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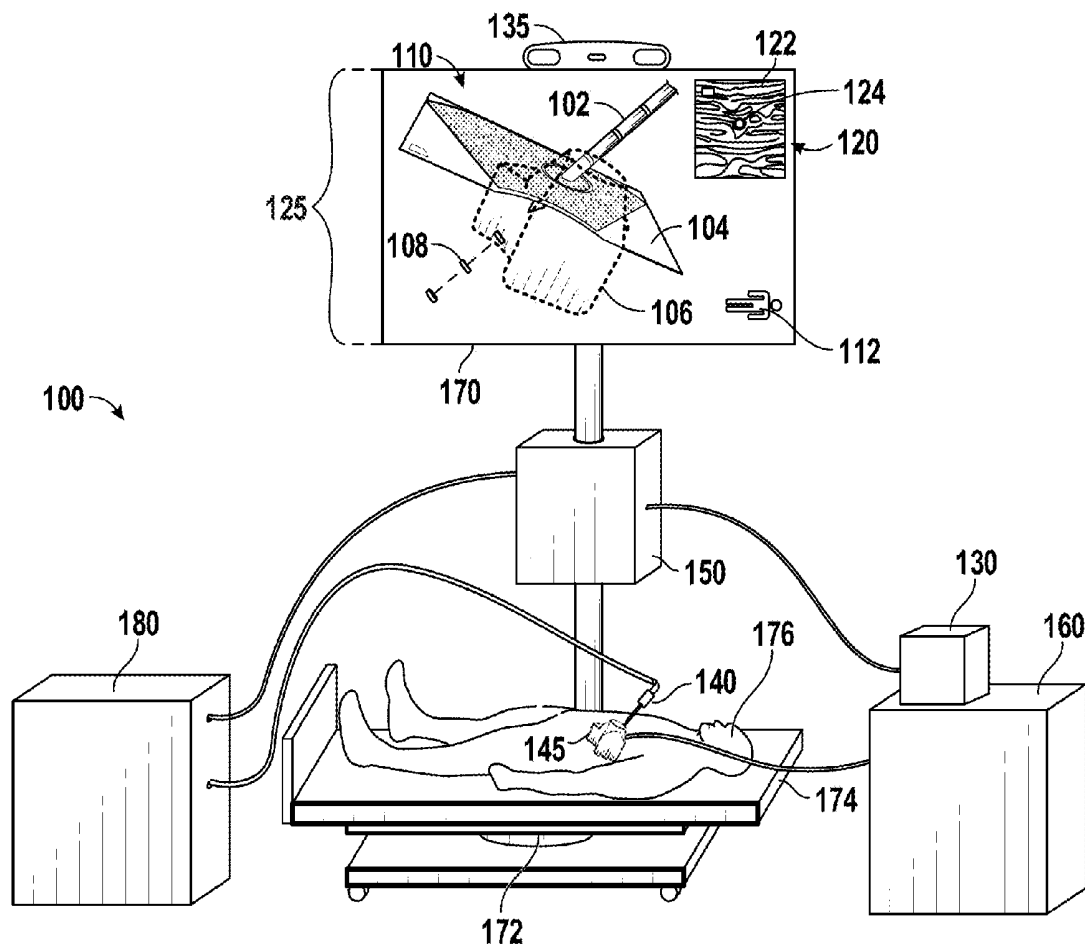(54) **SELECTIVE TRANSPARENCY TO ASSIST MEDICAL DEVICE NAVIGATION**

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(57)   **ABSTRACT**

A system and method for image guidance providing improved perception of a display object in a rendered scene for medical device navigation. The system can receive emplacement information associated with a medical device and determine an emplacement of a display object associated with the medical device. The system can further identify a selected surface of the display object and cause a display to display a selective-transparency rendering of the selected surface.
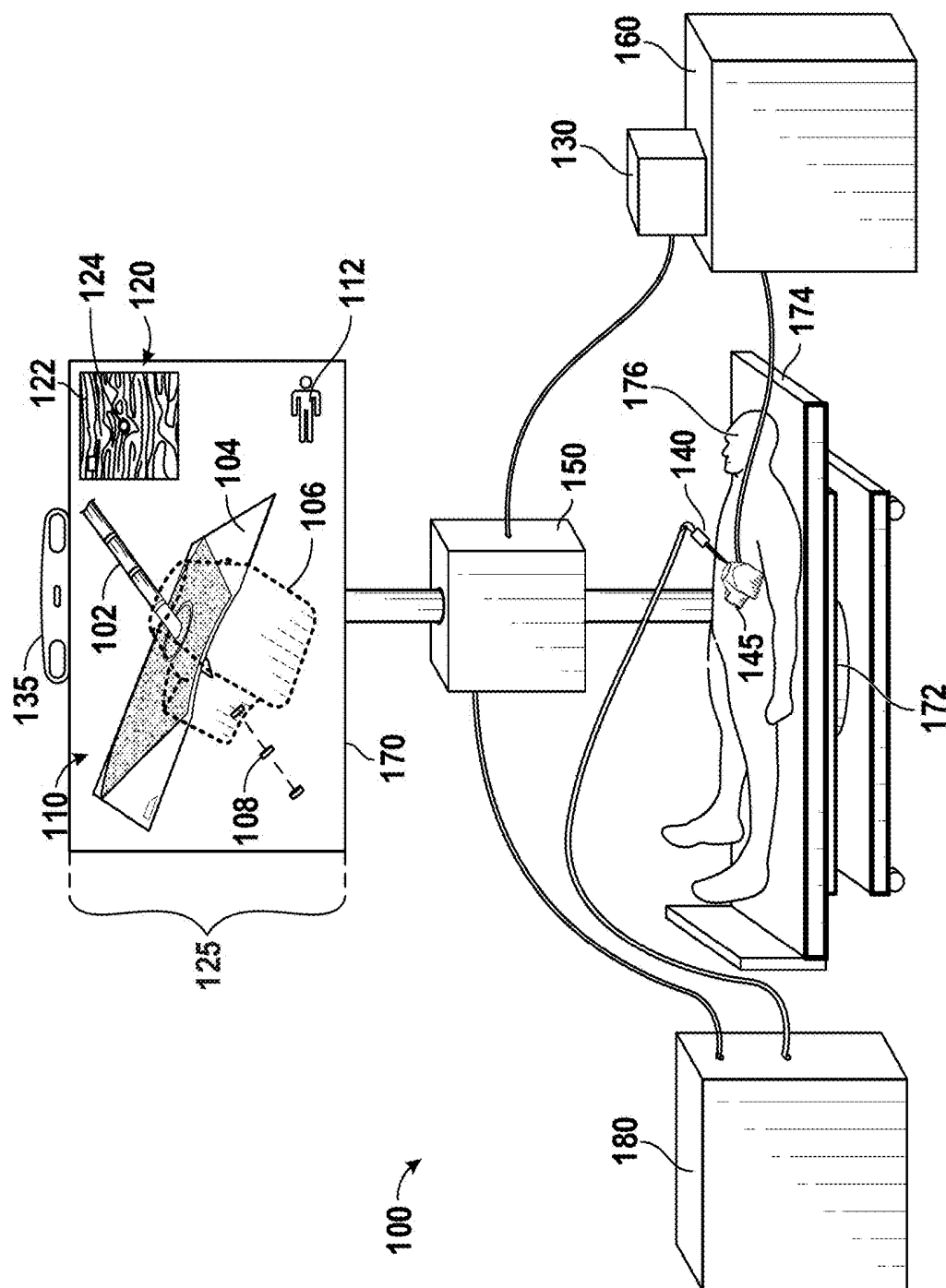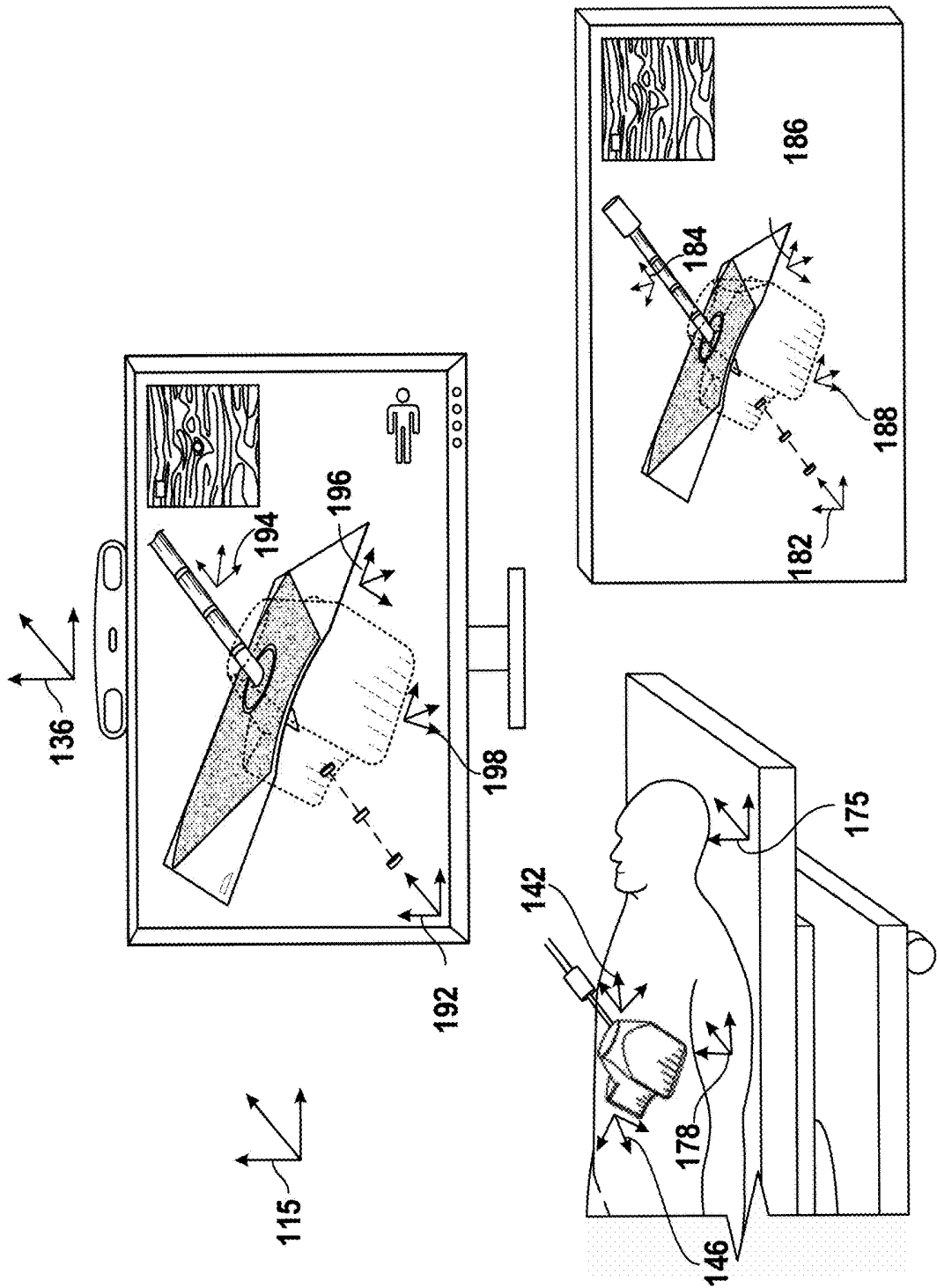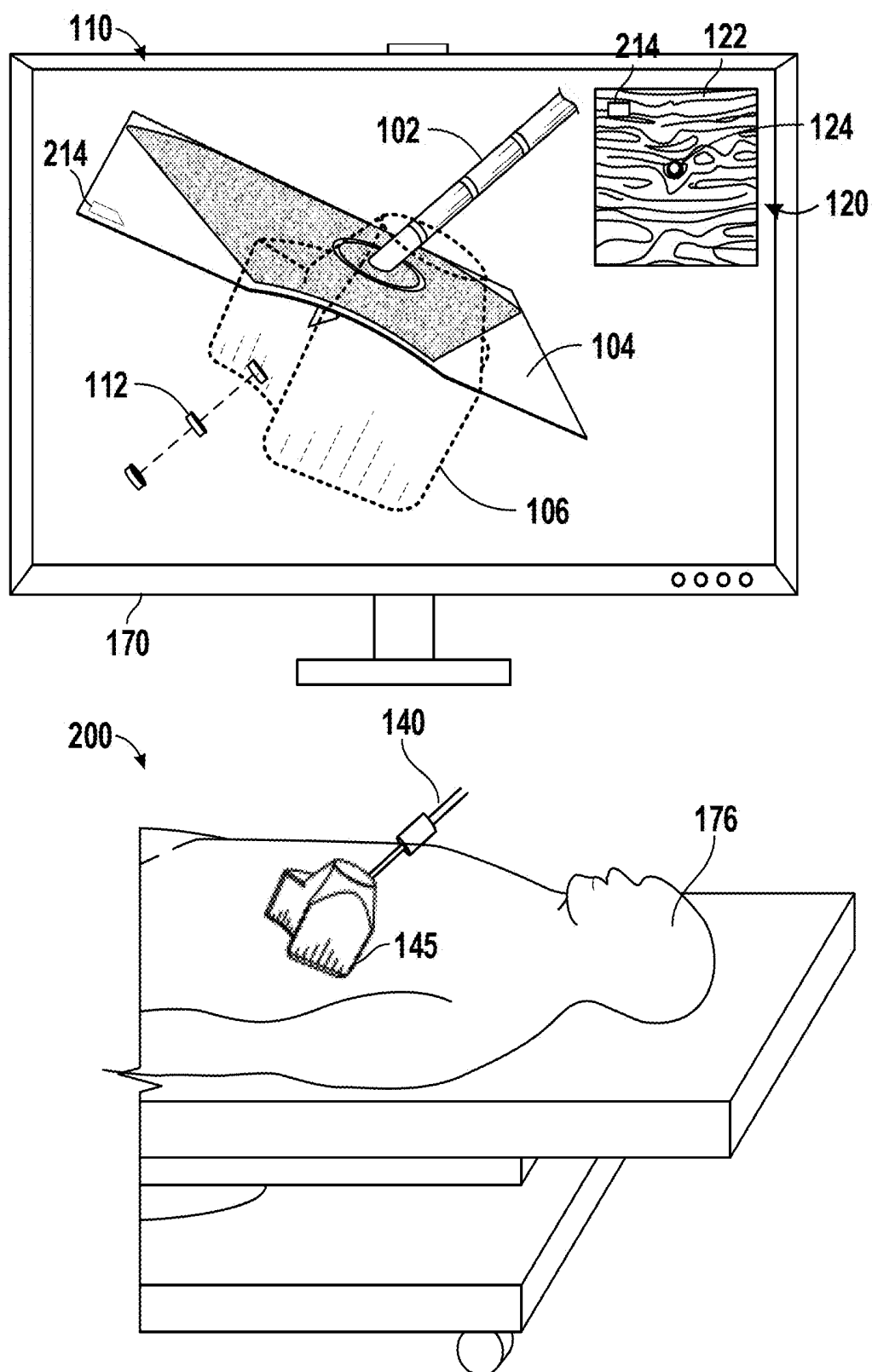
FIG. 1A

