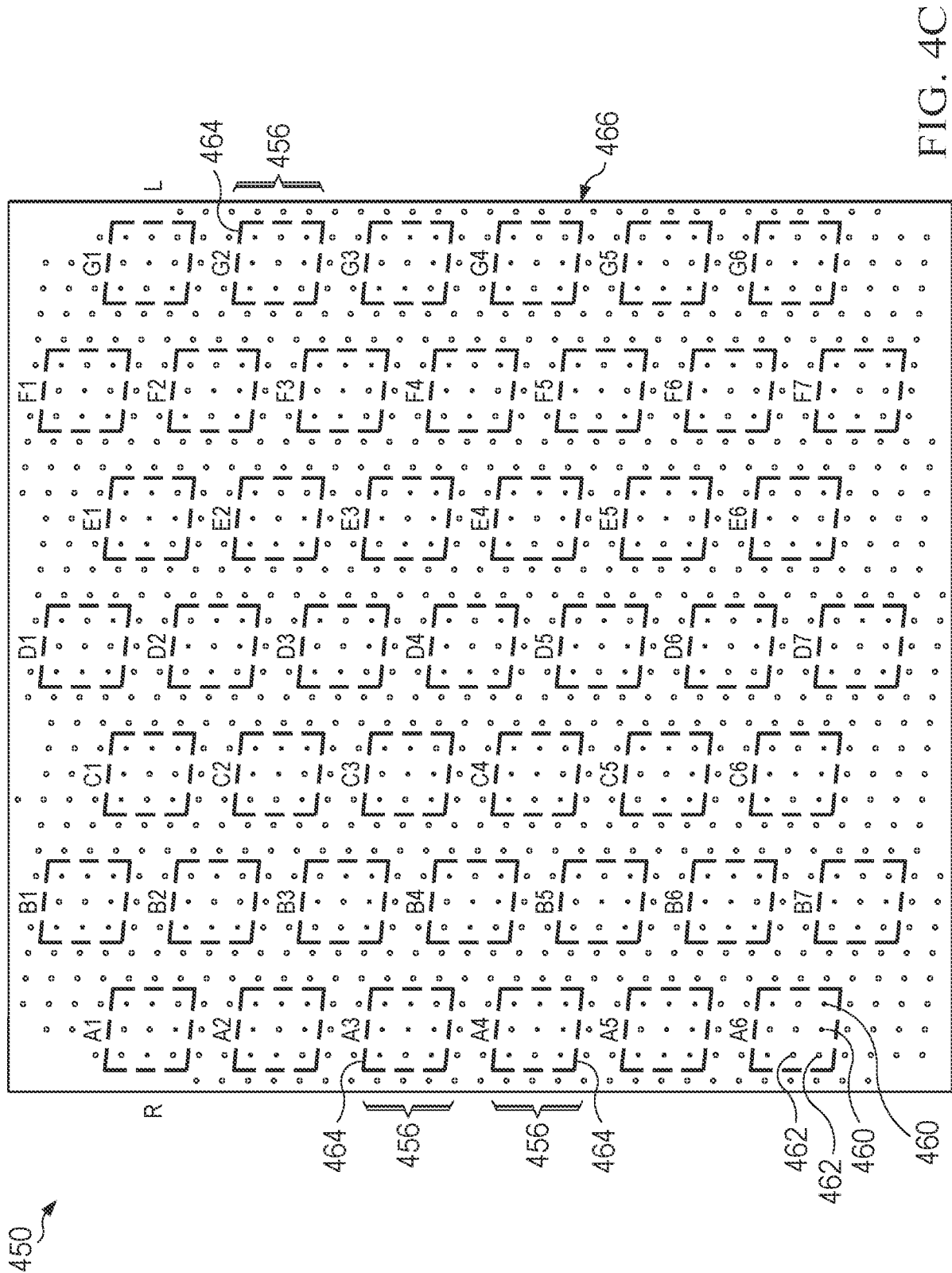


FIG. 4B



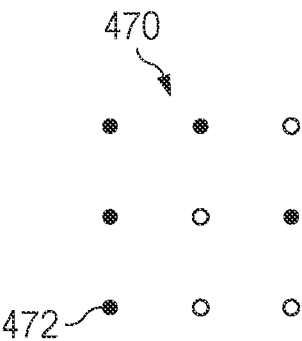


FIG. 4D

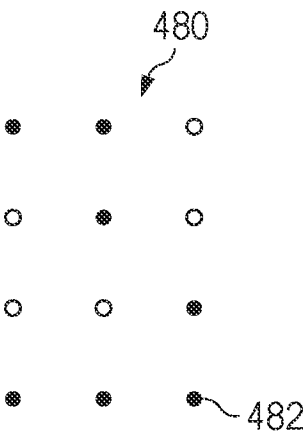


FIG. 4E

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