FIG. 1B

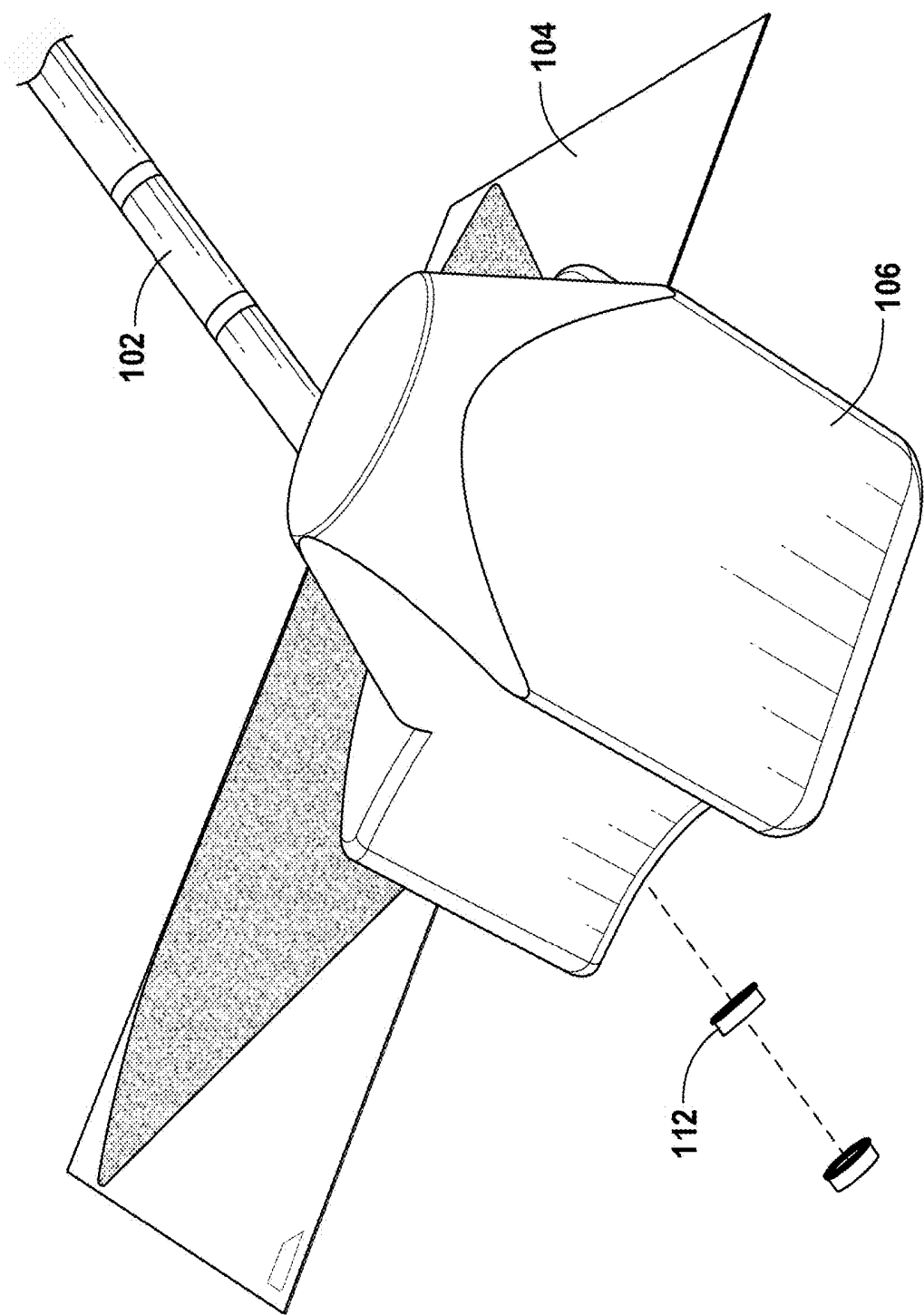FIG. 2

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112

FIG. 3

FIG. 4

FIG. 5

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FIG. 6

102

104

106

112

FIG. 7

FIG. 8A

FIG. 8B

FIG. 8C

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820

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822

820

802

804

FIG. 8D

104

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106

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832

830

804

802
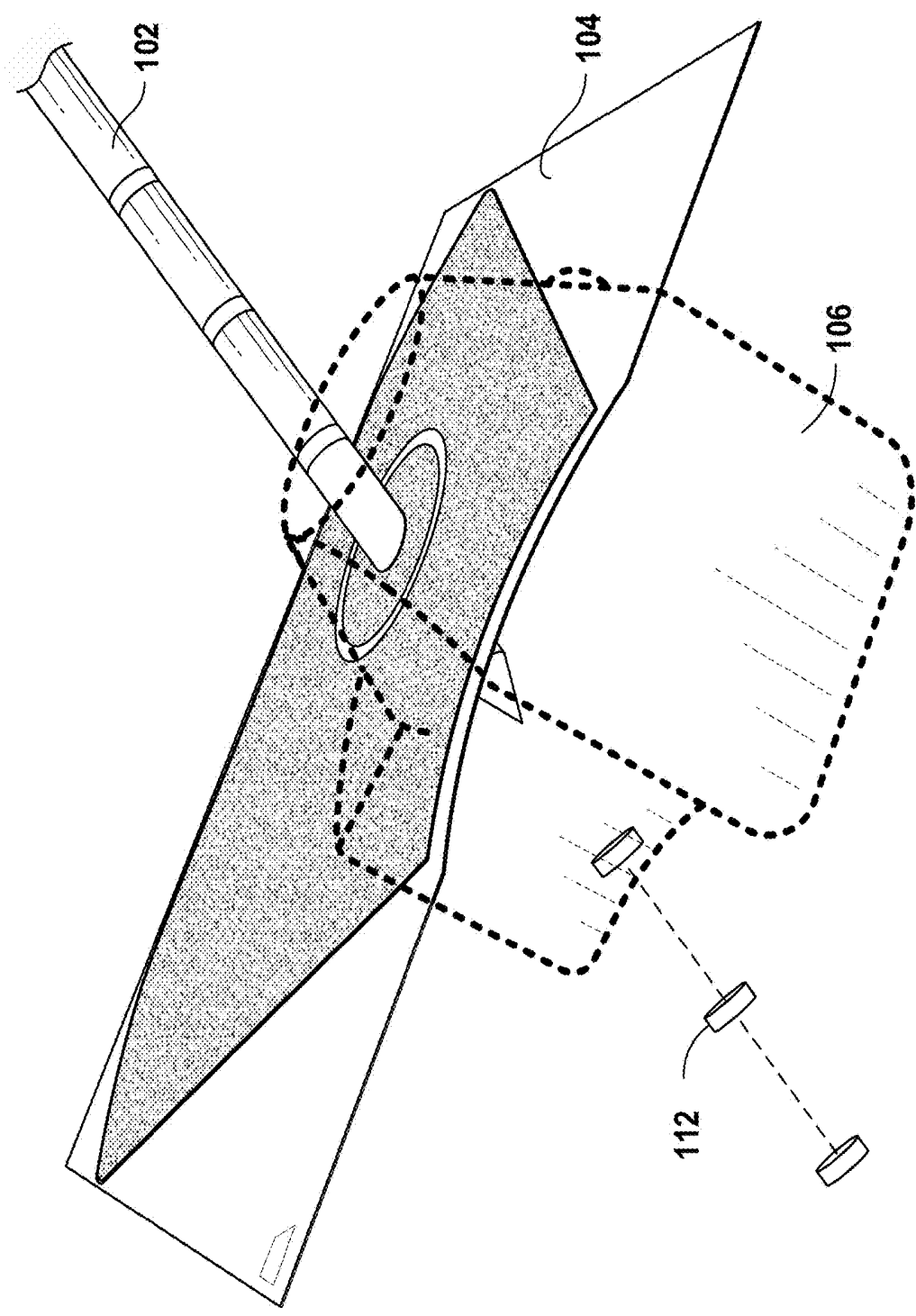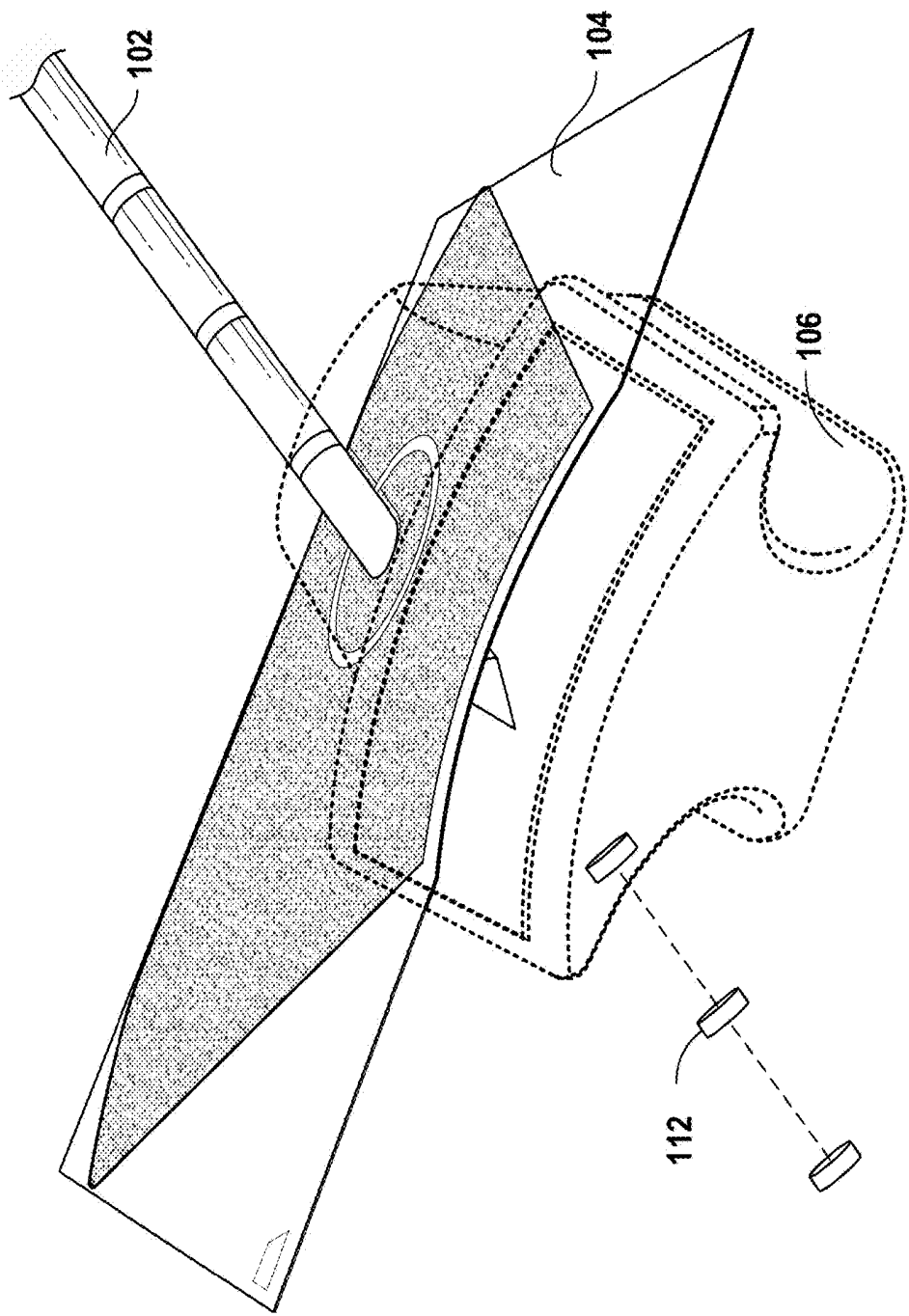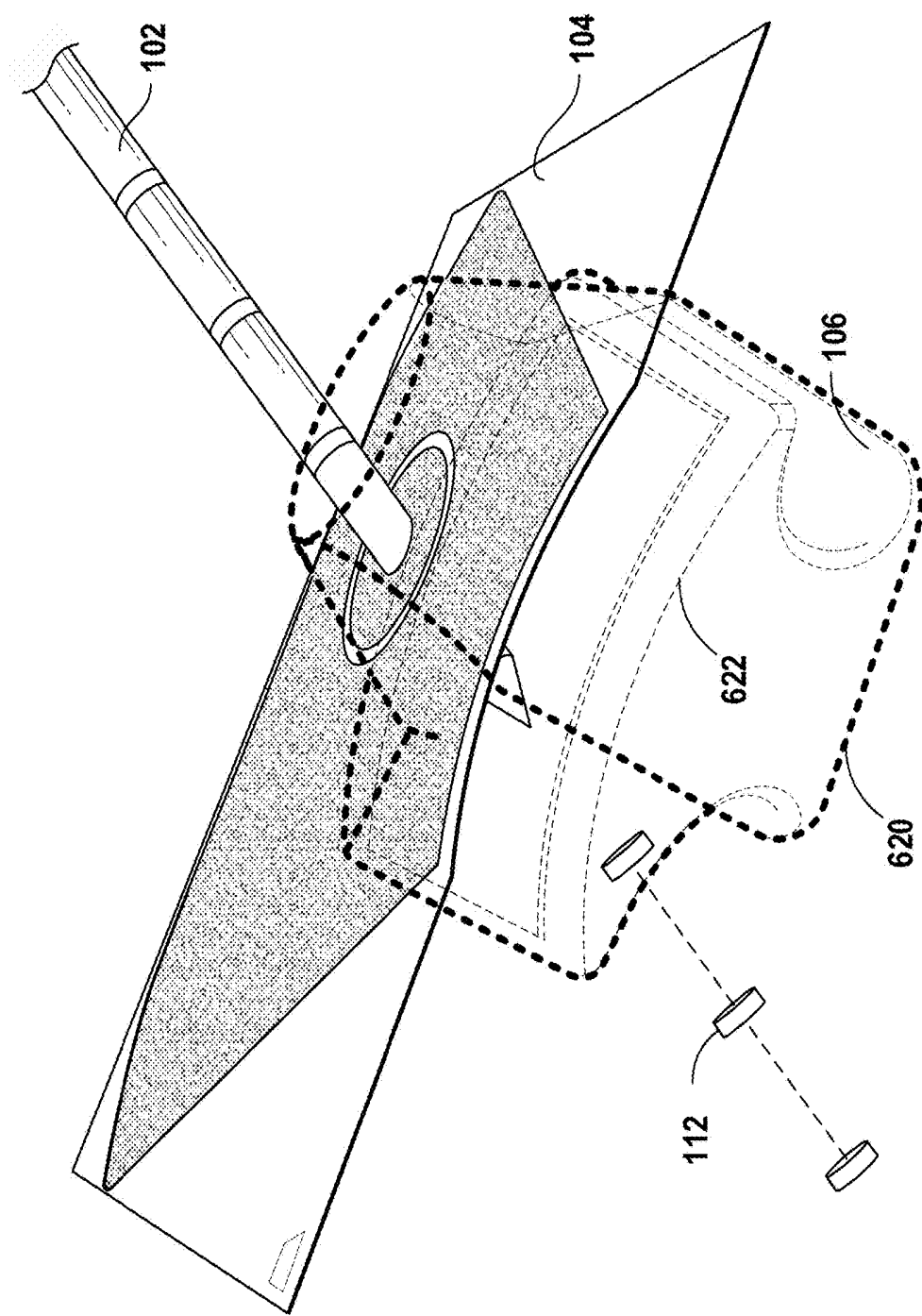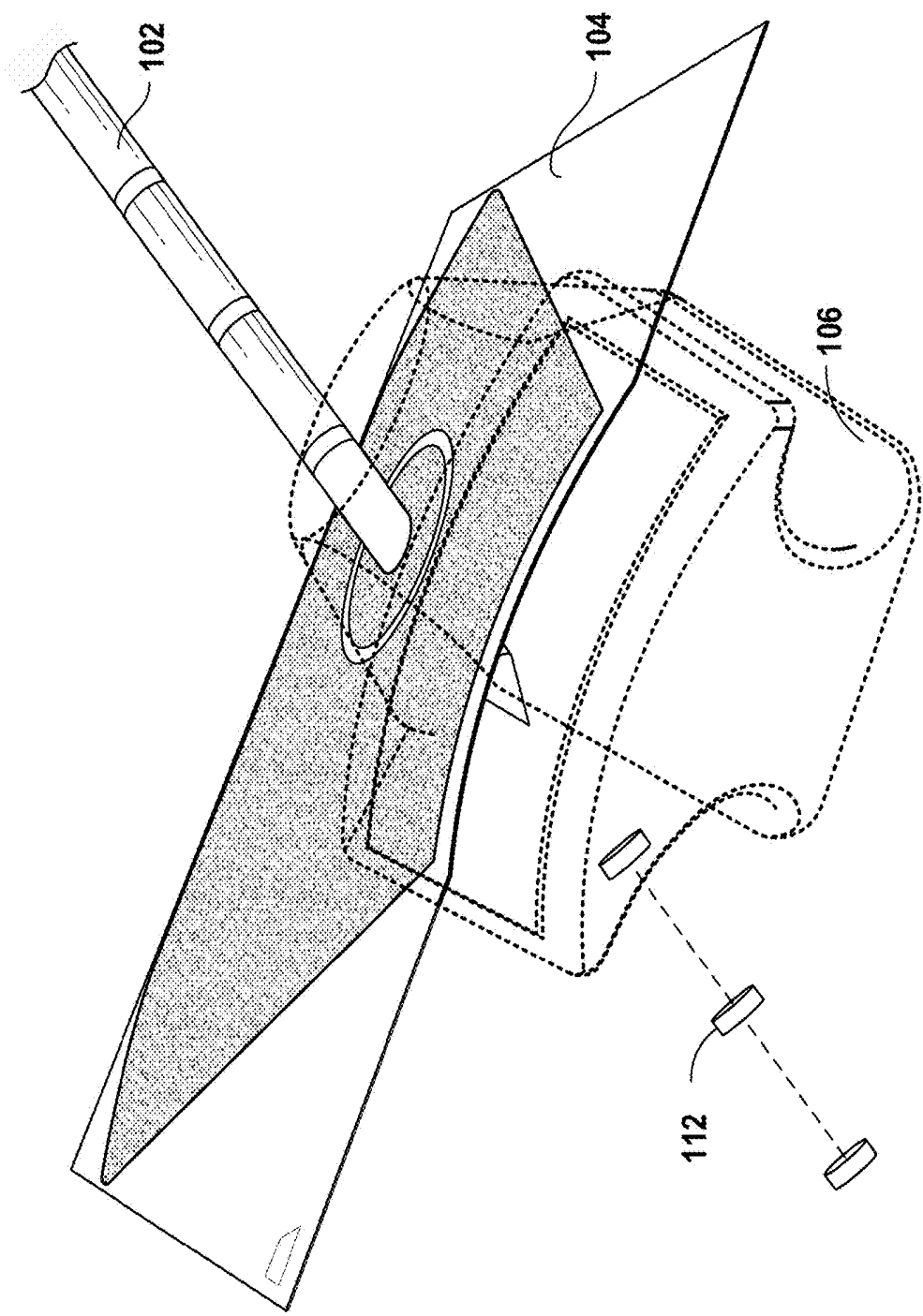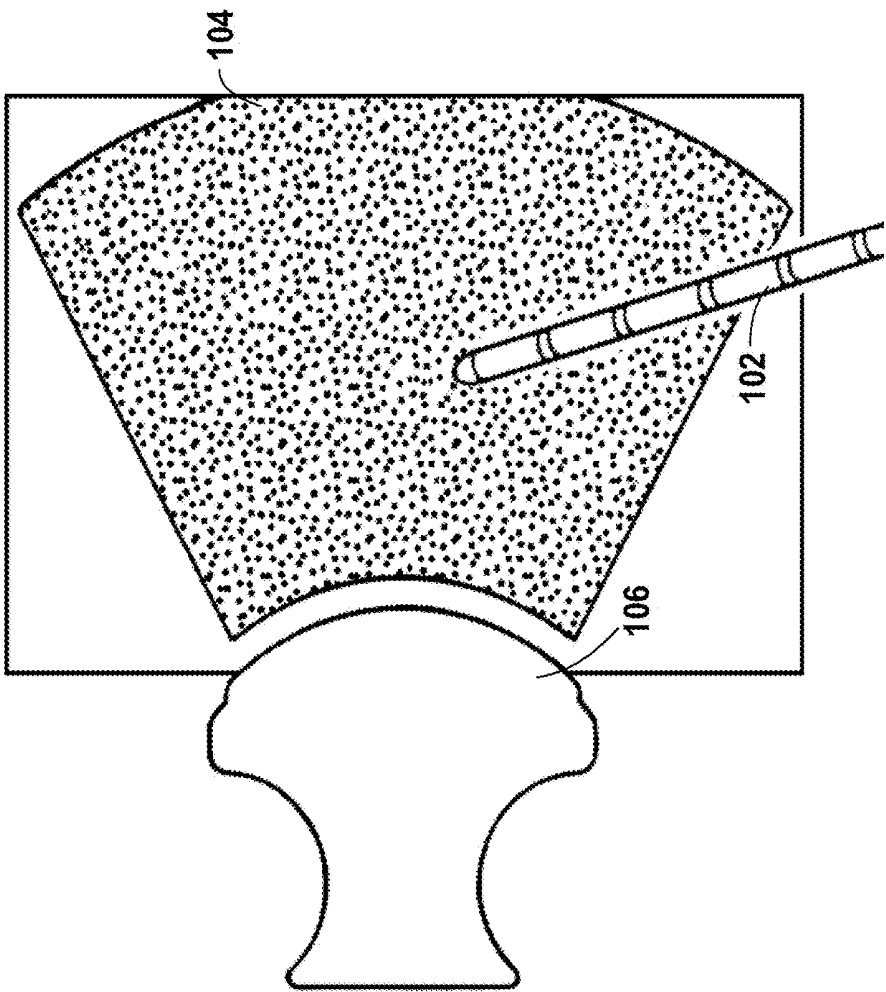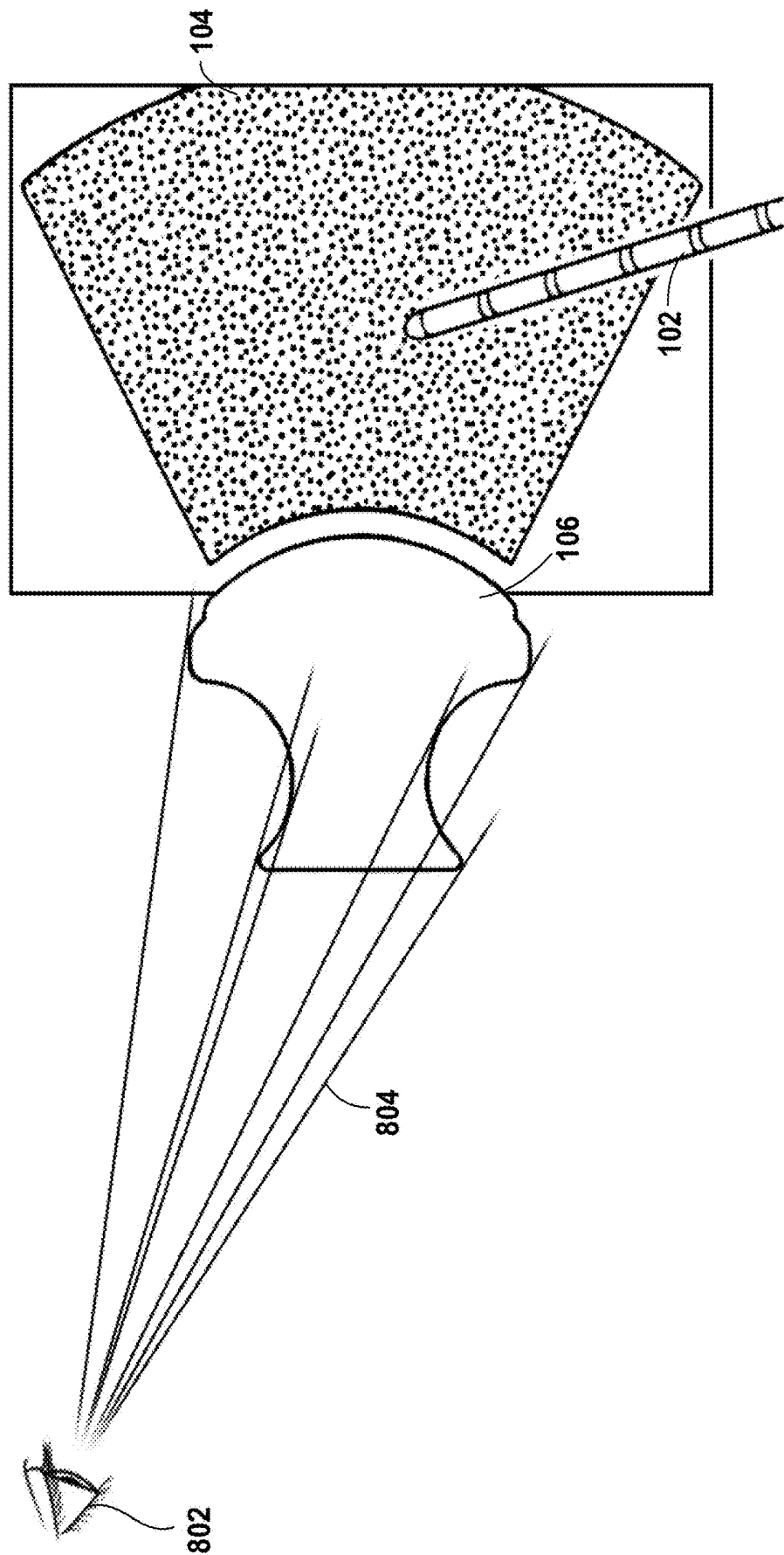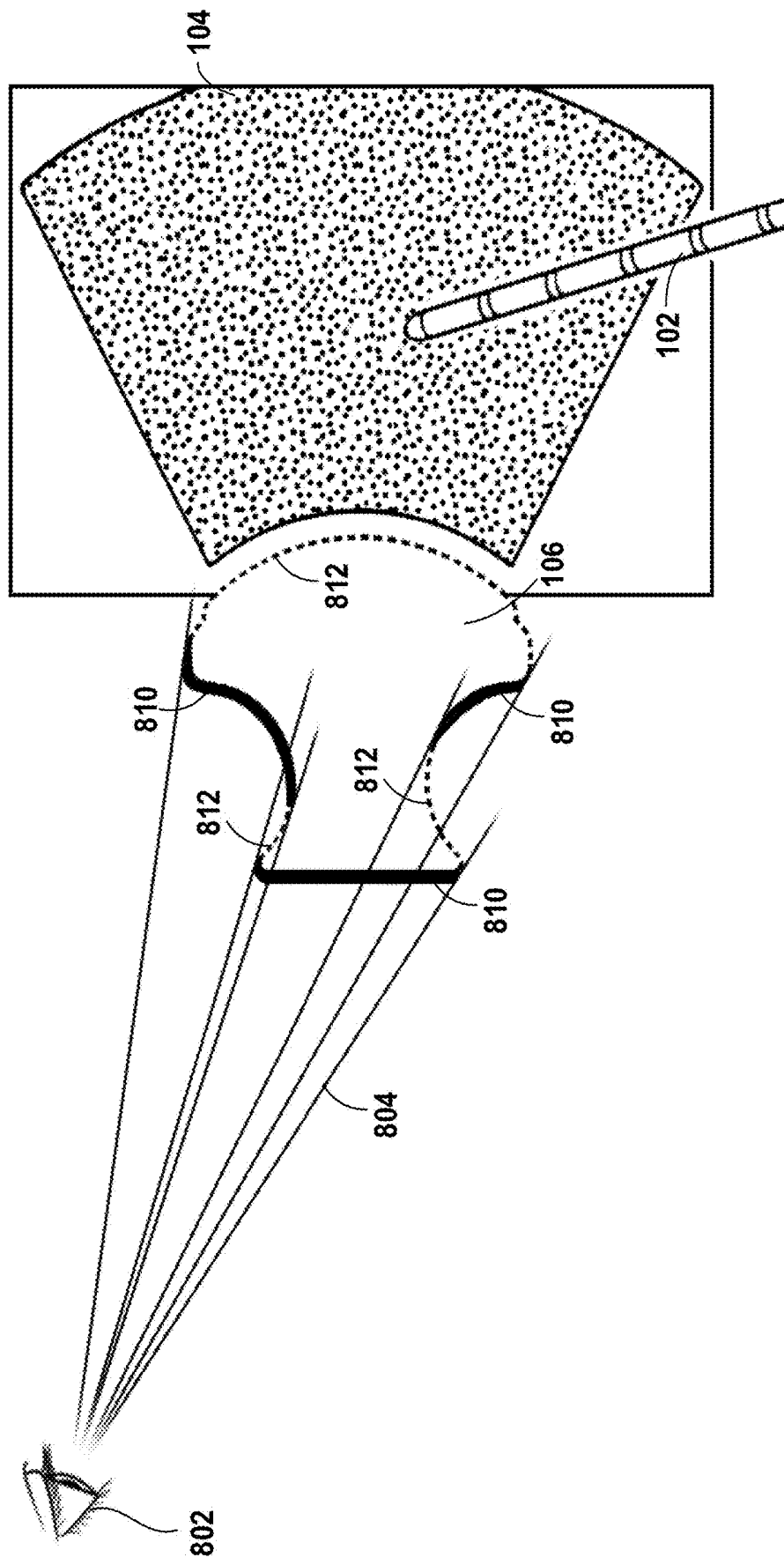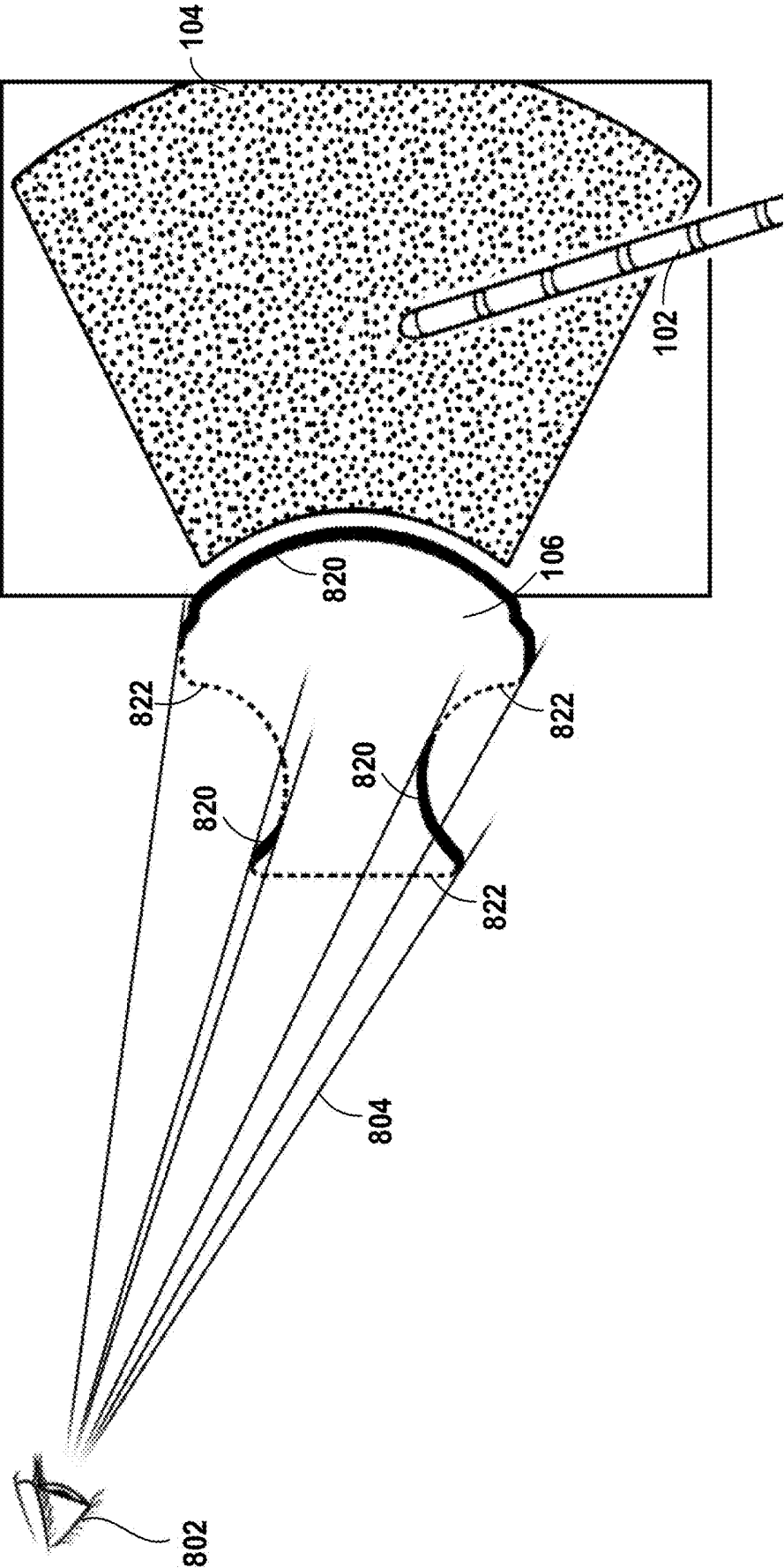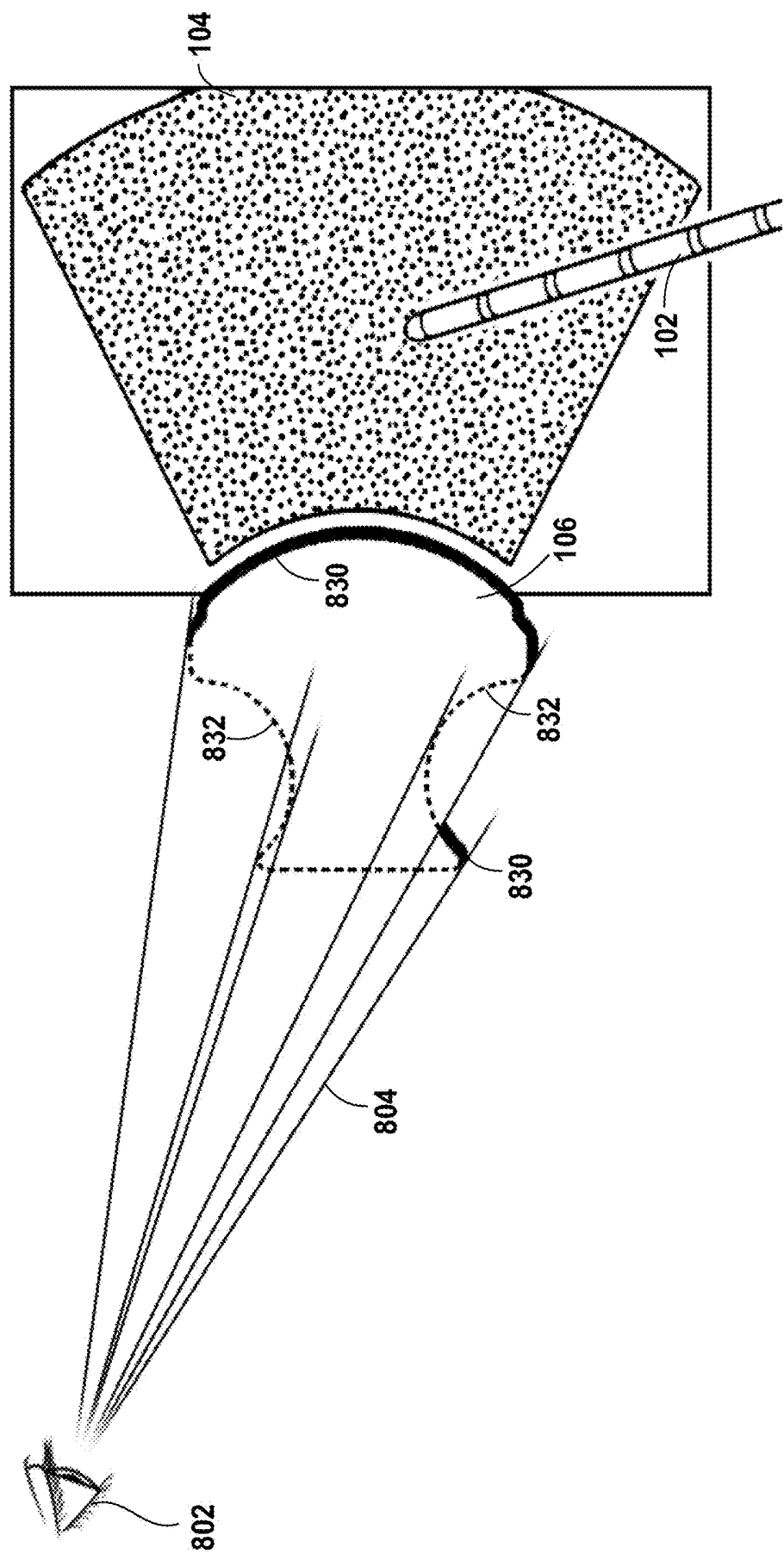
FIG. 8E
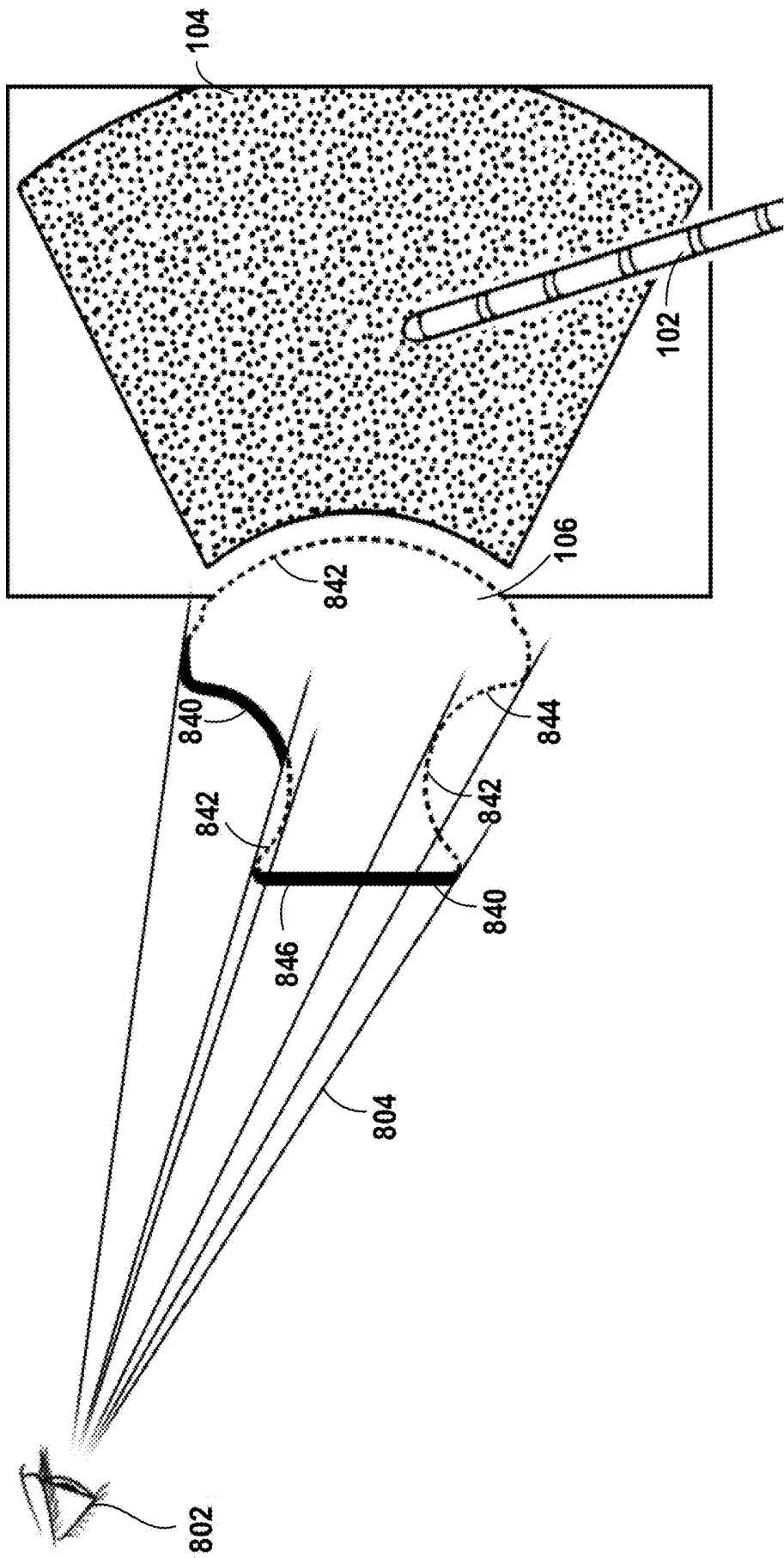
FIG. 8F

FIG. 9A

FIG. 9B

FIG. 9C

FIG. 9D

1000

1002 — RECEIVE FIRST EMPLACEMENT DATA ASSOCIATED WITH A FIRST EMPLACEMENT SENSOR ASSOCIATED WITH A FIRST MEDICAL DEVICE

1004 — RECEIVE FIRST EMPLACEMENT DATA ASSOCIATED WITH A SECOND EMPLACEMENT SENSOR ASSOCIATED WITH A SECOND MEDICAL DEVICE

1006 — DETERMINE AN EMPLACEMENT OF A FIRST VIRTUAL MEDICAL DEVICE CORRESPONDING TO THE FIRST MEDICAL DEVICE

1008 — DETERMINE AN EMPLACEMENT OF A SECOND VIRTUAL MEDICAL DEVICE CORRESPONDING TO THE SECOND MEDICAL DEVICE

1010 — DETERMINE AN EMPLACEMENT OF A MEDICAL IMAGE ASSOCIATED WITH THE SECOND MEDICAL DEVICE

1012 — IDENTIFY A SELECTED SURFACE OF THE SECOND VIRTUAL MEDICAL DEVICE BASED AT LEAST IN PART ON A POINT-OF-VIEW LOCATION

1014 — CAUSE THE DISPLAY TO DISPLAY A RENDERING OF PART OF THE FIRST VIRTUAL MEDICAL DEVICE OR PART OF THE MEDICAL IMAGE

1016 — CAUSE A DISPLAY TO DISPLAY A SELECTED TRANSPARENCY RENDERING OF THE SELECTED SURFACE

FIG. 10

1100

1102 — DETERMINE AN EMPLACEMENT OF A DISPLAY OBJECT CORRESPONDING TO A MEDICAL DEVICE

1104 — IDENTIFY A FIRST SELECTED SURFACE OF THE DISPLAY OBJECT RELATIVE TO A POINT-OF-VIEW LOCATION

1106 — IDENTIFY A SECOND SELECTED SURFACE OF THE DISPLAY OBJECT RELATIVE TO THE POINT-OF-VIEW LOCATION

1108 — CAUSE A DISPLAY TO DISPLAY A FIRST SELECTED TRANSPARENCY RENDERING OF THE FIRST SELECTED SURFACE

1110 — CAUSE A DISPLAY TO DISPLAY A SECOND SELECTED TRANSPARENCY RENDERING OF THE SECOND SELECTED SURFACE

FIG. 11

SELECTIVE TRANSPARENCY TO ASSIST MEDICAL DEVICE NAVIGATION

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims priority benefit to U.S. Provisional Application No. 62/539,729, entitled "MONOSTABLE TRANSPARENCY TO ASSIST MEDICAL DEVICE NAVIGATION," filed Aug. 1, 2017, which is hereby incorporated herein by reference in its entirety. Any and all applications for which a foreign or domestic priority claim is identified in the Application Data Sheet as filed with the present application are incorporated by reference under 37 CFR 1.57 and made a part of this specification.