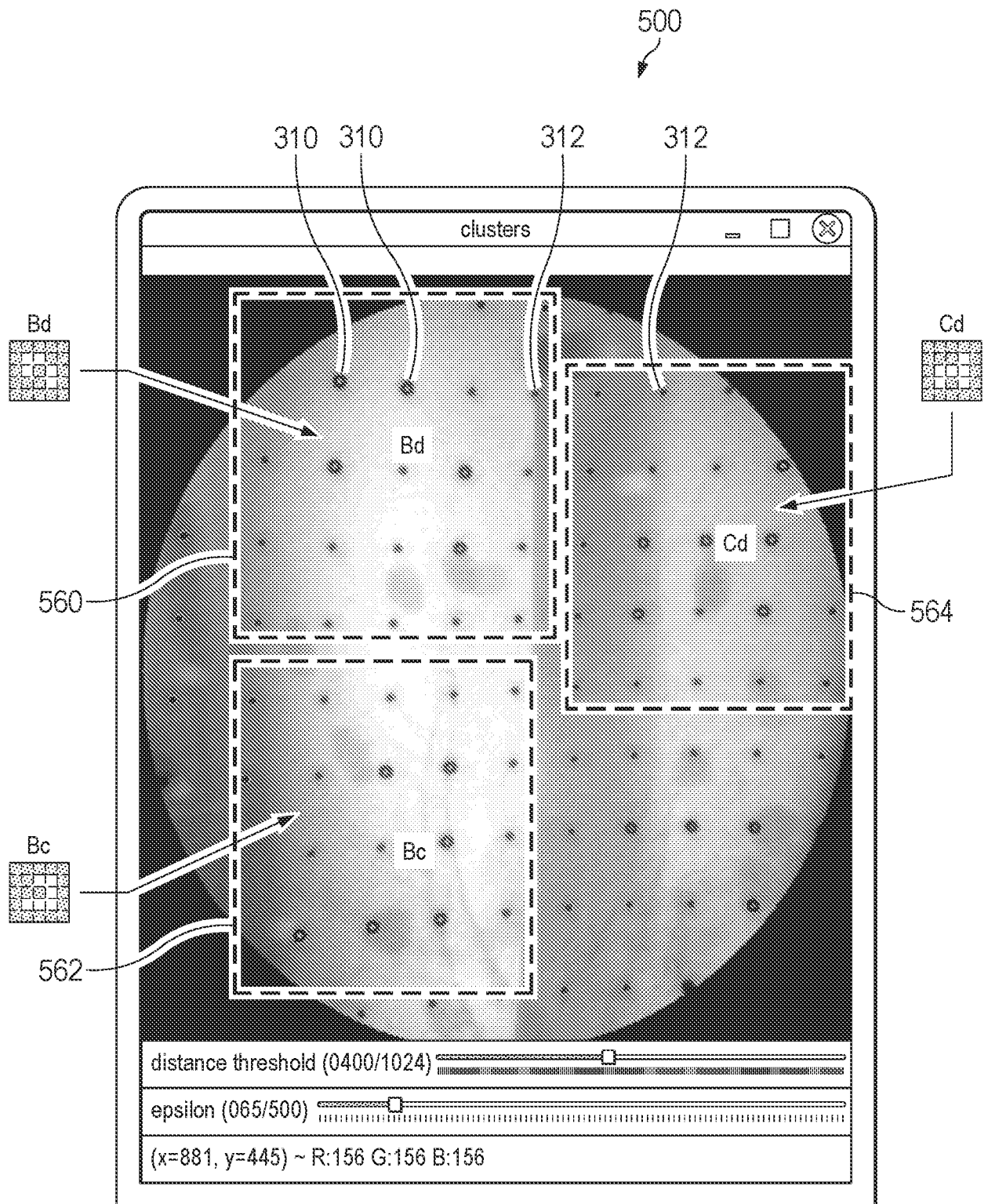
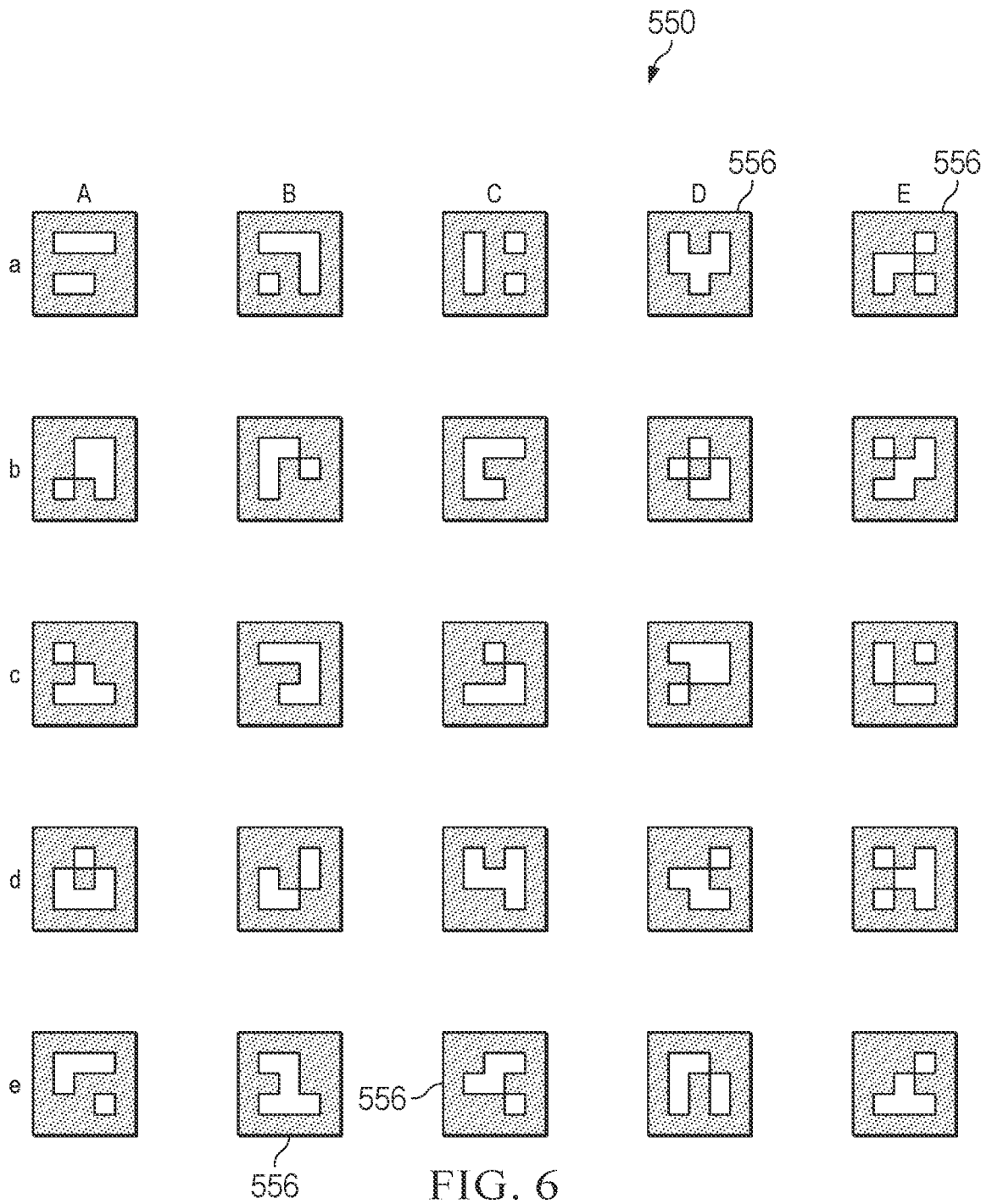


FIG. 5

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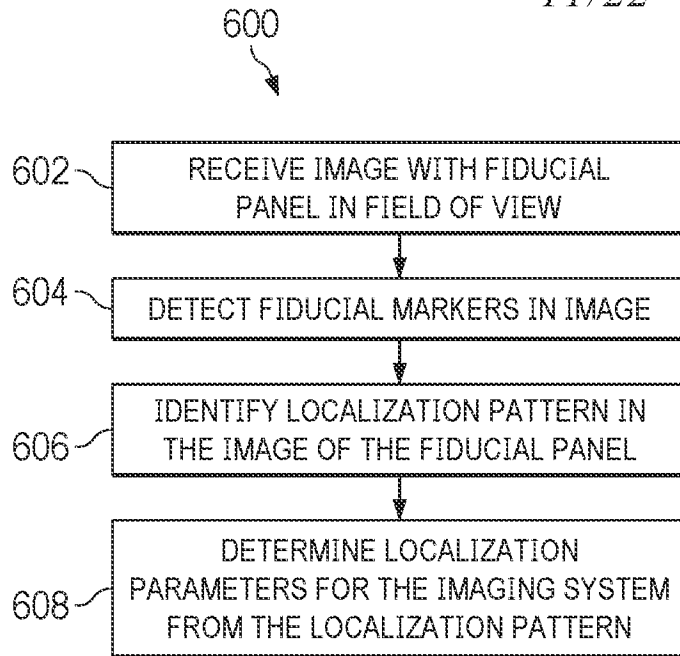