BACKGROUND

[0002] Various systems are available to aid a healthcare provider to guide a medical device in a patient or to provide a user viewing an object with additional information. The systems can provide image guidance cues to aid the healthcare provider or user and can also provide additional information for the user's benefit.
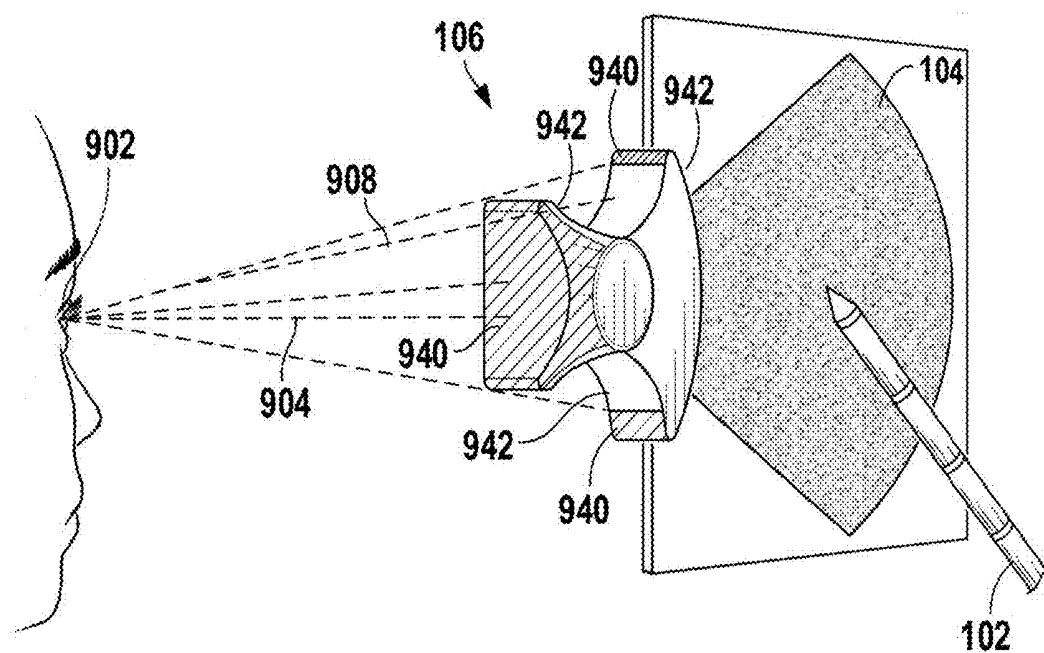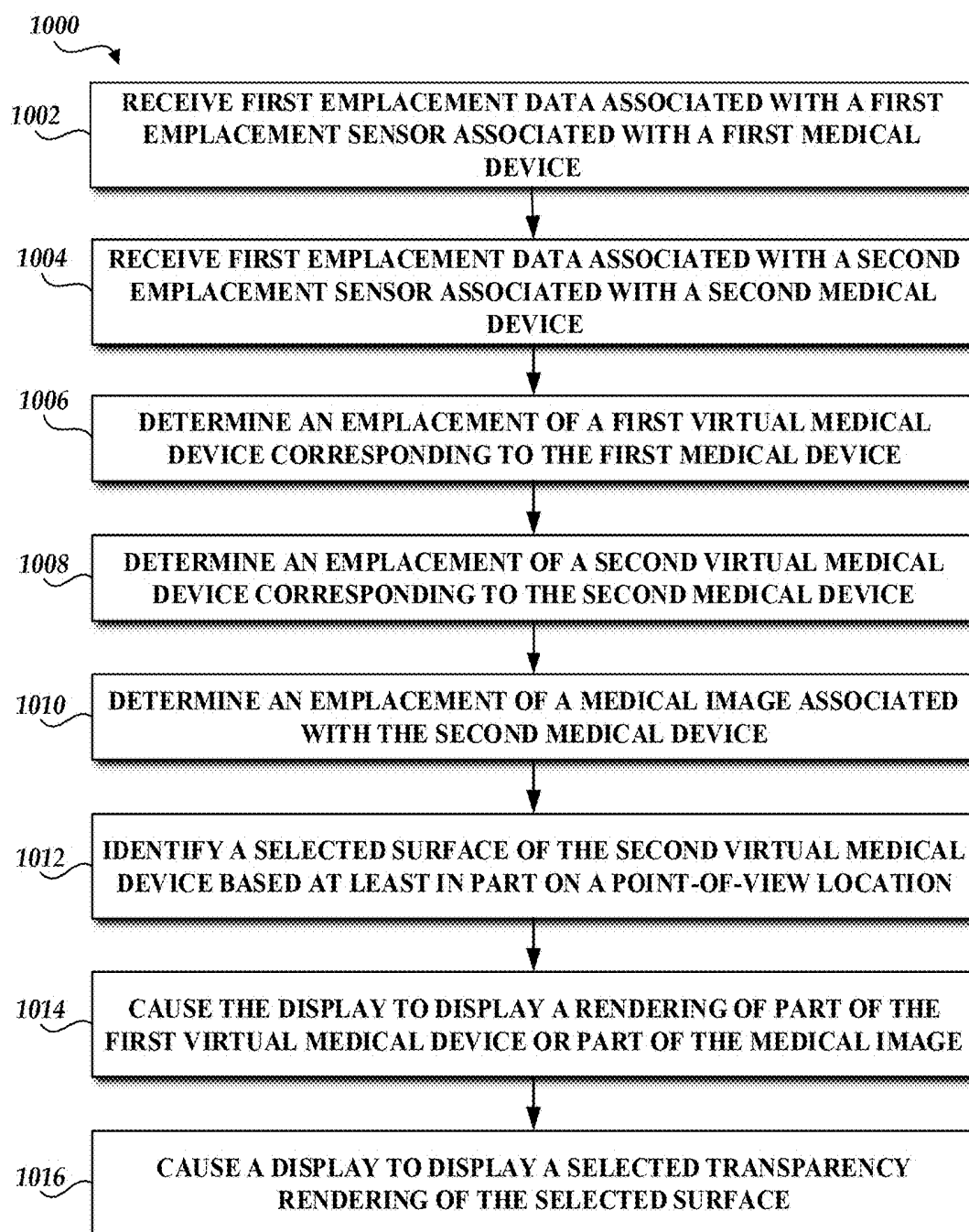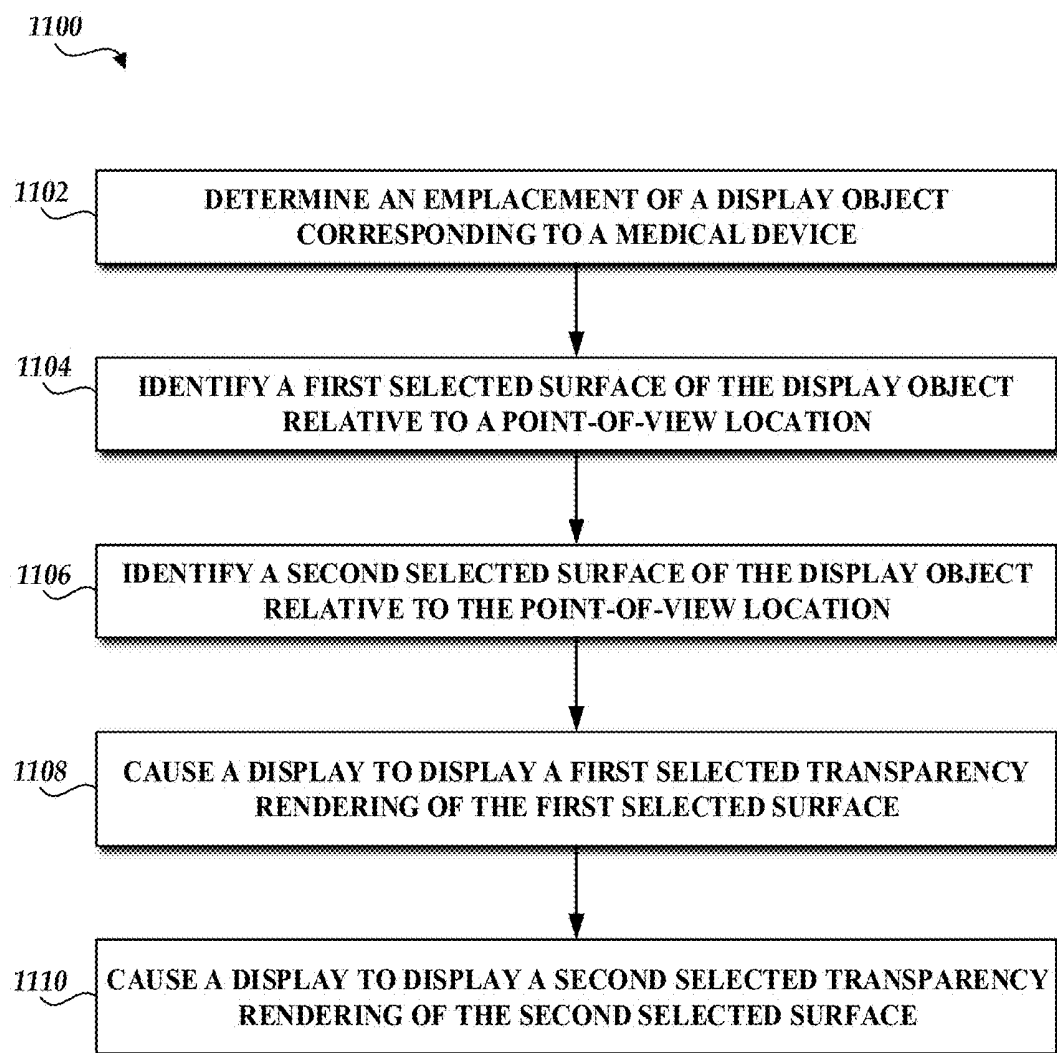
BRIEF DESCRIPTION OF THE DRAWINGS

[0003] FIG. 1A is a diagram illustrating an embodiment of an environment for image-guided medical procedures.
[0004] FIG. 1B is a diagram illustrating embodiments of coordinate systems that can be used by the system.
[0005] FIG. 2 illustrates an embodiment of a rendering of medical display objects on a display, as well as an embodiment of an environment for a medical device procedure.
[0006] FIG. 3 is a diagram illustrating an embodiment of a rendering of imaging guidance data in a 3D scene.
[0007] FIG. 4 is a diagram illustrating an embodiment of an example selective-transparency beginning-surface rendering of a virtual transducer.
[0008] FIG. 5 is a diagram illustrating an embodiment of an example selective-transparency ending-surface rendering of a virtual transducer.
[0009] FIG. 6 is a diagram illustrating an embodiment of an example selective-transparency beginning-surface and ending-surface rendering of a virtual transducer.
[0010] FIG. 7 is a diagram illustrating an embodiment of an example selective-transparency exterior surface rendering of a virtual transducer.
[0011] FIGS. 8A-8F are diagrams useful for illustrating differences between determining front-, back-, ending-, and beginning-surfaces.
[0012] FIGS. 9A-9D are diagrams useful for illustrating differences between determining front-, back-, ending-, and beginning-surfaces.
[0013] FIG. 10 is a flow diagram illustrative of an embodiment of a routine implemented by the system for providing improved perception of a virtual medical device in a virtual 3D scene for medical device navigation.
[0014] FIG. 11 is a flow diagram illustrative of an embodiment of a routine implemented by the system for providing improved perception of a display object in a virtual 3D scene for medical device navigation.

DETAILED DESCRIPTION

[0015] During image-guided medical procedures, displaying virtual medical devices that resemble real medical devices can help healthcare providers associate a virtual scene with the real world, and can provide more familiar guidance information to the healthcare provider, thereby further aiding the healthcare provider in the guidance task.
[0016] During these image-guided procedures, it can be important for a physician to understand spatial relationships between display objects, such as the relationships between virtual medical devices, medical images, or other display objects involved. Misinterpreting the relationships between the tools, or between the physician and a tool, can potentially lead to patient harm. Nonetheless, especially when multiple display objects are shown on a display, it can be easy for a physician to misinterpret or misunderstand the spatial relationships. These problems can be further exacerbated if one or more of the display objects overlaps on the display, as the spatial relationships become even more ambiguous.
[0017] In some implementations, the system disclosed herein provides improved perception of a display object in a virtual 3D scene for medical device navigation. For example, the system can use a selective-transparency rendering to display one or more objects in the scene. The selective-transparency rendering can be a selective-transparency surface rendering (e.g., selective-transparency beginning-surface rendering, selective-transparency ending-surface rendering, selective-transparency front-surface rendering, selective-transparency back-surface rendering), a selective-transparency object rendering (e.g., selective-transparency first object rendering, selective-transparency last object rendering, selective-transparency selected object rendering, etc.), etc.
[0018] The selective-transparency surface rendering can include a rendering of a selected surface at one or more transparency levels. For example, if the selected surface is a beginning-surface, in some cases, the system can render a display object such that, at each pixel, the nearest parts of that display object (relative to a point-of-view location) are shown at one or more transparency levels. Further, the system can omit other surfaces or portions of the display object. In other words, in certain embodiments, the system can render just those portions of the display object that both face the viewer and are unobstructed from the viewer by the object's shape (for example, the object's concavities).
[0019] In some cases, the system can display the selected surface of the display object at one or more transparency levels. The transparency levels can refer to how transparent an object or line of an object is to be drawn. For example, complete transparency or maximum transparency level can refer to an object not being visible, a higher transparency level can refer to lines of an object being faintly drawn (e.g., shown at 10-20% of the darkness of an opaque line), a low transparency level can refer to lines of an object that are drawn darker (e.g., shown at 70-80% of the darkness of an opaque line), and a lowest transparency level or opaque can refer to a solid line, such as a solid black line.
[0020] It will be understood that reference to displaying surfaces or objects at different transparency levels can refer to drawing portions of the objects with opaque lines or no transparency, drawing portions of the object with semi-transparent lines (higher or lower levels of transparency) and/or drawing portions of the object completely transparent. For example, the display object can be rendered such that portions of the selected surface that are closer to an edge of the object are displayed more opaquely than portions of the selected surface that are farther away from the edge. As

another example, the display object can be rendered such that only edges of the selected surface are displayed or are displayed more opaquely than other portions of the selected surface. In this way, other display objects that are potentially behind the display object would be visible through the display object, thereby clearly conveying the spatial relationships of the display objects.

[0021] In some cases, it can be advantageous to additionally or alternatively display subtle, unobtrusive but useful details about the most distant surface of the display object. For example, the system can identify and display the most distant (or "ending") surfaces or portions of the display object. In some cases, the system can render the beginning-surface of the display object, and can render the ending-surface with diminished opacity as compared to the beginning-surface, or with reduced contrast or modified color. By providing the viewer with an indication as to the closest portion (beginning-surface) and/or farthest portion (ending-surface) of the display object, the system can display the display object with improved perception. Likewise, by utilizing combinations of opacity, hue, saturation, and brightness for the beginning- and ending-surfaces, the system can further improve the perception of the display object, especially as compared with a display object that is displayed with a single transparency level.

Overview

[0022] Implementations disclosed herein provide systems, methods, and apparatus for displaying medical images, such as, but not limited to ultrasound, CT, and/or MRI images, facilitating medical device insertion into tissue by an operator. Certain embodiments pertain to a free-hand medical device guidance system. The system can provide the health-care provider manual control over the medical device, while making the spatial relationships between the target, medical device and medical image (also referred to as an image slice or rendered medical image), or image area corresponding to the medical image (also referred to as an image slice area or scan area), more intuitive via a visual display. Using this visual feedback, the operator can adjust the medical device's position, orientation, or trajectory. Certain of the contemplated embodiments can be used in conjunction with systems described in greater detail in U.S. patent application Ser. No. 13/014,587, filed Jan. 26, 2011, entitled "SYSTEMS, METHODS, APPARATUSES, AND COMPUTER-READABLE MEDIA FOR IMAGE MANAGEMENT IN IMAGE-GUIDED MEDICAL PROCEDURES." U.S. patent application Ser. No. 13/753,274, filed Jan. 29, 2013, entitled "MULTIPLE MEDICAL DEVICE GUIDANCE" (the '274 Application), U.S. patent application Ser. No. 14/213,033, filed Mar. 14, 2014, entitled "MEDICAL DEVICE GUIDANCE," U.S. patent application Ser. No. 14/872,930, filed Oct. 1, 2015, entitled "AFFECTED REGION DISPLAY" (the '930 Application), U.S. patent application Ser. No. 15/199,630, filed Jun. 30, 2016, entitled "LOUPE DISPLAY," and U.S. patent application Ser. No. 15/415,398, filed Jun. 30, 2016, entitled "MEDICAL INSTRUMENT NAVIGATION," each of which is hereby incorporated by reference in its entirety.

[0023] Medical interventions typically involve using an instrument to insert into, resect, cauterize, staple, seal, or otherwise manipulate soft tissue and organs. A physician must take great care to minimize blood loss and minimize damage to ancillary tissue while performing these tissue-altering interventions. This is even more difficult with minimally-invasive surgeries, such as laparoscopic, endoscopic, and robotic surgeries. A physician may use ultrasound to image the internal structures of an organ before stapling, transecting, resecting, sealing, grasping, or inserting a medical device into tissue, helping her avoid critical structures such as blood vessels. However, even with ultrasound imaging, there is a significant possibility of inadvertent damage to surrounding tissue and blood vessels during these procedures. This is because it is not obvious in the externally displayed medical image where a given internal structure is located relative to the medical device.

[0024] The system can aid the healthcare provider in guiding one or more medical devices through or around tissue of the patient and/or placing the medical devices. The system can be used to aid in stapling, transecting, resecting, sealing, grasping and/or inserting a medical device into tissue. Additionally, the system can be used for treatment of tumors, fibroids, cysts, damaged blood vessels, or other damages to internal structures of a patient. The system can be used during open surgery, laparoscopic surgery, endoscopic procedures, robotic surgeries, biopsies, and/or interventional radiology procedures.

[0025] The system can be used in conjunction with live intraoperative ultrasound (U/S), pre-operative CT, or any cross-sectional medical imaging modality (for example MRI, OCT, etc.). In addition, the system can use a variety of techniques to determine the position and/or orientation of one or more medical devices. For example, the system can use the NDI Aurora magnetic system, NDI Polaris optical system, etc. In some embodiments, a position sensor can be embedded inside or affixed to each medical device, for example, at the tip, along the shaft, and/or on the handle. Sensors can be built into the medical devices or attached after manufacturing, as described in greater detail in U.S. application Ser. No. 14/212,184, filed Mar. 14, 2014, entitled "Sensor Mount," which is hereby incorporated herein in its entirety.

[0026] Each medical device can be associated with one or more sensors, which can continually, or repeatedly, report position and/or orientation, or a single sensor can be used for all the medical devices. In some embodiments, where one sensor is used, the healthcare provider can attach the sensor to the particular medical device that she is intentionally repositioning, and then, once she has placed that medical device, she can remove the sensor and attach it to the next medical device she is repositioning. In some embodiments, the medical devices can be manipulated by the healthcare provider. In certain embodiments, the system can be used with a robotic manipulator, where the robot controls the medical devices. In some embodiments, visually-detectable fiducials can be used to determine or correct position and/or orientation for one or more of the medical devices.

[0027] In some embodiments, the handles of medical devices can have push-button switches, to allow the user to select a medical device, indicate a tissue target, etc. The handle can also have an indicator light to indicate to the users which medical device is selected. Finally, the handle can have an encoder to detect how much length of electrode has been exposed by the user, and report this information to the guidance system and therapeutic generator.

3

Image Guidance Systems

[0028] FIG. 1A is a diagram illustrating an embodiment of an image guidance system 100 for image management in image-guided medical procedures. As illustrated, the system 100 can include, but is not limited to, a position sensing unit 130, one or more medical devices 140 or 145, an image guidance unit 150, an imaging unit 160, a display 170, a surgical or therapeutic system 180, a stand 172, or a surgical table 174. Any of the position sensing unit 130, image guidance unit 150, one or more medical devices 140 or 145, imaging unit 160, display 170, or surgical system 180 can be communicatively coupled to each other, including one-to-one, one-to-many, and many-to-many relationships.

[0029] The position sensing unit 130 can be configured to track medical devices 140 or 145 within a tracking area and can be used to determine an emplacement or pose of medical devices 140 or 145. The term emplacement as used herein is a broad term and may refer to, without limitation, position and/or orientation or any other appropriate location information. Similarly, the term pose as used herein is a broad term encompassing its plain and ordinary meaning and may refer to, without limitation, position and/or orientation or any other appropriate location information. In some cases, one or more reference room coordinate systems (as described herein with reference to FIG. 1B), can be tracked by the position sensing unit 130, and an emplacement of the surgical devices 140 or 145 can be determined with respect to the reference room coordinate system. The position sensing unit 130 can provide emplacement data to the image guidance unit 150.

[0030] The position sensing unit 130 can be implemented using one or more of various techniques. For example, a tracking unit can be mounted, affixed, or coupled in or on one or more medical devices 140 and 145, and the position sensing unit 130 can track the tracking units. In addition or alternatively, a position sensing unit 130 can be implemented as a tracking unit, and can be attached or affixed to either or both of the medical devices 140 and 145. The position sensing unit 130 can include one or more sensing devices (such as the HiBall tracking system, a GPS device, or signal emitting device) that allow for tracking of the emplacement of a tracking unit. The term tracking unit (also referred to as an emplacement sensor), as used herein, is a broad term encompassing its plain and ordinary meaning and includes without limitation all types of magnetic coils or other magnetic field sensing devices for use with magnetic trackers, fiducials or other optically detectable markers for use with optical trackers, such as those discussed herein. For example, FIG. 1A illustrates an example optical tracking unit 135, mounted on the display 170.

[0031] For example, the position sensing unit 130 can include a magnetic tracker, and tracking units, which can include one or more magnetic coils, can be mounted in or on, or coupled to the medical devices 140 and 145. The position sensing unit 130 can include an electromagnetic measurement system (for example, an NDI Aurora system) that uses sensor coils for tracking units attached to the first or second surgical devices 140 and 145.

[0032] In some implementations, the tracking units can be implemented using optical position sensing devices, such as the HiBall tracking system, and the position sensing unit 130 can form part of the HiBall tracking system. For example, the position sensing unit 130 can include an optical 3D tracking system using fiducials. One or more visually-detectable fiducials can be coupled to or otherwise associated with the medical devices 140 or 145. Such optical 3D tracking systems can include the NDI Polaris Spectra, Vicra, Certus, PhaseSpace IMPULSE, Vicon MX, InterSense IS-900, NaturalPoint OptiTrack, Polhemus FastTrak, IsoTrak, or Claron MicronTracker2. In addition or alternatively, the system can utilize one or more camera-based marker (or markerless) tracking systems or algorithms such as ArUco, AR Toolkit, Vuforia, Wikitude, SLAM, or the like.

[0033] Tracking units can additionally or alternatively include a GPS device or signal emitting device that allows for tracking of the emplacement of the tracking unit. In some embodiments, a signal emitting device might include a radio-frequency identifier (RFID). In such embodiments, the position sensing unit 130 can use the GPS coordinates of the tracking units or can, for example, triangulate the radio frequency signal being emitted by the RFID associated with tracking units. The tracking systems can also include one or more 3D mice.

[0034] In some implementations, the position sensing unit 130 can include an inertial 3D tracking system that includes a compass, accelerometer, tilt sensor, or gyro, such as the InterSense InertiaCube or a Nintendo Wii controller. For example, devices 140 and 145 can include or have coupled thereto one or more accelerometers, which can be used to estimate movement, position, or location of the devices. In some embodiments, the position sensing unit 130 can be an Ascension Flock of Birds, Nest of Birds, driveBAY, medSAFE, trakSTAR, miniBIRD, MotionSTAR, pciBIRD, or Calypso 2D Localization System and tracking units attached to the first or second medical devices 140 and 145 can be magnetic tracking coils.

[0035] The position sensing unit 130 can be located in various locations, such as on, beside, above, or below the table 174 or patient 176. For example, in embodiments where the position sensing unit 130 is a magnetic tracker, the position sensing unit 130 can be mounted on or below the table 174. Such an arrangement can be useful when the tracking volume of the position sensing unit 130 is dependent on the location of the position sensing unit 130, as with many magnetic trackers.