FIG. 7

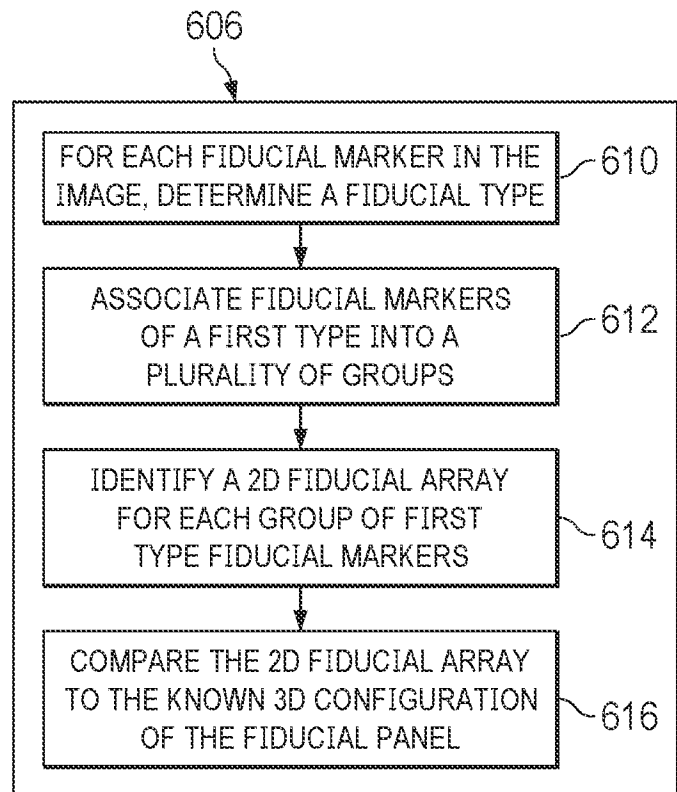


FIG. 8

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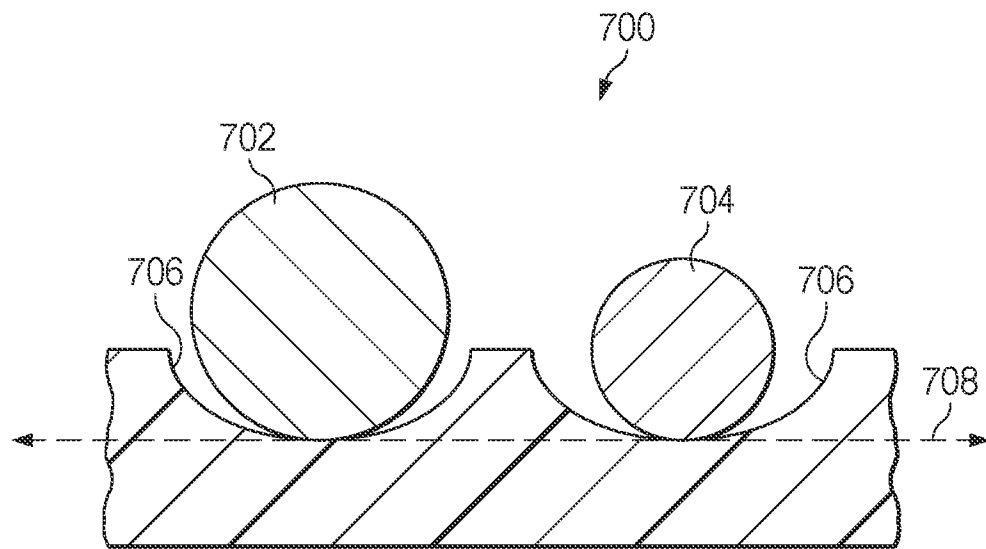