[0036] The medical devices 140 or 145 can include invasive medical devices that enter a part of the body. For example, the medical devices 140 and 145 can include, but are not limited to, one or more of a grasper, a stapler, a vessel sealer, an electrocautery device, a resecting device, a transecting device, a scalpel, a biopsy needle, an ablation needle, a surgical needle, a nerve-block needle, another needle, a catheter, a stent, a laparoscope or laparoscopic camera, implantable hardware, an ultrasound probe (for example, laparoscopic ultrasound probes that enter the patient, Transesophageal echocardiography (TEE), or an ultrasound transducer on the tip of a catheter, needle, or other medical device), or another invasive instrument. In addition or alternatively, the medical devices 140 and 145 can include one or more non-invasive medical devices that, in some cases, might not enter the body. For example, medical devices 140 or 145 can include, but are not limited to, one or more of an ultrasound transducer, ultrasound probe, or other external imaging device. The medical devices 140 and 145 include medical imaging devices that provide or aid in the selection of medical images for display.

[0037] Image guidance unit 150 can be used to produce images 125 that are displayed on display 170. For example, the image guidance unit 150 can receive, process, or combine emplacement data from the position sensing unit 130, information about and from multiple surgical systems 180, information about and from attached medical devices 140, 145 (and additional medical devices not shown), or other data and can cause the display 170 to display image guidance data. A healthcare provider can use this image guidance data to guide a procedure and improve patient care. The image guidance data can include one or more display objects or one or more image guidance cues. It will be understood that a display object as used herein is a broad term encompassing, without limitation, one or more portions of a virtual medical device or a medical image. Further, an image guidance cue can include one or more trajectory indicators, intersection indicators, plane indicators, or other data.

[0038] The medical image can include or be associated with imaging data obtained from one or both of medical devices 140 and 145, or one or more additional medical devices. For example, the medical image can include data from modalities such as a CT scan, MRI, open-magnet MRI, optical coherence tomography ("OCT"), positron emission tomography ("PET") scans, fluoroscopy, ultrasound, or other preoperative or intraoperative 2D or 3D anatomical imaging data.

[0039] The image guidance data, such as one or more display objects or image guidance cues, can be displayed concurrently or simultaneously. Reference to displaying objects "concurrently" or "simultaneously" is to be interpreted broadly and may refer to displaying objects in such a way that to a human observer the objects are visible at the same time.

[0040] In some cases, the system can include imaging unit 160, which can be an imaging unit that is additional or alternative to image guidance unit 150. For example, imaging unit 160 can be used to produce images that are displayed on a second display (not shown). For example, the imaging unit 160 can receive or process medical imaging data received from an imaging device. As a non-limiting example, the imaging unit 160 can be an ultrasound machine, and the second display can be a display associated with the ultrasound machine 160 that displays medical images obtained by the ultrasound machine 160. In addition, the medical device 145 can be implemented as a movable imaging device, such as an ultrasound transducer or ultrasound probe. In such examples, the movable imaging unit 145 can be connected to image guidance unit 150 or the imaging unit 160, and can be useful for allowing a user to indicate what portions of a first set of imaging data are to be displayed. For example, the movable imaging unit 145 can be an ultrasound transducer 145 or other medical device, and can be used by a user to indicate what portions of imaging data, such as a pre-operative CT scan, to show on a display 170 as image 125. The image guidance data displayed on display 170 and the imaging data displayed on the second display can be the same or different. In addition, the position sensing unit 130 can be part of any of the image guidance unit 150 or the imaging unit 160, or it can be separate.

[0041] The images 125 can be produced on the display 170 by the image guidance unit 150. The display 170 or screen can be implemented using a TV, computer screen, head-mounted display, projector, or the like. In the illustrated embodiment, the images 125 include a 2D viewing area 120 and a 3D viewing area 110. In the 2D viewing area 120, some image guidance data can be displayed as 2D objects. For instance, the 2D viewing area can include a 2D view of a medical image 122 (for example, an ultrasound slice), a 2D view of a medical device 124 (for example, a needle) intersecting the image plane, or one or more image guidance cues. It will be understood that some or all of the display objects in the 2D viewing area can be displayed as 3D objects.

[0042] In the 3D viewing area 110, at least some image guidance data can be displayed as 3D objects. For example, the 3D viewing area 110 can include a perspective view of each of the medical image 104, a first virtual medical device 102 corresponding to the first medical device 140, a second virtual medical device 106 corresponding to the second medical device 145, one or more trajectory guidance cues 108, a patient orientation indicator 112, or other image guidance data. It will be understood that any combination of the image guidance data can be displayed in the 2D view or 3D view as desired.

[0043] As a non-limiting example, if the first medical device 140 includes a needle and the second medical device 145 includes an ultrasound probe 145, then images 125 produced on display 170 can include images, or video, from the ultrasound probe, combined with display objects (such as virtual medical device 102 or 106) or image guidance cues (such as trajectory indicator 108). In addition or alternatively, if the first medical device 140 includes an ultrasound probe 140 and the second medical device 145 includes a laparoscopic camera 145, then images 125 produced on display 170 can include the video from the laparoscopic camera 145 combined with ultrasound data superimposed on the laparoscopic image. The system can additionally or alternatively process or display collected data, such as preoperative CT scans, X-Rays, MRIs, laser scanned 3D surfaces etc.

[0044] As noted above, images 125 can be generated based on live, intraoperative, or real-time data obtained using medical device 145, which can be coupled to imaging unit 160. The term real-time as used herein is a broad term and has its ordinary and customary meaning, including without limitation instantaneously or nearly instantaneously. The use of the term real-time can also mean that actions are performed or data is obtained with the intention to be used immediately, upon the next cycle of a system or control loop, or any other appropriate meaning. Additionally, as used herein, real-time data can be data that is obtained at a frequency that would allow a healthcare provider to meaningfully interact with the data during surgery. For example, in some embodiments, real-time data can be a medical image of a patient that is updated one time per second. In some embodiments, real-time data can be ultrasound data that is updated multiple times per second.

[0045] In some embodiments, the display 170 displays 3D images to a user, such as a healthcare provider. Stereoscopic 3D displays separate the imagery shown to each of the user's eyes. This can be accomplished by a stereoscopic display, a lenticular auto-stereoscopic display, a head-mounted display, or any other appropriate type of display. The display 170 can be an alternating row or alternating column display. Example alternating row displays include the Miracube G240S, as well as Zalman Trimon Monitors. Alternating column displays include devices manufactured by Sharp, as well as many "auto-stereoscopic" displays (for example,

Philips). In some embodiments, Sony Panasonic 3D passive displays and LG, Samsung, or Vizio 3D TVs can be used as well. Display **170** can also be a cathode ray tube. Cathode Ray Tube (CRT) based devices, can use temporal sequencing, showing imagery for the left and right eye in temporal sequential alternation. This method can also be used for projection-based devices, as well as by liquid crystal display (LCD) devices, light emitting diode (LED) devices, or organic LED (OLED) devices.

[0046] In certain embodiments, the display **170** can be a head-mounted display worn by the user in order to receive 3D images from the image guidance unit **150**. In such embodiments, a separate display, such as the pictured display **170**, can be omitted. The 3D graphics can be produced using underlying data models, stored in the image guidance unit **150** and projected onto one or more 2D planes in order to create left and right eye images for a head mount, lenticular, or other 3D display. The underlying 3D model can be updated based on the relative emplacements of the various devices **140** and **145**, as determined by the position sensing unit(s) **130**, or based on new data associated with the devices **140** and **145**. For example, if the second medical device **145** is an ultrasound probe, then the underlying data model can be updated to reflect the most recent medical image. If the first medical device **140** is a stapler, then the underlying model can be updated to reflect any changes related to the jaws, such as information regarding the likely affected anatomy region or angles of the jaws or transecting knife. Any appropriate 3D graphics processing can be used for rendering including processing based on OpenGL, Direct3D, Java 3D, etc. Whole, partial, or modified 3D graphics packages can also be used, such packages including 3DS Max, SolidWorks, Maya, Form Z, Cybermotion 3D, VTK, Slicer, or any others. In some embodiments, various parts of the needed rendering can occur on traditional or specialized graphics hardware. The rendering can also occur on the general CPU, on programmable hardware, on a separate processor, be distributed over multiple processors, over multiple dedicated graphics cards, or using any other appropriate combination of hardware or technique.

[0047] Images **125** can be produced based on intraoperative or real-time data obtained using first medical device **140**, which can be coupled to a surgical system **180**. In the illustrated embodiment of FIG. 1A, the surgical system **180** is shown as coupled to image guidance unit **150**. The coupling between the first surgical system **180** and image guidance unit **150** may not be present in all embodiments. In some embodiments, the coupling between first surgical system **180** and image guidance unit **150** can be included where information about first medical device **140** available to first surgical system **180** is useful for the processing performed by image guidance unit **150**. For example, in some embodiments, it can be useful to send one or more operating parameters of the medical device **140** to image guidance unit **150** so that image guidance unit **150** can show, highlight, outline or otherwise present an affected region of tissue which is located around a tip of the medical device. In other embodiments, the surgical system **180** is not coupled to the image guidance unit **150**. Example embodiments including images and graphics that can be displayed are included below.

[0048] One or more components, units, devices, or elements of various embodiments can be packaged or distributed as part of a kit. For example, in one embodiment, a medical device, one or more tracking units, 3D viewing glasses, or a portion of an ultrasound wand can form a kit. Other embodiments can have different elements or combinations of elements grouped or packaged together. Kits can be combined or distributed separately from or with the other portions of the system.

[0049] Although two medical devices (devices **140** and **145**) are shown in FIG. **1**, it will be understood that additional or fewer medical devices can be included in the system **100**. For example, additional or fewer medical devices can be tracked and associated data can be provided to the image guidance unit **150**.

[0050] There are numerous other possible embodiments of system **100**. For example, many of the depicted components can be joined together to form a single component and can be implemented in a single computer or machine. Further, additional position sensing units can be used in conjunction with position sensing unit **130** to track all relevant medical devices **140** and **145**, as discussed in more detail below. Additional imaging units **160** can be included, and combined imaging data from the multiple imaging units **160** can be processed by image guidance unit **150** and shown on display **170**. Additionally, two or more surgical systems **180** can also be included. Additionally, one will readily recognize that there are numerous other examples of image guidance systems which can use, incorporate, support, or provide for the techniques, methods, processes, and systems described herein.

Coordinate Systems

[0051] FIG. 1B is a diagram illustrating embodiments of coordinate systems that can be used by the system **100**. The system **100** can utilize one or more coordinate systems to track and display the various image guidance data on the display **170**. In some cases, one or more coordinate systems can be associated with real objects. For example, the coordinate systems can include a table **174** coordinate system **175**, a first medical device **140** coordinate system **142**, a second medical device **145** coordinate system **146**, a patient **176** coordinate system **178**, or a room coordinate system **115**. In some cases, one or more coordinate systems can be associated with virtual or other objects. For example, the coordinate systems can include a 3D scene coordinate system **182**, a first virtual medical device coordinate system **184**, a second virtual medical device coordinate system **188**, or a medical image coordinate system **186**. In addition or alternatively, the coordinate systems can include a display coordinate system **192**, or corresponding display coordinate systems **194**, **196**, or **198** for the first or second virtual medical device or medical image.

[0052] As a non-limiting example, the position sensing unit **130** can determine an emplacement of one or more real objects (for example, first medical device **140**, second medical device **145**, or the like) relative to one or more of the coordinate systems. For example, in some embodiments, an emplacement can be determined relative to the table coordinate system **175**, which can be used by a magnetic tracker (not shown) tracking objects within a magnetic field volume, or to the optical tracker **135** coordinate system **136**, which can be used by an optical tracker **135** to track one or more objects.

[0053] In some cases, multiple coordinate systems can be utilized together. For example, a magnetic position sensing coordinate system **175** can be used in conjunction with

magnetic tracker tracking sensor coils within a position sensing region that are coupled to medical devices and an optical position sensing coordinate system **136** can be used in conjunction with an optical tracker **135** tracking a fiducial coupled to a head mounted display (HMD) or a user, or to an optical tracker analyzing an image captured by an image sensor. It will be understood that any combination of the tracker systems or coordinate systems can be used as desired. For example, the position sensing unit **130** can utilize the same coordinate system to track the tracking sensors associated with each of the one or more medical devices or tracking sensors associated with a user or HMD. Alternatively, a coordinate system, such as coordinate systems **142** and **146**, can be used for each tracking sensor, or any combination thereof.

[0054] Room coordinate system **115** can be used to determine the emplacement of objects within a room, such as an operating room. For example, the room coordinate system **115** can be used to determine or identify the relative emplacement of the position sensing unit **130**, medical devices **140**, **145**, tracking sensors, user, display **170**, etc. relative to each other within a room.

[0055] A 3D scene coordinate system **182**, which may also be referred to as a 3D volume or scene graph coordinate system, can be used to determine the emplacement of display objects within a virtual 3D scene. In some cases, the 3D scene coordinate system **182** can identify the relative emplacement of virtual objects within the 3D scene. In certain embodiments, the virtual objects can correspond to real objects, such as to medical devices **140**, **145** or to computer-generated objects, such as such as trajectory cues **108**. In certain embodiments, display objects can correspond to real objects, virtual objects, or computer generated objects. In addition or alternatively, the 3D scene coordinate system **182** can be used to determine an emplacement of, register an emplacement of, or model one, multiple, or all of the objects in the room, such as the patient, the operating table, the physician, the display, or the like. In some cases, the display **170** can display a subset of the data associated with the 3D scene coordinate system **182**. In some cases, one or more portions of the image guidance data can have an associated coordinate system.

[0056] A display coordinate system **192** can be used to determine the emplacement of display objects for display on the display **170**. For example, the display coordinate system **192** can be used to determine the emplacement of virtual medical devices, medical images, image guidance cues, or the like, within a display **170**. In some embodiments, the display coordinate system **192** can be used to determine how the objects within the 3D scene are to be displayed on the display. For example, the display coordinate system **192** can be used to determine a point-of-view location, or eye point, relative to the 3D scene (or 3D volume coordinate system **182**) or scene graph for viewing the contents of the 3D scene. As mentioned above, multiple display coordinate systems **192** can be used. For example, left-eye, right-eye, or center-eye display coordinate systems can be used to display different perspective of the display objects within a 3D scene, such as when a 3D display or a head-mounted display (HMD) is being used.

[0057] A medical image coordinate system **196** can be used in conjunction with medical images used or processed by the system. As described previously, the medical images can be ultrasound images, CT image, MRI, images, etc. The images can be different sizes or shapes. For example, one ultrasound can output an image having one size and shape while a different ultrasound can output an image having a different size or shape. Similarly, CT, MRI, and ultrasound images may have different sizes and shapes. Accordingly, the medical image coordinate system **196** can be used to identify the particular size and shape of the medical image being used or processed by the system **100**.

[0058] It will be understood that fewer, more, or different coordinate systems can be used as desired. For example, in some embodiments, the 3D scene coordinate system **182** can be omitted or combined with display coordinate system **192** or the table coordinate system **175**. Furthermore, in some cases, one or more tracking sensor coordinate systems, medical device coordinate systems **146**, **142**, virtual medical device coordinate systems **184**, **194**, **188**, **198**, or other objects etc., can have their own coordinate system. The coordinate systems for the tracking sensors, medical devices, or virtual medical devices can be used to identify the dimensions of the sensor/device/display object and relationship of the sensor/device/display object to another sensor/device/display object or other coordinate systems. For example, a medical device coordinate system (or virtual medical device coordinate system) can identify the dimensions of a corresponding medical device or virtual medical device, as well as the emplacement of a tracking sensor relative to the medical device (or vice versa). Similarly, a medical imaging device coordinate system can identify the dimensions of the corresponding medical imaging device (or virtual medical imaging device) or an emplacement of a medical image relative to the medical imaging device (non-limiting example: the emplacement of an ultrasound image relative to the corresponding ultrasound transducer), or vice versa. The system **100** can use various coordinate systems to determine the emplacement of a portion or the entire object with respect to each other and with respect to the other coordinate systems.

[0059] The system **100** can use the various coordinate systems to determine emplacement of objects relative to each other and determine how to display the display objects on a display, such as the display **170**.

[0060] As a non-limiting example, the second medical device **145** can include an ultrasound transducer. To display a virtual rendering **106** of an ultrasound transducer **145** and a virtual rendering **104** of an ultrasound image on the display **170**, the system **100** can determine the emplacement of a magnetic tracking sensor coupled to the ultrasound transducer **145** within a magnetic position sensing coordinate system **175**. Using a magnetic tracking sensor coordinate system **175**, the system **100** can determine the location of each portion of the magnetic tracking sensor within the magnetic position sensing coordinate system **175**. The system **100** can also determine the emplacement of each portion the ultrasound transducer **145** within the magnetic position sensing coordinate system by mapping the ultrasound transducer coordinate system **146** to the magnetic tracking sensor coordinate system **175** (or vice versa).

[0061] In addition, the system **100** can map each portion of the ultrasound image corresponding to the ultrasound transducer **145** to the magnetic position sensing coordinate system **175** by mapping an ultrasound image coordinate system to the ultrasound transducer coordinate system **146** or the magnetic tracking sensor coordinate system **175**.

[0062] To display the virtual ultrasound transducer **106** and virtual ultrasound image slice **104**, the system **100** can map the various objects from the magnetic position sensing coordinate system **175** to a room coordinate system **115**, which can identify the relative emplacement of the coordinate system **175** to a display **170**. The system can then map data to the 3D scene coordinate system **182** or the display coordinate system **192**. For 3D viewing, the system **100** can map the objects to multiple display coordinate systems **192**, such as left-eye or right-eye coordinate systems.

[0063] With continued reference to the non-limiting example, the system **100** can determine an emplacement of an optical tracking sensor corresponding to a user within an optical position sensing coordinate system **136**. The emplacement of the optical tracking sensor within the optical position sensing coordinate system **136** can be mapped to the room coordinate system **115**, the 3D scene coordinate system **182**, or the display coordinate systems **192** for display. In this way the system **100** can determine the emplacement of the ultrasound transducer **145** and ultrasound image slice relative to the user and display a virtual rendering **106** of the ultrasound transducer and a virtual rendering **104** of the ultrasound image slice within the 3D scene relative to the determined emplacement of a user.

[0064] To display the virtual ultrasound transducer **106** and virtual ultrasound image slice **104**, the system **100** can map the various objects from the magnetic position sensing coordinate system **175** to a room coordinate system **115**, which can identify the relative emplacement of the coordinate system **175** to a display **170**. The system can then map data to the 3D scene coordinate system **182** or the display coordinate system **192**. For 3D viewing, the system **100** can map the objects to multiple display coordinate systems, such as left-eye or right-eye coordinate systems.

[0065] Although the non-limiting examples have been described as mapping the various objects and coordinate systems, to a coordinate system **175**, the room coordinate system **115**, the 3D scene coordinate system **184**, or to display coordinate systems **192**, it will be understood that one or more of the objects or coordinate systems can be mapped directly or indirectly to any other coordinate system. For example, the medical device image can be mapped directly to a left-eye display coordinate system, etc. Thus, any of the real or virtual objects described herein may be represented, detected, or imaged in any coordinate system, and conversion between the various coordinate systems can be performed in components of the system such as image guidance unit **150**, position sensing unit **130**, an HMD, or other components.

[0066] Furthermore, it will be understood that once the system **100** determines an emplacement of a medical device in one coordinate system, such as a coordinate system **175**, the system **100** can determine the emplacement of a corresponding virtual medical device in a different coordinate system, such as the 3D scene coordinate system **182** or the display coordinate system **192**, by mapping the coordinates of the first coordinate system to the coordinates of the second coordinate system, or vice versa. Accordingly, references made herein to determining an emplacement of the medical device can also refer to determining an emplacement of a virtual medical device corresponding to the medical device, or vice versa. Similarly, references made herein to determining an emplacement of a display object (non-limiting example: medical image) relative to the medi-

cal device can also refer to determining the emplacement of the display object relative to a corresponding virtual medical device.

Depicting Medical Devices

[0067] It can often be difficult to discern the content of a 3D scene from a 2D depiction of it, or even from a 3D depiction of it. Therefore, various embodiments herein provide image guidance that can help the healthcare provider better understand the scene and relative emplacements or poses of object in the scene, thereby providing improved image guidance.

[0068] FIG. **2** illustrates an embodiment of a rendering of medical display objects on a display **170**, as well as an embodiment of an environment **200** for a medical device procedure. As illustrated, the environment **200** includes a patient **176**, a first medical device **140**, and a second medical device **145**.

[0069] As described herein, image guidance data (for example, display objects **102**, **104**, or **106**, and image guidance cues **112**) displayed in the 3D scene **110** can correspond to one or more real-world objects of the surgical environment **200**. For example, display object **102** can correspond to the first medical device **140**, display object **106** can correspond to the second medical device **145**, and display object **104** can correspond to a medical image associated with the second medical device **145**.

[0070] In some cases, the display **170** can display the 3D scene **110** as if the surgical environment **200** is observed from a particular point-of-view location or viewpoint. The point-of-view location can refer to the location from which a virtual 3D space is viewed and can be any location as desired. In other words, if the display **170** is considered a window into the virtual 3D space, the point-of-view location can be the location of the window with respect to the objects in the virtual 3D space.

[0071] In some embodiments, as described in greater detail in U.S. patent application Ser. No. 14/212,933, filed Mar. 14, 2014, entitled MEDICAL DEVICE GUIDANCE (the '933 Application), incorporated herein by reference in its entirety, the point-of-view location can be a fixed location, such as in front of the display, a predetermined distance/angle from the screen **220** or stand **170**, or a location configured by the user. Alternatively, the point-of-view location can be dynamic. For example, point-of-view location can be based at least in part on an emplacement of a real-world object, such as a medical device, the position sensing unit, or a head-mounted display, or the point-of-view location can be based on an actual, expected, or desired location of a user. For example, the system can track a user in real-time and determine the point-of-view location based at least in part on the tracked location of the user.

[0072] One or more of the display objects in the 3D scene **110** can be implemented as a virtual medical device (sometimes referred to as an avatar). For example, a virtual medical device displayed in display **170** can resemble the real medical device to which it corresponds. Some models of medical devices have markings such as bands around the shaft to indicate distance along the shaft. Healthcare providers performing medical device procedures are often familiar with these markings and can use them to help understand the spatial relationship between the medical device and anatomy. The make and model of a medical device can be known to the image guidance system **100**, and

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a virtual medical device displayed in display **170** can resemble the real medical device to which it corresponds. For example, the virtual medical device **102** can resemble the real medical device **140**. Similarly, the virtual medical device **106** can resemble the real medical device **145**. Accordingly, it will be understood that the terms medical device and virtual medical device can sometimes be used interchangeably, as they can generally relate to the same object. That is, the medical device relates to the object in the real world and virtual medical device relates to a representation of the object, such as an avatar, in virtual space.

[0073] By displaying a virtual medical device that resembles a real medical device, the system can advantageously aid healthcare providers in associating the image guidance data with the real world. Furthermore, the more the healthcare provider is familiar with the guidance information, the more he or she is aided in the guidance task. For example, the healthcare provider can see the familiar markings on the medical device **102** being displayed on the display **170** and therefore be familiar with the distance and relative placement of the displayed medical device **102** with respect to other data, such as tissue seen in the medical image **104**. This knowledge of relative placement of items being displayed can help the healthcare provider move a real medical device into place.

[0074] The features of the real medical device that can be rendered in the 3D scene **110** (for example, as the virtual medical device) include, but are not limited to, the overall shape (for example, diameter, angles, cross sectional shape, curvature, etc.), color, distance markers, angle of the jaws, visuals or echogenic fiducial markers, the state of deployable elements such as tines, paddles, anchors, resection loops, stiffening or steerable sleeves, temperature, radiation, light or magnetic field sensors, lens, waveguides, fluid transfer channels, and the like. The type of medical device being used can be an input into the image guidance system **100**. For example, it can be a user input to the system or can be determined by the system. For instance, the medical device type can be detected by a camera or other device, can be received as data from an attached medical device, such as surgical system **180** in FIG. **1**, or the information can be received in any other appropriate manner. Alternatively, the type of medical device can be can be a system default.

[0075] Consider an embodiment in which the virtual medical device **102** in the display **170** is a virtual stapler depicting the portion of a stapler **140** that will perform the stapling. The displayed virtual medical device can include a joint member, a first limb member, a second limb member, or more limb members. In some cases, one or more coordinate systems can be assigned to each of the joint member, a first limb member, a second limb member, and any additional limb members. Further, the same or different tracking sensors or tracking methods can be applied to each. If the display **170** also includes ultrasound data, then the doctor can find the tissue she wishes to staple by moving the ultrasound probe **145** until she identifies the target tissue. In various embodiments, she will be able to see the displayed ultrasound data **104** and its location relative to the displayed medical device **102**. She can then direct the medical device **140** until she sees, on display **170**, that an effective region of operation of the virtual medical device **102** encompasses a region of the tissue likely to be stapled in the medical image.

Thus, when she activates the stapler, she can have a higher degree of confidence that she will staple the target portion of the tissue.

[0076] As another example, consider the physical markings that can be on the instruments themselves. These markings can help orient a healthcare provider during use of the instrument. In some embodiments, the image guidance unit can represent these markings in the images displayed in the display. For example, certain ultrasound transducers are built with an orientation mark (for example, a small bump) on one side of the transducing array. That mark can also be shown in the medical image on the scanner's display, to help the healthcare provider understand where the scanned anatomical structures shown on screen are located under the transducer, inside the patient.

[0077] As described herein, the image guidance data can be displayed in the virtual 3D space **110**, with the screen **170** acting as a window into the virtual 3D space. Furthermore, the emplacement of a virtual medical device within the virtual 3D space **110** can match or correspond to the emplacement of a corresponding real medical device. For example, if the real medical device **140** is moved to the right with respect to a point-of-view location, the virtual medical device **102** can also move to the right in the display **170**. Similarly, if the real medical device **140** is rotated or oriented such that its tip is pointing away from the point-of-view location, the virtual medical device **102** can likewise show the change in orientation. For example, the display **170** can show the tip of the virtual medical device **102** in the background and the other end of the virtual medical device **102** in the foreground, such that the tip of the virtual medical device **102** is pointing away from the screen **170**. Similarly, emplacement of the second virtual medical device **106** or the medical image **104** within the virtual 3D space **110** can match or correspond to the emplacement of the second real medical device **145**.

[0078] Once tracked and displayed, a healthcare provider is able to see image guidance data on display **170** that will allow her to know the relative pose, location, or emplacement of the tracked instrument(s) with respect to one another or with respect to imaging data and will be able to see, on display **170**, the features of the instrument rendered in the scene.

[0079] With continued reference to FIG. **2**, in some embodiments, the image guidance system can cause the display to concurrently display an additional 2D view **122** of the medical image, simultaneous to the 3D depiction **104**, so that the medical image is always visible, regardless of the emplacement in which the healthcare provider holds the ultrasound transducer **145**. The 2D view **122** of the medical data can be similar to what a healthcare provider is accustomed to seeing with traditional medical displays, such as ultrasound displays. This can be useful by presenting to the healthcare provider the imaging to which she is accustomed and allows a healthcare provider to see the medical data regardless of the then-current emplacement of the imaging device with respect to the user.

[0080] In some embodiments, the 2D view **122** of the medical image is depicted in the upper right corner of the display **170**, although it can be placed in any location. In some embodiments, the guidance system can automatically or continually choose a corner in which to render the 2D view **122** of the medical image, for example, based on the position of the medical devices in the rendered scene. For

example, in FIG. **2**, the needle **140** can be held in the healthcare provider's right hand and the needle's shaft can be to the right of the 3D view of the medical image. In this example, the 2D view **202** of the medical image is in the upper right corner of display **170** so that it does not cover any of the 3D features of the 3D scene **110** and the 3D scene **110** does not cover any of the features of the 2D medical image **122**. However, in some cases, to prevent the 2D view **122** from covering or overlapping with some of the image guidance data, the system can automatically move the 2D view **122** to a corner that would not otherwise be occupied by graphics or data.

[0081] The system can attempt to avoid having the 2D view **122** of the medical image quickly move among corners of the display in order to avoid overlapping with graphics and data in the display. For example, a function f can be used to determine which corner is most suitable for the 2D medical image to be drawn in. The inputs to f can include the locations, in the screen coordinate system, of the displayed medical device tip, the corners of the 3D view of the medical image, etc. In some embodiments, f's output for any given point in time is independent of f's output in the previous frames, which can cause the medical image to move among corners of the display rapidly. In some embodiments, the image guidance system will filter f's output over time. For example, the output of a filter g, for any given frame, could be the corner, which has been output by f the most number of times over the last n frames, possibly weighting the most recent values for f most heavily. The output of the filter g can be used to determine in which corner of display **170** to display the 2D medical image and the temporal filtering provided by g can allow the 2D view **122** of the medical image display to jump less frequently, moving more smoothly among the corners of the display **170**.

[0082] In some embodiments, other appropriate virtual information or image guidance cues can be overlaid on the 2D view **122** of the medical image as well as the 3D view **204**. Examples include: orientation indicator **214**, a portion of the virtual medical device **124**, an indication of the distance between the medical device's tip (for example, the tip of the first limb member or the tip of the second limb member) and the point in the plane of the medical image that is closest to the medical device tip, an affected area (for example, a cross section or outline of the affected region projected on the ultrasound slice), or intersection indicators (for example, a point, box, outline, etc.) indicating an intersection between one or more axes or trajectories of a display object and a plane-of-interest (for example, a medical image plane, a medical device plane, etc.).

[0083] In some embodiments, the image guidance system can display a symbolic 3D representation of an orientation mark **214** both next to the motion-tracked ultrasound slice **104** (for example, moving with the displayed ultrasound slice) and next to the 2D view **120** of the ultrasound slice **122**. An example of this orientation mark is displayed in FIG. **2**, where a small rectilinear volume **214** is shown both in proximity to the ultrasound slice displayed in the 3D view and the ultrasound slice displayed in a 2D view. In some embodiments, the orientation mark **214** corresponds to a feature, such as a physical marking, of the ultrasound probe. In some embodiments, the orientation mark **214** is displayed to provide assistance in associating the 3D view and the 2D view.

[0084] It will be understood that a medical image can correspond to image data received from an imaging device, such as an ultrasound transducer. In some embodiments, the image data can correspond to a cross-section of tissue having a certain thickness. In some instances, the imaging device can compact the image data, or treat the image data as 2D data, such that there is no perceived thickness. In certain embodiments, when the medical image is displayed in a 3D view, the system can treat the medical image as a 2D or quasi 2D object. In such embodiments, the system can cause the medical image to have little to no perceptible thickness. Accordingly, in certain embodiments, when the medical image is oriented orthogonally or perpendicularly with respect to the point-of-view location, the system can cause the display to display nothing or a line having a relatively small thickness, such as a few pixels, etc. In some cases, the number of pixels used to display the relatively small thickness of the medical image can be a function of the size of the display. For example, more pixels can be used for a larger display and fewer pixels can be used for a smaller display, etc.

[0085] Some embodiments can track and display other types of instruments and their features. For example, a healthcare provider may want to track one or more of a stapler, vessel sealer, grasper, scalpel, a biopsy, a cauterizer (including an electrocauterizer and Bovies), forceps, cutting loops on hysteroscopes, harmonic shears, lasers (including CO_2 lasers), etc. For example, in various embodiments, the following devices can be tracked and various aspects of their design displayed on display **170**: Olympus™ OES Pro Hystero-Resectoscope, SonoSurg Ultrasonic Surgical System Olympus™ GF-UC 160 Endoscope Wallus™ Embryo Transfer Catheter AngioDynamics NanoKnife™, Vena-Cure™ laser, StarBurst, Uniblade, Habib™, Resector Bovie™ Electrodes, Covidien Evident™, Cool-Tip™ Ablation Antennas, Opti4™ Electrodes Microsulis MEA (microwave endometrial ablation), Acculis Halt™ Medical System Optimed BigLumen Aspiration Catheter Optimed Optipure Stent Central venous catheterization introducer medical device (such as those made by Bard and Arrow).

[0086] Furthermore, it will be understood that other image guidance cues can be generated and displayed on the display as described in greater detail in the '274 Application, previously incorporated herein by reference. For example, the system **100** can generate or display graphical indicators that help indicate the spatial relationship between a medical device and a medical image plane (for example, graphical image plane indicators) or other plane (for example, graphical plane indicators), indicators to indicate the relative positions of the medical device(s) and medical image(s), features of interest, annotations, plane indicators, plane intersection indicators, other graphical indicators, approximate medical device location indicators, etc. As described in greater detail above and in the '274 Application, the various image guidance cues can be generated based at least in part on the emplacement information of the medical devices used with the system **100**.

[0087] Although two virtual medical devices **102, 106** are displayed, it will be understood that fewer or more medical devices can be tracked and displayed concurrently, or simultaneously, on screen **170**, as described in greater detail in the '274 Application, previously incorporated by reference. In some instances, a virtual medical device can sometimes be referred to as virtual surgical instrument, surgical instru-

ment, rendered surgical instrument, rendered medical device, avatar, rendered avatar, virtual avatar, or the like.

Opaque Display Object

[0088] As described herein, a 3D scene on a display **170** can include image guidance data, such as a first display object **102** and a second display object **106**. In instances where the second display object **106** is opaque, if a portion of the second display object **106** overlaps or occludes a portion of the first display object **102** (for example, the portions are co-located on the display **170** or share one or more of the same display pixels), then a viewer of the display **170** may not be able to see the covered portion of the first display object **102**. An example of this occlusion is illustrated in FIG. **3**.

[0089] FIG. **3** is a diagram illustrating an embodiment of a rendering of imaging guidance data in a 3D scene, including medical display objects **102**, **104**, **106** and image guidance cues **112**. In this example, display object **102** is a first virtual medical device **102** that corresponds to a real medical needle, display object **106** is a second virtual medical device **106** that corresponds to a real ultrasound transducer, and display object **104** is a medical image that corresponds to imaging data obtained from the real ultrasound transducer.

[0090] In FIG. **3**, the relationships between the virtual medical devices **102** and **106** and the medical image **104** can be described as the virtual ultrasound transducer **106** being in front of both the medical image **104** and the virtual needle **104** relative to a point-of-view location. In other words, the virtual ultrasound transducer **106** is closer to the point-of-view location than the medical image **104** and the virtual needle **104** are. In addition, the relationships between the virtual ultrasound transducer **106** and the image guidance cues **112** can be described as the virtual ultrasound transducer **106** being in front the image guidance cues **112**.

[0091] However, in the illustrated example, the opaquely drawn virtual ultrasound transducer **106** occludes a portion of the medical image **104**, as well as the virtual needle **102** and some of the image guidance cues **112**. In addition, in FIG. **3** the virtual ultrasound transducer **106** blocks a user's view of how or where the virtual needle **102** interacts with the medical image **104**. Thus, although the spatial relationships between the display objects can aid a user in placing the medical devices relative to each other, the opaque nature of the virtual ultrasound transducer **106** can make it difficult to view the interaction of the virtual medical device **102** with the medical image **104** and the corresponding patient tissue. This may make it more difficult for a physician to make a diagnosis, target the virtual needle **102**, or administer treatment.

Beginning-Surface Rendering

[0092] FIG. **4** is a diagram illustrating an embodiment of a rendering of imaging guidance data. FIG. **4** illustrates the display objects **102**, **104**, **106** in the same or similar orientation as shown in FIG. **3**. In addition, the transducer **106** is illustrated with a selective-transparency surface rendering where the selected surface is a beginning-surface. In the illustrated embodiment, the beginning-surface includes those surfaces, edges, or other portions of the display object that are facing the point-of-view location and that are not occluded from view by the object's shape. In some cases, the system can render only the beginning-surface of a display

object, or can render the beginning-surface more opaquely than other portions of the display object. Imagine a plurality of imaginary view-rays extending from the point-of-view location to the object. The "beginning-surface" portion of that object can include the closest surfaces of the object along multiple or all of the view-rays. In other words, the beginning-surface can include an aggregation of the initial entry points (into the object) from multiple or all of the view-rays. Note that the beginning-surface portions of the transducer **106** in FIG. **4** include the same portions of the transducer **106** displayed in FIG. **3**.

[0093] In the illustrated embodiment of FIG. **4**, the selective-transparency beginning-surface rendering of the transducer **106** includes a display of the beginning-surface at varying transparency levels, with other portions of the transducer **106**, such as the ending-surface, back-surface, interior, etc. being omitted, not shown, or completely transparent. Although in the illustrated embodiment of FIG. **4**, only a beginning-surface is used for the selective-transparency rendering, it will be understood that multiple surfaces can be used as part of a selective-transparency rendering. For example, a selective-transparency surface rendering can include a beginning-surface, ending-surface, front-surface, rear-facing surface, side-facing surface, etc.

[0094] In the illustrated embodiment of FIG. **4**, the selective-transparency of the beginning-surface is implemented with the beginning-surface becoming less transparent as it gets closer to an edge. In this way, the medical image **104**, the virtual needle **102**, and the image guidance cues **112** are each visible through the transducer **106**, and the spatial relationships between each of the transducer **106**, needle **102**, medical image **104**, and image guidance cues **112** can be seen. In some embodiments, the selective-transparency beginning-surface rendering of the transducer can reduce the number of displayed lines and improve a user's ability to properly understand the correct orientation of the transducer **106**.

[0095] It will be understood that the selective-transparency of the selected surface can be implemented in a variety of ways. For example, the selective-transparency can include displaying the selected surface at the same transparency level, displaying edges of the surface opaquely or as solid or dashed lines (non-limiting example: wire frame) and the rest of the selected surface transparently or vice versa, displaying portions of the surface that are in front of another display object transparently or more transparently than portions of the selected surface that are not in front of another display object, etc.

[0096] Moreover, when a selective-transparency rendering includes multiple surfaces, each surface can be rendered using the same selective-transparency or different selective transparencies. For example, a beginning-surface can be rendered such that portions of the beginning-surface that are closer to an edge are rendered at a different opacity (for example, more or less opaquely) than portions that are farther away from an edge. As another example, an ending-surface can be rendered such that the entire surface has a single level of transparency or alternatively can be rendered such that only edges of the ending-surface are rendered opaquely, while other portions of the ending-surface are render with a diminished opacity or are completely transparent.

[0097] In addition or alternatively to a selective-transparency rendering of the transducer, the system can render one

or more selected surfaces of one or more other display objects. For example, it can be advantageous for the physician to see at least the beginning-surface of every display object. Accordingly, in some cases, each display object (or portion of each display object) that is in front of another display object (with respect to the point-of-view location) can be rendered with a selective-transparency beginning-surface rendering. For instance, referring to the illustrated embodiment of FIG. **4**, a portion of the virtual needle **102** overlaps with a portion of the medical image **104**. In some cases, at least one of the beginning-surfaces of the virtual needle **102** or the medical image **104** can be displayed using a selective-transparency beginning-surface rendering such that each beginning-surface portion of every display object is visible to the physician. Furthermore, in some embodiments, all display objects, or a subset thereof, can be displayed using a selective-transparency rendering.

[0098] Furthermore, as described herein, the selected surfaces can be rendered selectively transparent in a variety of ways. For example, the system can render portions of the selected surface of a display object that overlap with other display objects transparently or more transparently than non-overlapping portions of the display object, which can be rendered opaquely (for example, like the transducer **106** as illustrated in FIG. **3**). In certain embodiments, the non-overlapping portions of the display object can be displayed at one or more different transparency levels similar to the overlapping portions of the selected surface. In some cases, if more than two display objects (or other image guidance data) are overlapping at the same location (for example, the same pixel on the display **170**), then two or more of the overlapping display objects or portions thereof can be displayed using a selective-transparency rendering. For example, the closest display object or portion thereof (relative to the point-of-view location) can be displayed using a selective-transparency beginning-surface rendering. In addition, the second closest display object or portion thereof (relative to the point-of-view location) can be displayed using a selective-transparency beginning-surface rendering. In some cases, the selective-transparency of the first and second objects can be different. For example, the second object can use a different selective-transparency scheme, such as more transparent or a uniform transparency level. Rendering the multiple beginning-surface renderings at different transparency levels can allow each overlapping portion to be visible to the physician, and can allow the physician to understand the spatial relationships between each display object, or other image guidance data.

[0099] Although only the edges of the beginning-surface of the virtual ultrasound transducer **106** are clearly depicted in FIG. **4** (for example, for stylistic reasons due to the constraints of black/white illustration), it should be noted that other portions of the beginning-surface may be displayed, such as the continuous portions between the edges. In some embodiments, the rendering of the transducer **106** can include shading and other visualization techniques to illustrate contours of the transducer **106**. For example, in some cases, surface shading can be added to the beginning-surface rendering of the virtual ultrasound transducer **106**, which can make the virtual ultrasound transducer **106** more salient and easier to see, despite its transparency.

[0100] As described above, in some cases, rendering the selective-transparency beginning-surface rendering of the transducer **106** can include omitting, ignoring, rendering

transparently or otherwise not showing portions of the transducer **106** that are not part of the beginning-surface. For example, portions that are not part of the beginning-surface can include the ending-surfaces (described in more detail below), the back-surface, the interior, one or more sides, or the like. As a non-limiting example, to render the selective-transparency beginning-surface rendering of the transducer **106**, the system can determine the beginning-surface of the transducer and can determine the portions of the transducer that are not included in the beginning-surface. In some cases, the system can display the selective-transparency beginning-surface rendering of the transducer **106** and can discard, omit, or display transparently the portions of the transducer that are not included in the beginning-surface.

Ending-Surface Rendering

[0101] FIG. **5** is a diagram illustrating an embodiment of a rendering of imaging guidance data. FIG. **5** illustrates the display objects **102**, **104**, **106** in the same or similar orientation as shown in FIGS. **3** and **4**. In addition, the transducer **106** is illustrated with a selective-transparency surface rendering where the selected surface is an ending-surface. In the illustrated embodiment, the ending-surface includes those surfaces, edges, or other portions of the display object that are most distant from the point-of-view location. Imagine a plurality of imaginary view-rays extending from the point-of-view location to the object. The "ending-surface" portion of that object can include the furthest surfaces of the object along multiple or all of the view-rays. In other words, the ending-surface can include an aggregation of the final exit points (from the object) from multiple or all of the view-rays.