FIG. 9A

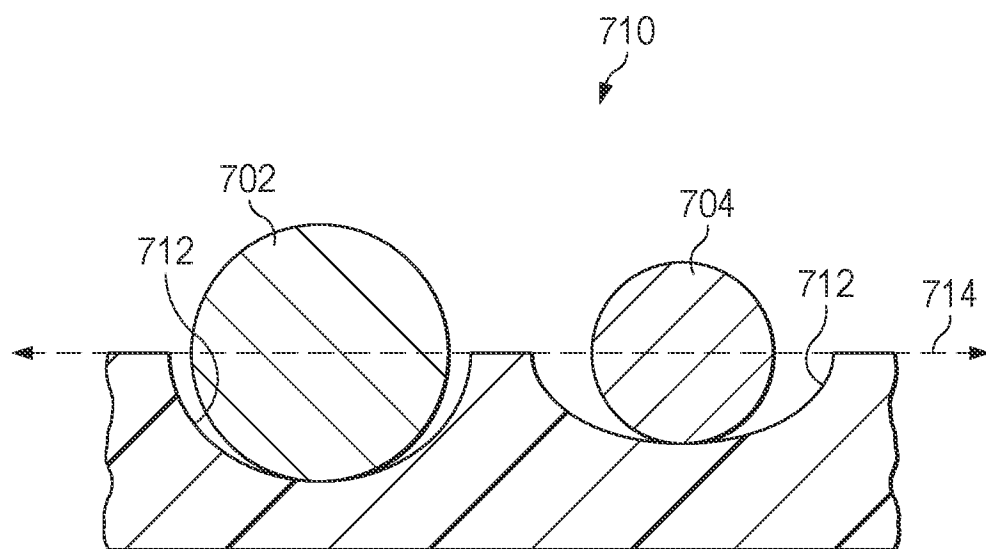


FIG. 9B

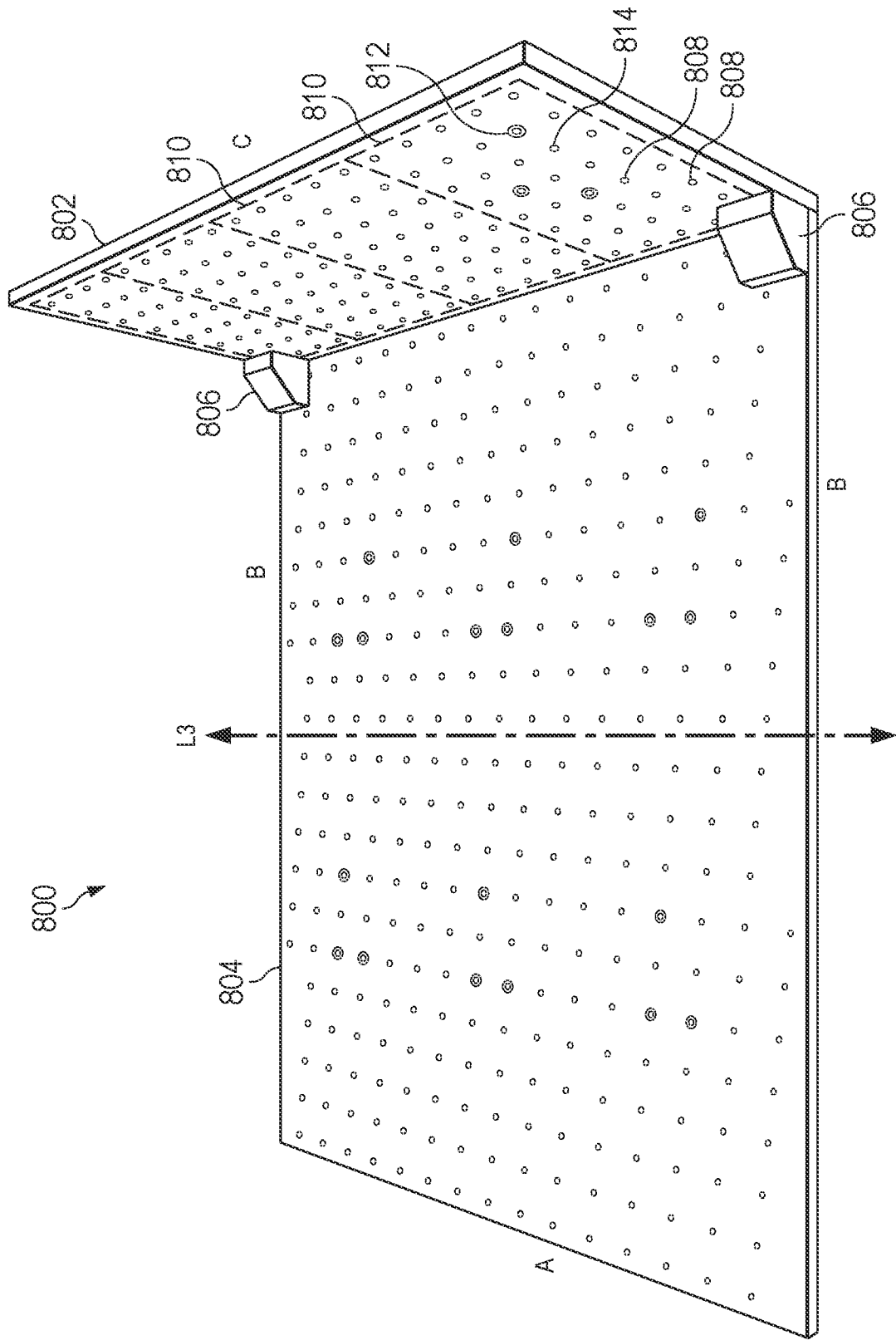


FIG. 10

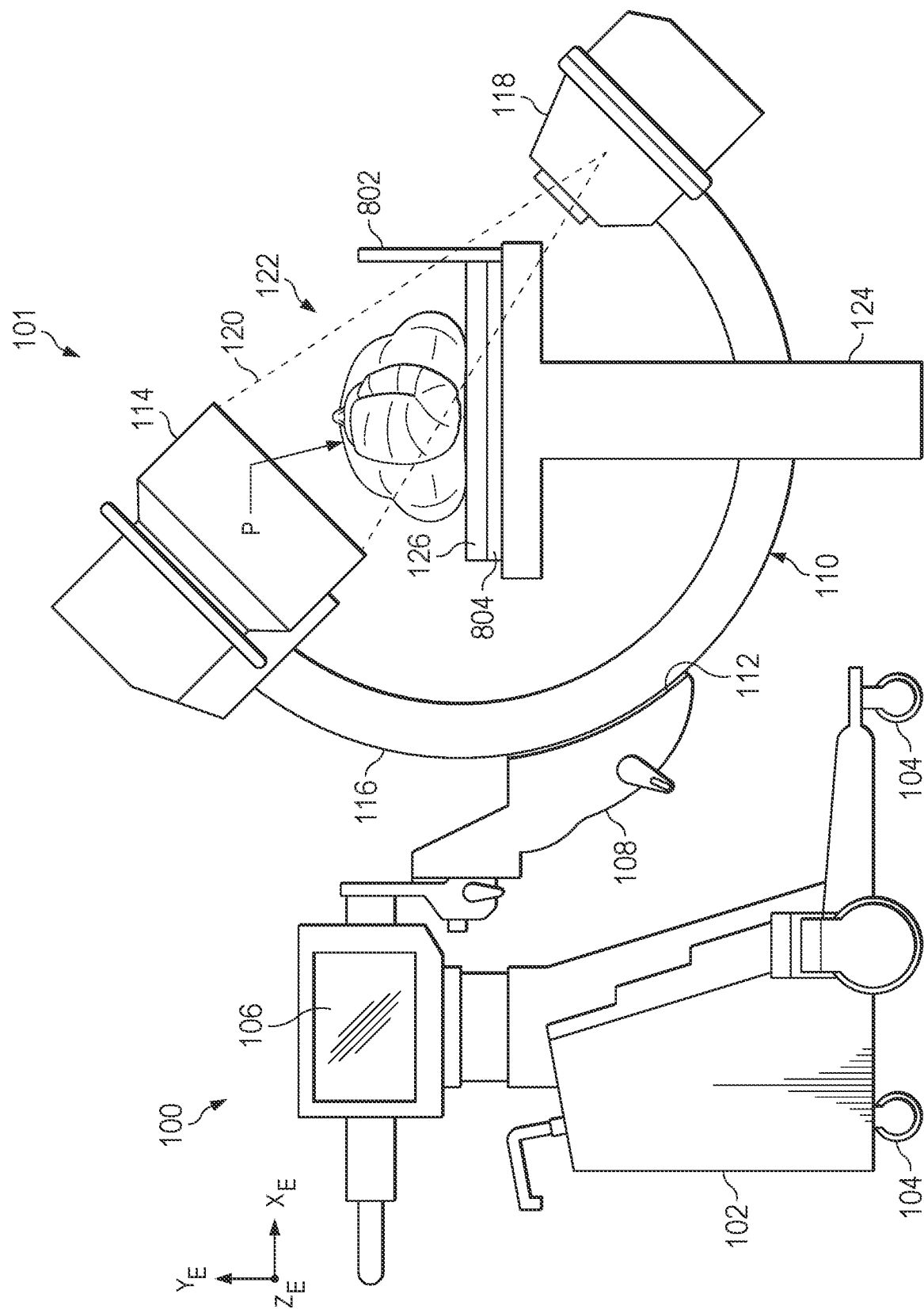