[0102] In some cases, the selective-transparency ending-surface rendering of the transducer **106** may cause the transducer **106** to appear flipped relative to its actual orientation. That is, the back portion of the transducer **106** may appear to some users to be closer to the point-of-view location than the front portion of the transducer **106**. However, as seen in FIG. **3**, the front portion the transducer **106** is actually closer to the point-of-view location than the back portion of the transducer **106**. This may confuse the brain's understanding of the transducer's **106** orientation, and thus the perceived spatial relationships between the image guidance data can be inaccurate. Nonetheless, in some cases, the selective-transparency ending-surface rendering of the transducer **106** can provide helpful information regarding the transducer **106**.

[0103] In the illustrated embodiment of FIG. **5**, the selective-transparency ending-surface rendering of the transducer **106** includes a display of the ending-surface at varying transparency levels, with other portions of the transducer **106**, such as the beginning-surface, front-surface, interior, etc. being omitted, not shown, or completely transparent. Although in the illustrated embodiment of FIG. **5**, only an ending-surface is used for the selective-transparency rendering, it will be understood that multiple surfaces can be used as part of a selective-transparency rendering. For example, a selective-transparency surface rendering can include a beginning-surface, ending-surface, front-surface, rear-surface, side-facing surface, etc.

[0104] In the illustrated embodiment of FIG. **5**, the selective-transparency of the ending-surface is implemented with the ending-surface becoming less transparent as it gets closer to an edge. In this way, the medical image **104**, the

virtual needle **102**, and the image guidance cues **112** are each visible through the transducer **106**, and the spatial relationships between each of the transducer **106**, needle **102**, medical image **104**, and image guidance cues **112** can be seen. In some embodiments, the selective-transparency ending-surface rendering of the transducer can reduce the number of displayed lines and improve a user's ability to properly understand the correct orientation of the transducer **106**.

[0105] It will be understood that the selective-transparency of the selected surface can be implemented in a variety of ways. For example, the selective-transparency can include displaying the selected surface at the same transparency level, displaying edges of the surface opaquely or as solid or dashed lines (non-limiting example: wire frame) and the rest of the selected surface transparently or vice versa, displaying portions of the surface that are in front of another display object transparently or more transparently than portions of the selected surface that are not in front of another display object, etc.

[0106] Moreover, when a selective-transparency rendering includes multiple surfaces, each surface can be rendered using the same selective-transparency or different selective transparencies. For example, an ending-surface can be rendered such that portions of the ending-surface that are closer to an edge are rendered at a different opacity (for example, more opaquely) than portions that are farther away from an edge. As another example, an ending-surface can be rendered such that the entire surface has a single level of transparency or alternatively can be rendered such that only edges of the ending-surface are rendered opaquely, while other portions of the ending-surface are render with a diminished opacity or are completely transparent.

[0107] In addition or alternatively to a selective-transparency rendering of the transducer, the system can render one or more selected surfaces of one or more other display objects. For example, it can be advantageous for the physician to see at least the ending-surface of every display object. Accordingly, in some cases, each display object (or portion of each display object) that is in front of another display object (with respect to the point-of-view location) can be rendered with a selective-transparency ending-surface rendering. For instance, referring to the illustrated embodiment of FIG. **5**, a portion of the virtual needle **102** overlaps with a portion of the medical image **104**. In some cases, at least one of the ending-surfaces of the virtual needle **102** or the medical image **104** can be displayed using a selective-transparency ending-surface rendering such that each ending-surface portion of every display object is visible to the physician. Furthermore, in some embodiments, all display objects, or a subset thereof, can be displayed using a selective-transparency rendering.

[0108] Furthermore, as described herein, the selected surfaces can be rendered selectively transparent in a variety of ways. For example, the system can render portions of the selected surface of a display object that overlap with other display objects transparently or more transparently than non-overlapping portions of the display object, which can be rendered opaquely (for example, like the transducer **106** as illustrated in FIG. **3**). In certain embodiments, the non-overlapping portions of the display object can be displayed at one or more different transparency levels similar to the overlapping portions of the selected surface. In some cases, if more than two display objects (or other image guidance

data) are overlapping at the same location (for example, the same pixel on the display **170**), then two or more of the overlapping display objects or portions thereof can be displayed using a selective-transparency rendering. For example, the closest display object or portion thereof (relative to the point-of-view location) can be displayed using a selective-transparency ending-surface rendering. In addition, the second closest display object or portion thereof (relative to the point-of-view location) can be displayed using a selective-transparency ending-surface rendering. In some cases, the selective-transparency of the using a selective-transparency ending-surface renderings of the first and second objects can be different. For example, the second object can use a different selective-transparency scheme, such as more transparent or a uniform transparency level. Rendering the multiple ending-surface renderings at different transparency levels can allow each overlapping portion to be visible to the physician, and can allow the physician to understand the spatial relationships between each display object, or other image guidance data.

[0109] Although only the edges of the ending-surface of the virtual ultrasound transducer **106** are clearly depicted in FIG. **5** (for example, for stylistic reasons due to the constraints of black/white illustration), it should be noted that other portions of the ending-surface may be displayed, such as the continuous portions between the edges. In some embodiments, the rendering of the transducer **106** can include shading and other visualization techniques to illustrate contours of the transducer **106**. For example, in some cases, surface shading can be added to the ending-surface rendering of the virtual ultrasound transducer **106**, which can make the virtual ultrasound transducer **106** more salient and easier to see, despite its transparency.

[0110] As described above, in some cases, rendering the selective-transparency ending-surface rendering of the transducer **106** can include omitting, ignoring, rendering transparently or otherwise not showing portions of the transducer **106** that are not portions of the ending-surface. For example, portions that are not part of the ending-surface can include the beginning-surfaces, the back-surface, the interior, one or more sides, or the like. As a non-limiting example, to render the selective-transparency ending-surface rendering of the transducer **106**, the system can determine the ending-surface of the transducer and can determine the portions of the transducer that are not included in the ending-surface. In some cases, the system can display the selective-transparency ending-surface rendering of the transducer **106** can discard, omit, or display transparently the portions of the transducer that are not included in the ending-surface.

Beginning-Surface and Ending-Surface Rendering

[0111] FIG. **6** is a diagram illustrating an embodiment of a rendering of imaging guidance data. FIG. **6** illustrates the display objects **102**, **104**, **106** in the same or similar orientation as shown in FIGS. **3-5**. In addition, the transducer **106** is illustrated with a selective-transparency surface rendering where the multiple surfaces are selected. In the illustrated example, the selected surfaces include a beginning-surface, such as described with respect to FIG. **4**, and an ending-surface, such as described with respect to FIG. **5**.

[0112] In the illustrated embodiment of FIG. **6**, the selective-transparency beginning-surface and ending-surface rendering of the transducer **106** includes a display of the

beginning- and ending-surfaces at varying transparency levels, with other portions of the transducer **106**, such as the interior or side-surface being omitted, not shown, or completely transparent. Although in the illustrated embodiment of FIG. **6**, only beginning- and ending-surfaces are used for the selective-transparency rendering, it will be understood that other surfaces can be used as part of a selective-transparency rendering. For example, a selective-transparency surface rendering can include a beginning-surface, ending-surface, front-surface, rear-facing surface, side-facing surface, interior, etc.

[0113] In the illustrated embodiment of FIG. **6**, the selective-transparency rendering is implemented with the selective-transparency scheme of the rendered portion of the ending-surface being different than (for example, diminished as compared to) the selective-transparency scheme of the rendered portion of the beginning-surface, where the beginning-surface is represented by a thick, dashed line **620** and the ending-surface is represented by a thin, dashed line **622**. By selecting various combinations of opacity, hue, saturation, and brightness for the beginning- and ending-surfaces of the transducer **106**, the system can achieve improved perception of the transducer **106** as compared to the transducer rendering being implemented with a single transparency level. In the illustrated embodiment of FIG. **6**, the medical image **104**, the virtual needle **102**, and the image guidance cues **112** are each visible through the transducer **106**, and the spatial relationships between each of the transducer **106**, needle **102**, medical image **104**, and image guidance cues **112** can be seen. Furthermore, the physician can understand the poses of the display objects, as well as the spatial relationships between each display object or other image guidance data.

[0114] It will be understood that the selective-transparency of the selected surfaces can be implemented in a variety of ways. For example, the selective-transparency can include displaying one or more of the selected surfaces at the same transparency level, displaying edges of a surface opaquely or as solid or dashed lines (non-limiting example: wire frame) and the rest of that selected surface transparently or vice versa, displaying portions of a surface that are in front of another display object transparently or more transparently than portions of that selected surface that are not in front of another display object, etc.

[0115] Moreover, when a selective-transparency rendering includes multiple surfaces, each surface can be rendered using the same selective-transparency or different selective transparencies. For example, an ending-surface can be rendered such that portions of the selected surfaces that are closer to an edge are rendered at a different opacity (for example, more opaquely) than portions that are farther away from an edge. As another example, a selected surface can be rendered such that the surfaces have a single level of transparency or alternatively can be rendered such that only edges of the selected surfaces are rendered opaquely or partially transparently, while other portions of the selected surfaces are render with a diminished opacity or are completely transparent.

[0116] In addition or alternatively to a selective-transparency rendering of the transducer, the system can render one or more selected surfaces of one or more other display objects. For example, it can be advantageous for the physician to see at least a beginning-surface and/or an ending-surface of every display object. Accordingly, in some cases,

each display object (or portion of each display object) that is in front of another display object (with respect to the point-of-view location) can be rendered with a selective-transparency beginning-surface and/or ending-surface rendering. For instance, referring to the illustrated embodiment of FIG. **6**, a portion of the virtual needle **102** overlaps with a portion of the medical image **104**. In some cases, at least one of the beginning- and/or ending-surfaces of the virtual needle **102** or the medical image **104** can be displayed using a selective-transparency beginning-surface and/or ending-surface rendering such that each beginning-surface and/or ending-surface portion of every display object is visible to the physician. Furthermore, in some embodiments, all display objects, or a subset thereof, can be displayed using a selective-transparency rendering.

[0117] Furthermore, as described herein, the selected surfaces can be rendered selectively transparent in a variety of ways. For example, the system can render portions of the selected surface of a display object that overlap with other display objects transparently or more transparently than non-overlapping portions of the display object, which can be rendered opaquely (for example, like the transducer **106** as illustrated in FIG. **3**). In certain embodiments, the non-overlapping portions of the display object can be displayed at one or more different transparency levels similar to the overlapping portions of the selected surface. In some cases, if more than two display objects (or other image guidance data) are overlapping at the same location (for example, the same pixel on the display **170**), then two or more of the overlapping display objects or portions thereof can be displayed using a selective-transparency rendering. For example, the closest display object or portion thereof (relative to the point-of-view location) can be displayed using a selective-transparency beginning-surface and/or ending-surface rendering. In addition, the second closest display object or portion thereof (relative to the point-of-view location) can be displayed using a selective-transparency beginning-surface and/or ending-surface rendering. In some cases, the selective-transparency of the using a selective-transparency beginning-surface and/or ending-surface renderings of the first and second objects can be different. For example, the second object can use a different selective-transparency scheme, such as more transparent or a single transparency level. Rendering the multiple beginning-surface and/or ending-surface renderings at different transparency levels can allow each overlapping portion to be visible to the physician, and can allow the physician to understand the spatial relationships between each display object, or other image guidance data.

[0118] Although only the edges of the beginning- and ending-surfaces of the virtual ultrasound transducer **106** are clearly depicted in FIG. **6** (for example, for stylistic reasons due to the constraints of black/white illustration), it should be noted that other portions of the beginning- or ending-surface may be displayed, such as the continuous portions between the edges. In some embodiments, the rendering of the transducer **106** can include shading and other visualization techniques to illustrate contours of the transducer **106**. For example, in some cases, surface shading can be added to the beginning-surface or ending-surface renderings of the virtual ultrasound transducer **106**, which can make the virtual ultrasound transducer **106** more salient and easier to see, despite its transparency.

[0119] As described above, in some cases, rendering the selective-transparency ending-surface rendering of the transducer **106** can include omitting, ignoring, rendering transparently or otherwise not showing portions of the transducer **106** that are not portions of the beginning-surface or the ending-surface. For example, portions that are not part of the beginning-surface or the ending-surface can include the portions of a side-surface or interior of the transducer.

Exterior Surface

[0120] FIG. **7** is a diagram illustrating an embodiment of a rendering of imaging guidance data. FIG. **7** illustrates the display objects **102**, **104**, **106** in the same or similar orientation as shown in FIGS. **3**-**6**. In addition, the transducer **106** is illustrated with a selective-transparency surface rendering where the multiple surfaces are selected. In the illustrated example, the selected surfaces include exterior surfaces of the transducer **106**. In the illustrated embodiment, the exterior surfaces include each of the outer surfaces of the transducer **106**. For example, the exterior surfaces can include a combination of surfaces, edges, or other portions of the beginning-surface, ending-surface, front-surface, back-surface, side-surface, or the like.

[0121] In the illustrated embodiment of FIG. **7**, physical details of the virtual ultrasound transducer **106** that were occluded or located on the far side of the transducer of FIG. **3** are now visible, thereby rendering a more informative image. For example, the image includes extra details of the transducer, such as the transducer's contours. In some cases, these details can lead to the brain's misunderstanding of the transducer's **106** orientation. This phenomenon, known as multistable, ambiguous perception, can cause the user to perceive that the transducer is in an orientation that is different from the actual orientation of the transducer **106**. For example, as illustrated in FIG. **7**, the orientation of the transducer **106** can appear flipped as compared to the orientation of the transducer shown in FIG. **3**. Nonetheless, in some cases, the selective-transparency exterior surface rendering of the transducer **106** can provide information regarding the transducer **106** that can aid a user in placing the needle **102**.

[0122] In the illustrated embodiment of FIG. **7**, the selective-transparency exterior surface rendering of the transducer **106** includes a display of each of the exterior surfaces at varying transparency levels, with other portions of the transducer **106**, such as the interior, being omitted, not shown, or completely transparent. Although in the illustrated embodiment of FIG. **7**, only exterior surfaces are used for the selective-transparency rendering, it will be understood that other surfaces can be used as part of a selective-transparency rendering. For example, a selective-transparency surface rendering can include an interior of the transducer. Furthermore, it will be understood that the selective-transparency rendering can include fewer surfaces than illustrated in FIG. **7**. For example, one or more of the beginning-, ending-, front-, back-, or side-surface can be omitted, not shown, or can be retendered completely transparently.

[0123] In the illustrated embodiment of FIG. **7**, the selective-transparency of the exterior surface is implemented with the exterior surface becoming less transparent as it gets closer to an edge. In this way, the medical image **104**, the virtual needle **102**, and the image guidance cues **112** are each visible through the transducer **106**, and the spatial relation-

ships between each of the transducer **106**, needle **102**, medical image **104**, and image guidance cues **112** can be seen. In some embodiments, the selective-transparency exterior surface rendering of the transducer can reduce the number of displayed lines and improve a user's ability to properly understand the correct orientation of the transducer **106**.

[0124] It will be understood that the selective-transparency of the selected surface can be implemented in a variety of ways. For example, the selective-transparency can include displaying the selected surface at the same transparency level, displaying edges of the surface opaquely or as solid or dashed lines (non-limiting example: wire frame) and the rest of the selected surface transparently or vice versa, displaying portions of the surface that are in front of another display object transparently or more transparently than portions of the selected surface that are not in front of another display object, etc.

[0125] Moreover, when a selective-transparency rendering includes multiple surfaces, each surface can be rendered using the same selective-transparency or different selective transparencies. For example, an exterior surface can be rendered such that portions of the exterior surface that are closer to an edge are rendered at a different opacity (for example, more opaquely) than portions that are farther away from an edge. As another example, an exterior surface can be rendered such that the entire surface has a single level of transparency or alternatively can be rendered such that only edges of the exterior surface are rendered opaquely, while other portions of the exterior surface are render with a diminished opacity or are completely transparent.

[0126] In addition or alternatively to a selective-transparency rendering of the transducer, the system can render one or more selected surfaces of one or more other display objects. For example, it can be advantageous for the physician to see at least the exterior surface of every display object. Accordingly, in some cases, each display object (or portion of each display object) that is in front of another display object (with respect to the point-of-view location) can be rendered with a selective-transparency exterior surface rendering. For instance, referring to the illustrated embodiment of FIG. **7**, a portion of the virtual needle **102** overlaps with a portion of the medical image **104**. In some cases, at least one of the exterior surfaces of the virtual needle **102** or the medical image **104** can be displayed using a selective-transparency exterior surface rendering such that each exterior surface portion of every display object is visible to the physician. Furthermore, in some embodiments, all display objects, or a subset thereof, can be displayed using a selective-transparency rendering.

[0127] Furthermore, as described herein, the selected surfaces can be rendered selectively transparent in a variety of ways. For example, the system can render portions of the selected surface of a display object that overlap with other display objects transparently or more transparently than non-overlapping portions of the display object, which can be rendered opaquely (for example, like the transducer **106** as illustrated in FIG. **3**). In certain embodiments, the non-overlapping portions of the display object can be displayed at one or more different transparency levels similar to the overlapping portions of the selected surface. In some cases, if more than two display objects (or other image guidance data) are overlapping at the same location (for example, the same pixel on the display **170**), then two or more of the

overlapping display objects or portions thereof can be displayed using a selective-transparency rendering. For example, the closest display object or portion thereof (relative to the point-of-view location) can be displayed using a selective-transparency exterior surface rendering. In addition, the second closest display object or portion thereof (relative to the point-of-view location) can be displayed using selective-transparency exterior surface rendering. In some cases, the selective-transparency of the using a selective-transparency exterior surface renderings of the first and second objects can be different. For example, the second object can use a different selective-transparency scheme, such as more transparent or a uniform transparency level. Rendering the multiple exterior surface renderings at different transparency levels can allow each overlapping portion to be visible to the physician, and can allow the physician to understand the spatial relationships between each display object, or other image guidance data.

[0128] Although only the edges of the exterior surface of the virtual ultrasound transducer **106** are clearly depicted in FIG. **7** (for example, for stylistic reasons due to the constraints of black/white illustration), it should be noted that other portions of the exterior surface may be displayed, such as the continuous portions between the edges. In some embodiments, the rendering of the transducer **106** can include shading and other visualization techniques to illustrate contours of the transducer **106**. For example, in some cases, surface shading can be added to the exterior surface rendering of the virtual ultrasound transducer **106**, which can make the virtual ultrasound transducer **106** more salient and easier to see, despite its transparency.

[0129] As described above, in some cases, rendering the selective-transparency exterior surface rendering of the transducer **106** can include omitting, ignoring, rendering transparently or otherwise not showing portions of the transducer **106** that are not portions of the exterior surface. For example, portions that are not part of the exterior surface can include the interior of the transducer.

Example Front-, Back-, Ending-, and Beginning-Surfaces

[0130] FIGS. **8A-8F** are diagrams useful for illustrating differences between determining front-, back-, ending-, and beginning-surfaces. For ease of reference, FIGS. **8A-8F** illustrate an orthographic projection of a 3D scene for display on display **170**. It will be understood that these diagrams are illustrative in nature, and should not be construed as limiting. Further, the associated description of FIGS. **8A-8F** can be applicable to three-dimensional objects, as well as to the illustrated two-dimensional object.

[0131] FIG. **8A** is a block diagram illustrating an embodiment of a virtual surgical environment, such as the 3D scene **110** described herein, on the right side of the figure. In addition, FIG. **8A** illustrates a viewpoint or point-of-view location **802** (in this example, depicted as a user's eye) on the left side of the figure. As described herein, the point-of-view location **802** can refer to the location from which a virtual 3D space is viewed. Accordingly, in this example, a viewer of the display **170** would be viewing the scene from the perspective of the illustrated eye **802**.

[0132] FIG. **8B** is a block diagram illustrating an embodiment of a virtual surgical environment that includes a plurality of view-rays **804** extending from the point-of-view location **802** to the virtual transducer **106**. The plurality of view-rays **804** can include an infinite number of view-rays,

such that every portion or fragment of the virtual transducer **106** intersects with a view-ray. It will be understood that the view-rays **804** are for illustrative or calculation purposes and are not necessarily rendered by the system. Rather, as illustrated in FIGS. **8C-8F**, these view-rays can be useful in distinguishing between a front-surface, back-surface, beginning-surface, and ending-surface.

Example Front-Surface

[0133] FIG. **8C** is a block diagram illustrating an embodiment of a virtual surgical environment that includes a plurality of view-rays **804** extending from the point-of-view location **802** to the virtual transducer **106**. As illustrated by the bolded lines **810** outlining portions of the transducer **106**, the front-surface of an object can include the surfaces, edges, and/or other portions of the transducer **106** that face the point-of-view location **802**. Further, in certain embodiments, as illustrated by the dashed lines **812** outlining other portions of the transducer **106**, the front-surface can omit the surfaces, edges, or other portions of the transducer **106** that do not face the point-of-view location **802**. Furthermore, in certain embodiments, the front-surface of the transducer **106** can omit the interior or inner portions of the transducer. Accordingly, in some embodiments, the front-surface may only include outer surfaces of the object.