FIG. 11

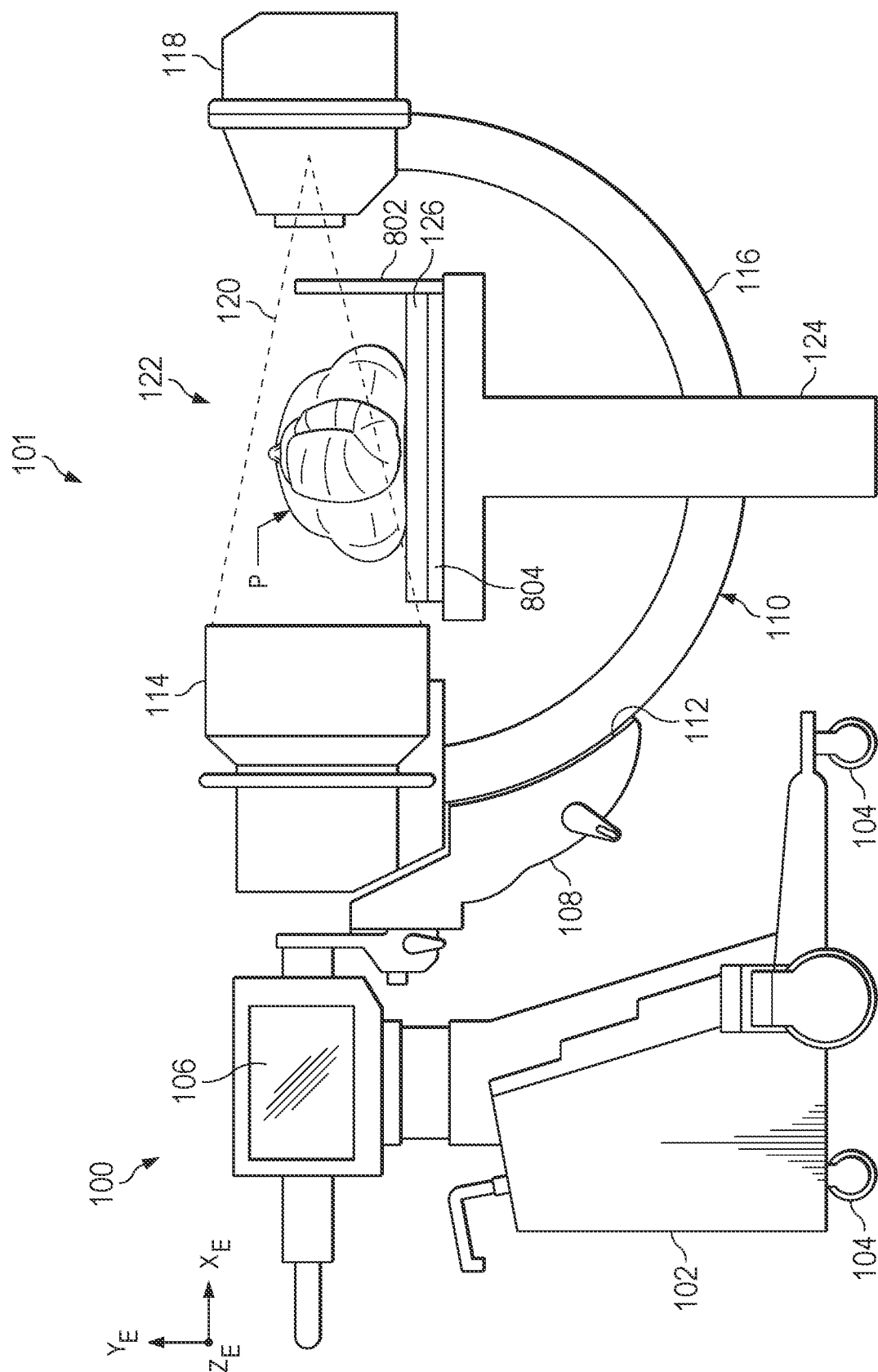


FIG. 12

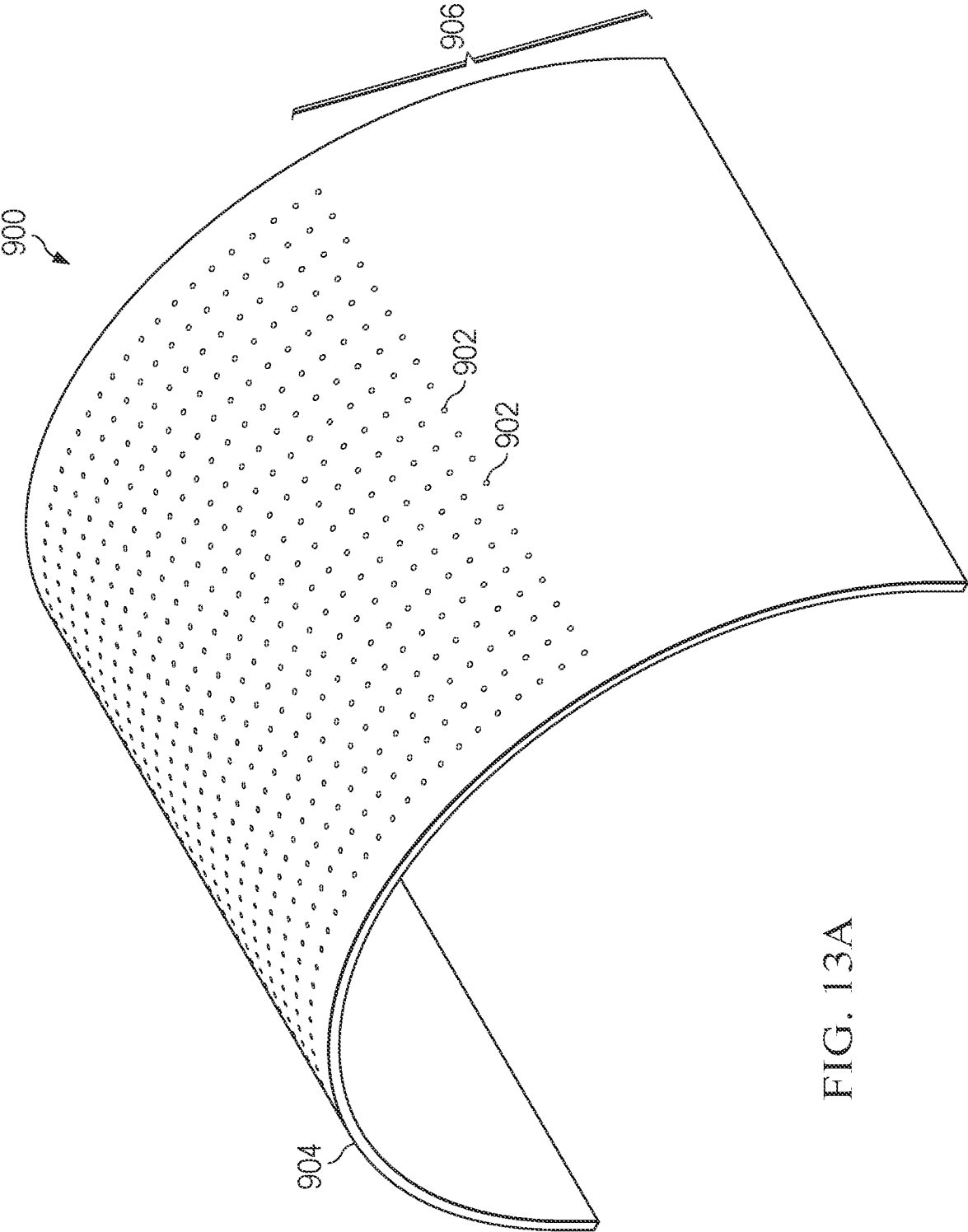


FIG. 13A

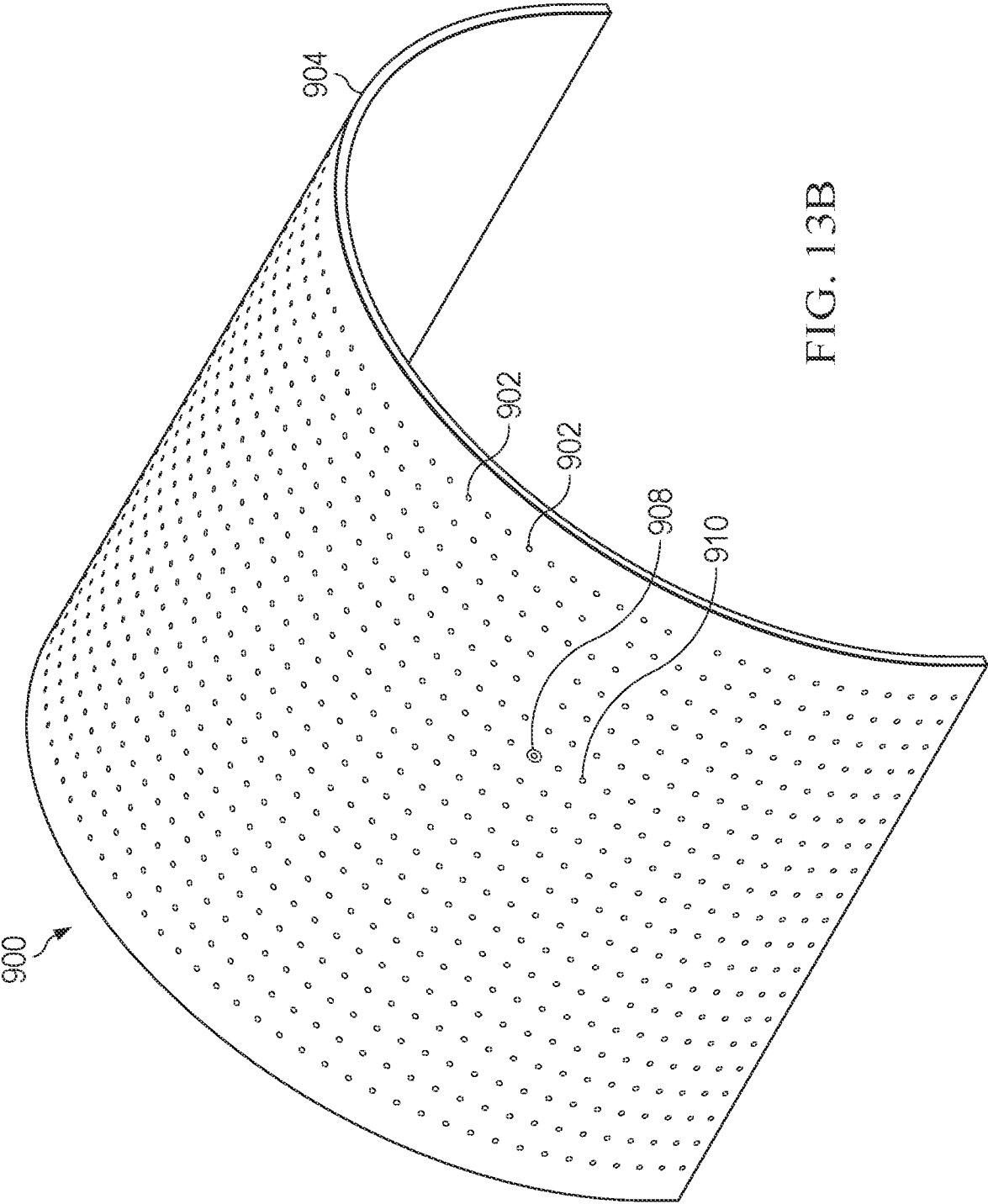


FIG. 13B

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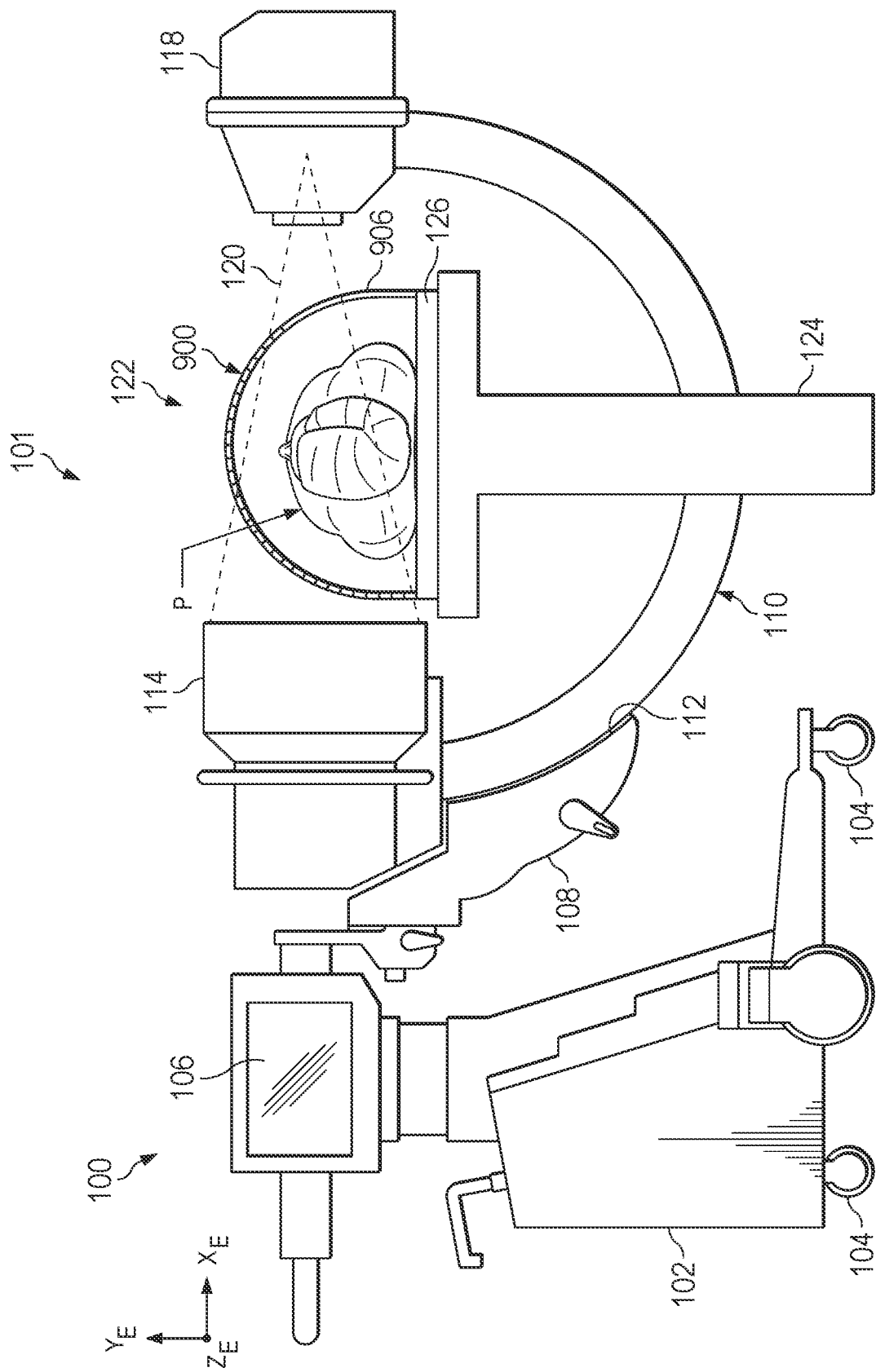


Fig. 14.

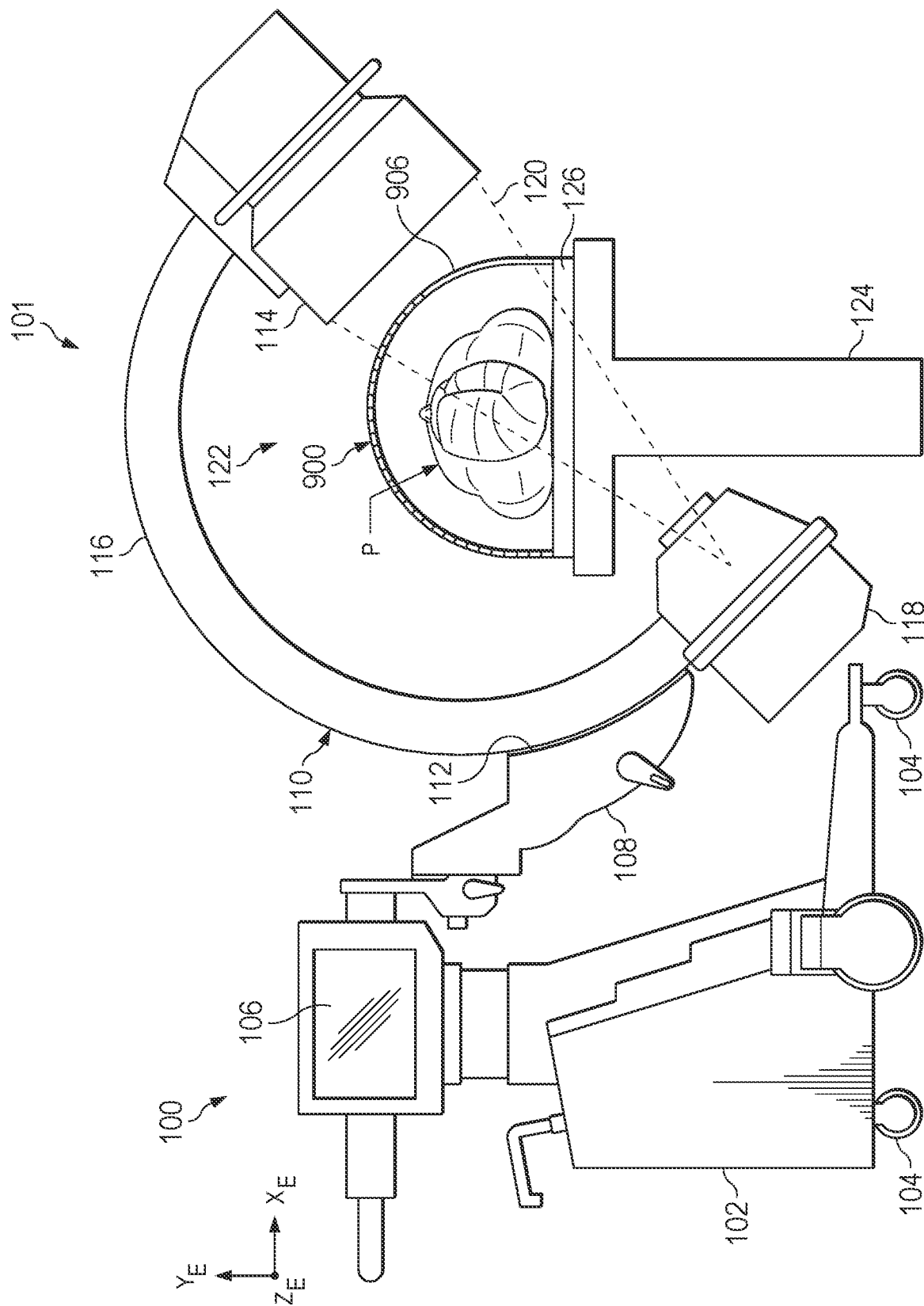


FIG. 15

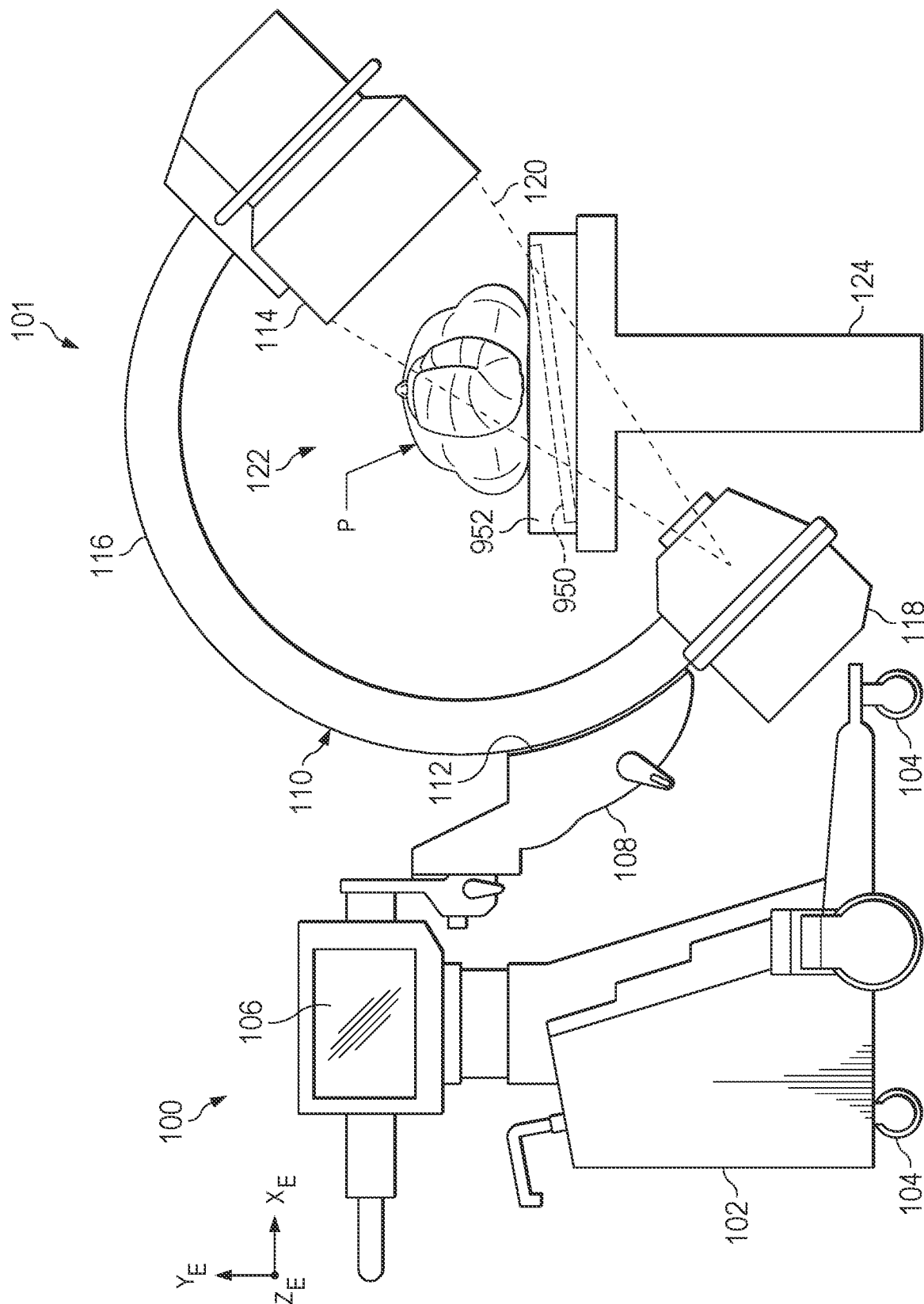


FIG. 16

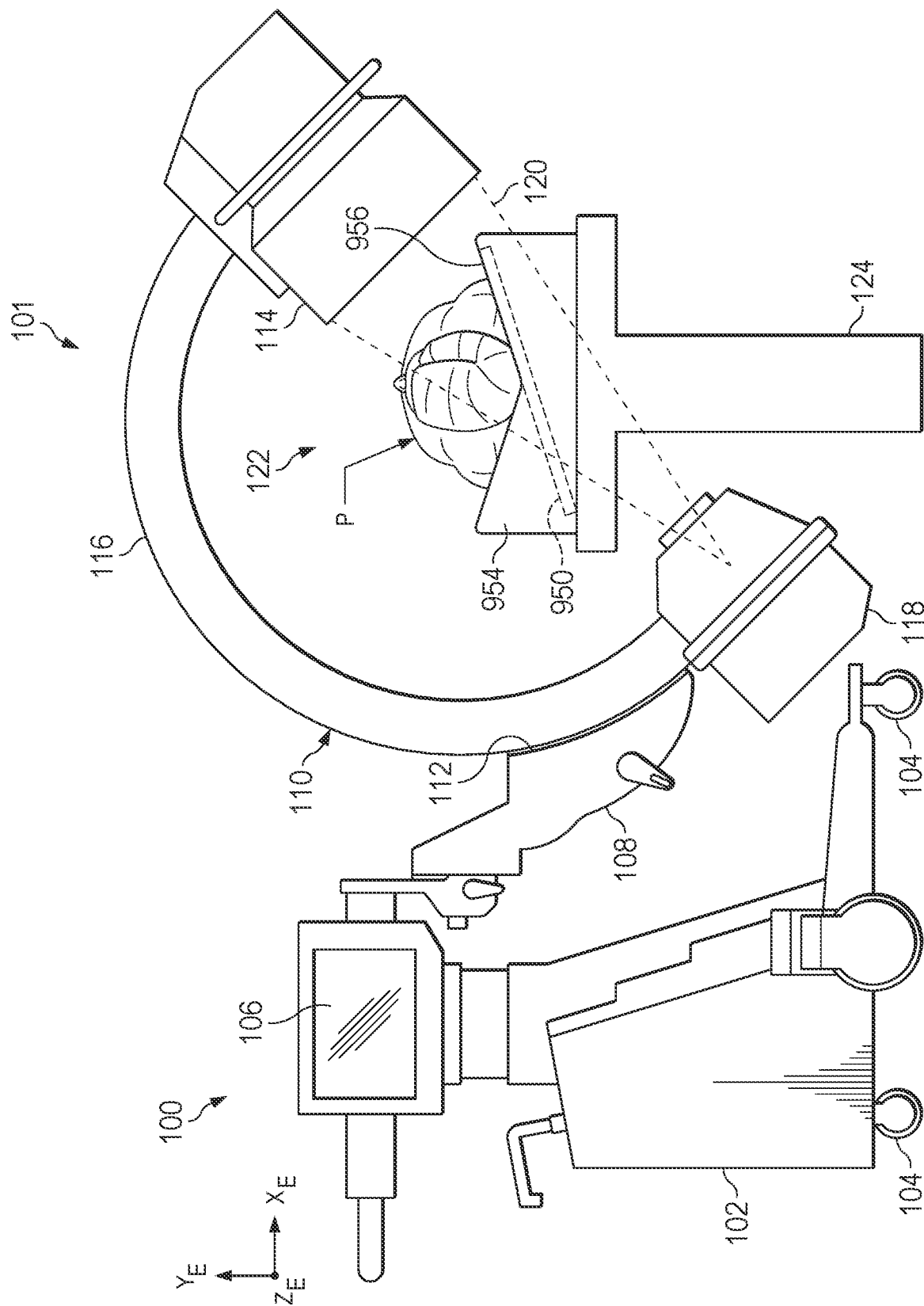


FIG. 17

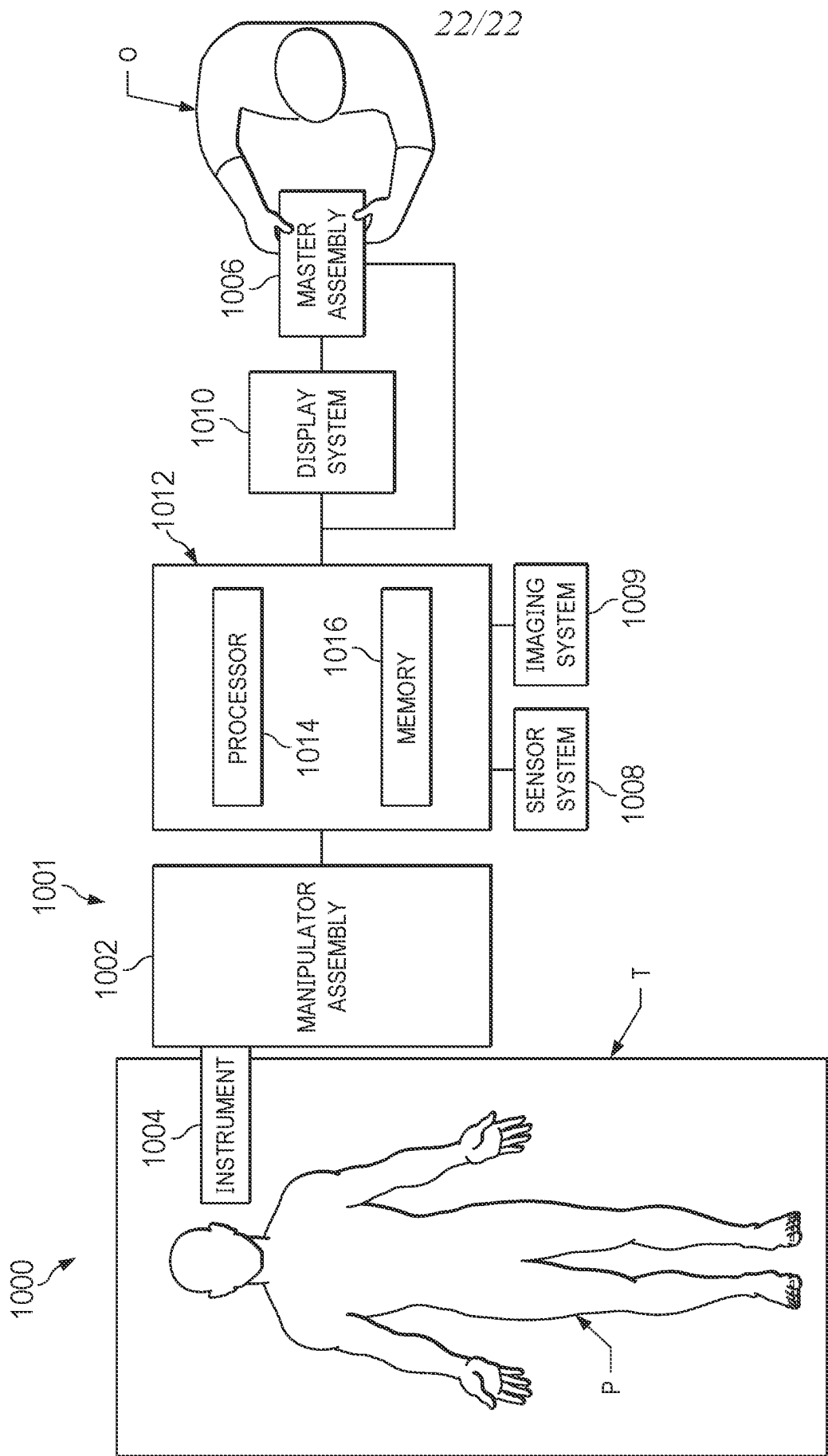


FIG. 18

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2024/023967

A. CLASSIFICATION OF SUBJECT MATTER INV. A61B90/00 A61B34/10 A61B6/58 A61B17/00 ADD.		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) A61B Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2019/328482 A1 (IZMIRLI ALON [IL] ET AL) 31 October 2019 (2019-10-31) paragraphs [0007], [0021], [0033], [0036]; claim 7; figures 1,5,6 -----	1 - 37
X	US 2019/274775 A1 (OLIVE SEBASTIEN [FR] ET AL) 12 September 2019 (2019-09-12) paragraphs [0067], [0070]; figures 1-4 -----	1, 27
A	US 2019/038365 A1 (SOPER TIMOTHY D [US] ET AL) 7 February 2019 (2019-02-07) paragraph [0073] paragraph [0076] paragraph [0079] paragraph [0086] paragraph [0087] figures 6A-7C -----	1 - 37
☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 5 July 2024		Date of mailing of the international search report 18/07/2024
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Christen, Jérôme

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2024/023967

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