Example Back-Surface

[0134] FIG. **8D** is a block diagram illustrating an embodiment of a virtual surgical environment that includes a plurality of view-rays **804** extending from the point-of-view location **802** to the virtual transducer **106**. As illustrated by the bolded lines **820** outlining portions of the transducer **106**, the back-surface of an object can include the surfaces, edges, and/or other portions of the transducer **106** that do not face the point-of-view location **802**. Further, in certain embodiments, as illustrated by the dashed lines **822** outlining other portions of the transducer **106**, the back-surface can omit the surfaces, edges, or other portions of the transducer **106** that face the point-of-view location **802**. Thus, as can be seen by a comparison of FIGS. **8C** and **8D**, in some embodiments, a back-surface can be described as the opposite of the front-surface. Furthermore, in certain embodiments, the back-surface of the transducer **106** can omit the interior or inner portions of the transducer. Accordingly, in some embodiments, the back-surface may only include outer surfaces of the object.

Example Ending-Surface

[0135] FIG. **8E** is a block diagram illustrating an embodiment of a virtual surgical environment that includes a plurality of view-rays **804** extending from the point-of-view location **802** to the virtual transducer **106**. In the illustrated embodiment, an example ending-surface is shown by the solid, bolded lines **830** outlining portions of the transducer **106**, while the other outer surfaces of the transducer are shown by broken lines **832** outlining portions of the transducer **106**.

[0136] In some embodiments, the ending-surface can be described with reference to the view-rays **804** extending from the point-of-view location **802**. As illustrated, multiple view-rays intersect with the object **106**. Although, in some cases, a particular view-ray may have multiple exit points (for example, depending on the shape of the object, a

view-ray may enter the object, then exit the object, then re-enter the object, then re-exit the object and so on), a view-ray that intersects with the object **106** has one final exit point from the object. In some embodiments, the ending-surface can be determined as the aggregation of final exit points of multiple or all of the view-rays **804**, as illustrated by the bolded lines **830** outlining portions of the transducer **106**. For example, in certain cases, the ending-surface can be determined by aggregating the final exit points of the view-rays **804** that intersect with the object **106**.

[0137] Although the view-rays **804** illustrated in FIG. **7** extend from a point-of-reference, in some cases, the view-rays **804** can extend from a plane of reference. For example, the view-rays can extend orthogonally or obliquely from a plane of reference and a subset of the view-rays can intersect with the object, as described above. In this example, the ending-surface could similarly include the aggregation of final exit points from multiple or all of the view-rays.

Example Beginning-Surface

[0138] FIG. **8F** is a block diagram illustrating an embodiment of a virtual surgical environment that includes a plurality of view-rays **804** extending from the point-of-view location **802** to the virtual transducer **106**. In the illustrated embodiment, an example the beginning-surface is shown by the solid, bolded lines **840** outlining portions of the transducer **106**, while the other outer surfaces of the transducer are shown by broken lines **842** outlining portions of the transducer **106**.

[0139] As illustrated by the bolded lines **840** outlining portions of the transducer **106**, in some embodiments, the beginning-surface can include those surfaces, edges, or other portions of the object **106** that are both facing the point-of-view location **802** and not occluded from view by the object's shape. Further, in certain embodiments, a beginning-surface may only include those surfaces, edges, or other portions of the object **106** that are both facing the point-of-view location **802** and not occluded from view by the object's shape. Accordingly, in contrast to the front-surface representation in FIG. **8C**, in some cases, the beginning-surface may not include each of the surfaces of the object **106** that face the point-of-view location **802**. An example of this is shown by the dashed surface **844**, which faces the point-of-view location **802** but is occluded from view by the object's shape. For example, the dashed surface **844** is occluded from view at the point-of-view location **802** at least by surface **846**.

[0140] In some embodiments, the beginning-surface of an object may also be explained or described with reference to the view-rays **804** which are illustrated as extending from the point-of-view location **802**. As illustrated, multiple view-rays **804** intersect with a portion of the object **106**. Although, in some cases, a particular view-ray may have multiple entry points (for example, depending on the shape of the object, a view-ray may initially enter the object, then exit the object, then re-enter the object and so on), a view-ray that intersects with the object **106** has one initial entry point into the object. Accordingly, in some embodiments, the beginning-surface can be determined using the aggregation of initial entry points of multiple or all of the view-rays **804**. For example, in certain cases, the beginning-surface can be determined by aggregating the initial entry points of the view-rays **804** that intersect with the object **106**.

[0141] Although the view-rays **804** illustrated in FIG. **8F** extend from a point-of-reference, in some cases, the view-rays **804** can extend from a plane of reference. For example, the view-rays can extend orthogonally or obliquely from a plane of reference and a subset of the view-rays can intersect with the object, as described above. In this example, the beginning-surface could similarly include the aggregation of initial entry points from multiple or all of the view-rays.

[0142] It should be noted that, in certain embodiments, the beginning- and ending-surfaces do not necessarily complement each other to the complete object surface. In other words, the beginning- and ending-surfaces may not be mirror images of or opposite each other. For example, as illustrated in FIGS. **8E** and **8F**, at least some portions of an object may not be included in a beginning-surface or an ending-surface of the object. This can be the case for objects with concavities, for example.

Example Front-, Back-, Ending- and Beginning-Surfaces

[0143] FIGS. **9A-9D** are diagrams useful for illustrating differences between determining front-, back-, ending-, and beginning-surfaces. Each of FIGS. **9A-9D** illustrate a viewpoint or point-of-view location **902** (in this example, depicted as a user's eye) on the left side of the figure. As described herein, the point-of-view location **902** can refer to the location from which a virtual 3D space is viewed. Accordingly, in these examples, a viewer of the display **170** would be viewing the scene from the perspective of the illustrated eye **902**. It will be understood that these diagrams are illustrative in nature, and should not be construed as limiting. Further, the associated description of FIGS. **9A-9D** can be applicable to two-dimensional objects, as well as to other three-dimensional objects.

Example Front-Surface

[0144] FIG. **9A** is a block diagram illustrating an embodiment of a virtual surgical environment. As illustrated by the shaded portions **910** of the transducer **106**, the front-surface of an object can include the surfaces, edges, and/or other portions of the transducer **106** that face the point-of-view location **902**. Further, in certain embodiments, the front-surface can omit, the surfaces, edges, or other portions of the transducer **106** that do not face the point-of-view location **902**, such as those portions of the transducer that cannot be seen in FIG. **9A** (for example, the back side of the transducer **106**). Furthermore, the selective-transparency front-surface rendering of the transducer **106** can omit the interior or inner portions of the transducer. Accordingly, in some embodiments, the front-surface may only include outer surfaces of the object.

Example Back-Surface

[0145] FIG. **9B** is a block diagram illustrating an embodiment of a virtual surgical environment. As illustrated by the shaded portions **920** of the transducer **106**, the back-surface of an object can include surfaces, edges, or other portions of the transducer **106** that do not face the point-of-view location **902**. Further, in certain embodiments, the back-surface can omit, the surfaces, edges, or other portions of the transducer **106** that do not face the point-of-view location **902**, such as those portions of the transducer that cannot be seen in FIG. **9B** (for example, the front side of the transducer **106**). Furthermore, the selective-transparency back-surface

rendering of the transducer **106** can omit the interior or inner portions of the transducer. Accordingly, in some embodiments, the back-surface may only include outer surfaces of the object.

Example Ending-Surface

[0146] FIG. 9C is a block diagram illustrating an embodiment of a virtual surgical environment. In the illustrated embodiment, an example the ending-surface is shown by the shaded portions **930** of the transducer **106**.

[0147] In some embodiments, the ending-surface can be described with reference to the view-rays **904** extending from the point-of-view location **902**. As illustrated, multiple view-rays intersect with the object **106**. Although, in some cases, a particular view-ray may have multiple exit points (for example, view-ray **906**), a view-ray that intersects with the object **106** has one final exit point from the object. In some embodiments, the ending-surface can be determined as the aggregation of final exit points of multiple or all of the view-rays **804**, as illustrated by the shaded portions **930** of the transducer **106**.

[0148] In certain embodiments, the ending-surface can omit, the surfaces, edges, or other portions of the transducer **106** that are not included in the aggregation of final exit points of the view-rays **904**, such as those portions of the transducer that cannot be seen in FIG. 9B, as well as the non-shaded sides of the transducer **106**. Furthermore, the selective-transparency ending-surface rendering of the transducer **106** can omit the interior or inner portions of the transducer. Accordingly, in some embodiments, the ending-surface may only include outer surfaces of the object.

Example Beginning-Surface

[0149] FIG. 9D is a block diagram illustrating an embodiment of a virtual surgical environment. In the illustrated embodiment, an example of a beginning-surface is shown by the shaded portions **940** of the transducer **106**. As illustrated by the shaded portions **940**, in some embodiments, the beginning-surface can include those surfaces, edges, or other portions of the object **106** that are both facing the point-of-view location **902** and not occluded from view by the object's shape.

[0150] In some embodiments, the beginning-surface of an object may also be explained or described with reference to the view-rays **904** which are illustrated as extending from the point-of-view location **902**. As illustrated, multiple view-rays **904** intersect with a portion of the object **106**. Although, in some cases, a particular view-ray may have multiple entry points (for example, depending on the shape of the object, a view-ray may initially enter the object, then exit the object, then re-enter the object and so on), a view-ray that intersects with the object **106** has one initial entry point into the object. Accordingly, in some embodiments, the beginning-surface can be determined as the aggregation of initial entry points from multiple or all of the view-rays.

[0151] In contrast to the front-surface rendering in FIG. 9A, in some cases, the beginning-surface may not include each of the surfaces of the object **106** that face the point-of-view location **902**. An example of this is shown by view-ray **908**, which intersects two surfaces that are facing the point-of-view location **802**, where only the first intersected surface is included in the beginning-surface.

[0152] It should be noted that, in certain embodiments, the beginning- and ending-surfaces do not necessarily complement each other to the complete object surface. In other words, the beginning- and ending-surfaces are not necessarily mirror images of each other. For example, as illustrated in FIGS. 9C and 9D, at least some portions of an object may not be included in a beginning-surface or an ending-surface of the object. This can be the case for objects with concavities, for example.

Image Visualization

[0153] The system can utilize various methods to generate images **125**. In some cases, the system can determine what is to be displayed at the different pixels of the display **170** by fragmenting the display objects or treating the display objects as a combination of fragments. For example, multiple fragments of different display objects can be mapped to the same pixel (non-limiting example: located at the same vertical and horizontal coordinate of the screen **170**). When this occurs, the system can determine which fragment, or combination thereof, to display at the pixel. As such, a pixel can display a single fragment or a combination or blend of fragments. For example, if one or more of the portions of different display objects overlap (for example, one display object is in front of another display object), then the system can determine what is to be displayed on the pixels corresponding to the overlapping sections, or fragments, of the display objects. In some embodiments and with reference to the example of one display object being in front of the other, the system can cause the pixel to display a fragment from the front object, a fragment of the back object, or some blend of the fragments.

[0154] The system can use a variety of techniques to determine which fragment or combination of fragments are to be displayed at the pixel, such as, but not limited to, depth order, a fragment identifier, a priority identifier, and/or transparency level, etc.

[0155] In some cases, the selection can be based on depth order. For example, the closest fragment to the point-of-view location can be selected for each pixel, and the remaining fragments discarded.

[0156] As a non-limiting example, the system can start in depth order (for example, front-to-back) and can select the closest fragment (for example, relative to the point-of-view location) that has a fragment identifier corresponding to an ultrasound transducer. The system can discard, ignore, or otherwise not display all other fragments. For example, assuming that the ultrasound transducer is a volume, any particular pixel can have multiple ultrasound transducer fragments, corresponding to the depth of the transducer. In this example, by selecting only the closest fragments of the ultrasound transducer, the result of the rendering would be a beginning-surface rendering of the ultrasound transducer.

[0157] A similar technique can be used to render an ending-surface of the transducer. As a non-limiting example, the system can start in depth order and can select the furthest fragment (for example, relative to the point-of-view location) that has a fragment identifier corresponding to an ultrasound transducer. The system can discard, ignore, or otherwise not display all other fragments. For example, the system could proceed in a back-to-front depth order and, similar to the above example, the system can select the first fragment, for each pixel, that has a fragment identifier corresponding to an ultrasound transducer. Alternatively, the

system could proceed in a front-to-back depth order and can select the last fragment, for each pixel, that has a fragment identifier corresponding to an ultrasound transducer. The result of these rendering can be an example ending-surface rendering of the ultrasound transducer. It will be understood that similar techniques could be utilized for image guidance data other than a transducer display object. Furthermore, it will be understood that these techniques can be utilized to identify portions of an object other than a beginning- or ending-surface. For example, these techniques can be utilized to render an exterior surface of a display object.

[0158] In certain embodiments, at least some of the fragments can include a fragment identifier that can identify, among other things, the object to which it belongs, its depth as compared to the point-of-view location, and/or its coordinates relative to a coordinate plane. In some embodiments, the system can use the identifier to determine which fragment to display at a pixel. For example, the system can determine that trajectory indicators are to always be displayed, regardless of depth position, etc.

[0159] Moreover, in certain embodiments, a fragment can be associated with or include a priority identifier that identifies the fragment's priority level relative to other fragments. Accordingly, in some cases, the system can select a fragment or fragments for a particular pixel based at least in part on the fragment identifier(s) of the pixel. In certain embodiments, the fragment can correspond to a pixel on a display that displays an image. In some embodiments, a fragment can refer to one or multiple pixels, such as an array of pixels. When two fragments are mapped to the same pixel, the system can display the fragment with the higher priority level and discard any other fragments.

[0160] In some cases, two or more fragments are considered mapped to the same pixel if the fragments satisfy a location threshold. To determine whether the fragments satisfy a location threshold, the system can compare the coordinates of a first fragment with the coordinates of a second fragment. Any coordinate system can be used to compare the coordinates of the fragments. For example, the coordinate system of the display and/or the coordinate system of a medical device can be used, as desired.

[0161] In some embodiments, the coordinate system of the display is used. The coordinate system of the display can be any pose as desired. In certain embodiments, the coordinates of the display are that the x-axis is the width of the display, the y-axis is the height of the display, and the z-axis is the depth (e.g., into and out of) the display. In such embodiments, the system 100 can determine that a first fragment satisfies a location threshold and/or is level with a second fragment based at least in part on the x and y coordinates of the fragments. For example, if the x and y coordinates of the first fragment and the x and y coordinates of the second fragment match (or satisfy a distance threshold), the system 100 can determine that the first fragment and the second fragment satisfy the location threshold.

[0162] The distance threshold can be a predefined distance, such as one or more bits, one or more pixels, etc. In some embodiments, the distance threshold can be based at least in part on whether the distance between the coordinates is perceptible to a user, which may be based at least in part on the size of the display, the size of the display relative to the image and/or imaged area, and/or the distance between the point-of-view location and the display, etc. For example, in some case the distance threshold can be smaller for larger

displays (or larger display:image ratios) and larger for smaller displays (or smaller display:image ratios), or vice versa. In certain cases, the distance threshold can be larger for larger distances between the point-of-view location and the display and smaller for smaller distances between the point-of-view location and the display, or vice versa. In certain embodiments, the distance threshold can be different for each coordinate.

[0163] Although reference is made to the x and y coordinates, it will be understood that the coordinates used to determine whether the first fragment and the second fragment satisfy the location threshold can coordinate to any coordinates system. For example, in some embodiments, the coordinate system used can include the x-axis as the depth (e.g., forward/backward), the y-axis as lateral movement (e.g., side-to-side), and the z-axis as elevation (e.g., up/down). In such embodiments, the system 100 can determine that the first fragment satisfies the location threshold if the y and z coordinates of the first fragment match (or satisfy a distance threshold) the y and z coordinates of the second fragment.

[0164] In certain embodiments, the system 100 can determine that the first fragment satisfies the location threshold and/or is level with the second fragment if the first fragment and the second fragment are co-located when mapped to a 2D plane. In some embodiments, the 2D plane can be based at least in part on the point-of-view location. For example, the 2D plane can be orthogonal to the point-of-view location. In certain embodiments, the system 100 can determine that the first fragment satisfies the location threshold if the first fragment overlaps with the second fragment in a virtual image (e.g., one is directly in front of or behind the other in the virtual image). In certain embodiments, the system 100 can determine that the first fragment satisfies the location threshold if the first fragment and the second fragment map to the same location on a display, such as the same pixel or same array of pixels.

[0165] In some embodiments, the system can blend fragments with the same priority level or with a priority level that satisfies a threshold priority level and discard fragments with a lower priority level or with a priority level that does not satisfy that the threshold priority level. In certain embodiments, the system can blend fragments of different priority levels but display fragments with a higher priority level more opaquely than fragment levels with a lower priority level or give a fragment with a higher priority level a greater weighting when blending (non-limiting example: 70% of pixel is determined based on fragment with higher priority level and 30% is split between fragments with a lower priority level, etc.).

[0166] In some cases, the system can use a combination of identifiers to determine what is to be shown at a pixel. For example, the system can, for some pixels, select the closest fragment that has a fragment identifier corresponding to an ultrasound transducer for display, unless another fragment mapped to the same pixel has a higher priority identifier. For example, a fragment that is related to an image guidance cue, such as image guidance cue 112, can be given a higher priority identifier than the priority identifier of the ultrasound transducer. Thus, for pixels that include a transducer fragment, the system can select the closest fragment having a transducer fragment identifier for display. However, if a particular pixel has an image guidance cue fragment with a higher priority identifier, then the system can select the

image guidance cue fragment for display instead of the closest transducer fragment, or blend the transducer fragment and the image guidance cue fragment. Such a scenario can result in a rendering that includes a beginning-surface of the transducer, and any image guidance cue that overlaps with the transducer.

[0167] In some cases, the system can use a combination of identifiers to determine whether portions of image guidance data intersect. For example, the system can determine, based on one or more identifiers, that an image guidance cue, such as image guidance cue 112, is within the interior of the ultrasound transducer. In other words, the system can determine if the image guidance cue is penetrating the ultrasound transducer. As described above, in some cases, the image guidance cue can be associated with a higher priority identifier than the ultrasound transducer, and thus the system can select the image guidance cue fragment for display instead of the transducer fragment, or blend the transducer fragment and the image guidance cue fragment. Furthermore, in some cases, to further illustrate that the image guidance cue fragment is within the interior of the ultrasound transducer, the system can alter surface attributes of the image guidance cue fragment. For example, the image guidance cue fragment can be emphasized, such as by changing its color, texture, size, or opacity. Alternatively, the image guidance cue fragment can be de-emphasized, such as by changing its color, texture, size, opacity, or by removing or discarding the fragment.

[0168] In some cases, the image guidance cue fragment can be removed, discarded, or otherwise not displayed if determined to be within the interior of the transducer. For example, in some cases, a fragment can be given a conditional priority identifier. As a non-limiting example, a fragment that is related to an image guidance cue, such as image guidance cue 112, can be given a higher priority identifier than the priority identifier of the ultrasound transducer, but only if that image guidance cue fragment is not within the interior of the ultrasound transducer (or another object). In other words, in this example, the image guidance cue fragment can have a higher priority identifier when the image guidance cue is in front of or behind, but not within, the ultrasound transducer. Such a scenario can result in a rendering that includes a selected surface of the transducer, and any image guidance cue that is in front of or behind the transducer. However, in this example, any image guidance cue or portion thereof that is within the interior of the transducer may not be shown.

[0169] In certain embodiments, a fragment's priority level relative to other fragments can be based on the depth of the object (relative to the point-of-view location) identified by those fragments. For example, an object that is closer to the point-of-view location can be associated with a higher priority identifier than an object that is further from the point-of-view location. As a non-limiting example, a scene can include an ultrasound transducer and a medical image. The ultrasound transducer can be closer to the point-of-view location than the medical image. Furthermore, at least a portion of the transducer intersects with at least a portion of the medical image. In this example, fragments corresponding to the interior of the transducer can have a higher priority level than fragments corresponding the medical image. Thus, for medical image fragments that fall within the interior of the transducer, the system can select a transducer fragment for display instead of the medical image fragment

and/or discard the medical image fragments from the rendering. However, in some cases, to enable visibility of the medical image, fragments corresponding to the medical image can have a higher priority identifier if the medical image is behind, but not within, the ultrasound transducer. Thus, for medical image fragments that are behind the transducer (relative to the point-of-view location), the system can select a medical image fragment for display instead of the transducer fragment, or blend the transducer fragment and the medical image fragment. Such a scenario can result in a rendering that includes the selected surface of the transducer, and a portion of a medical image that is visible though the selected surface of the transducer, but that excludes a cutoff region corresponding to the region of the medical image that intersects with, or is within the interior of, the transducer. Examples of this scenario are illustrated in FIGS. 4-9D, where the medical image is illustrated with a curved cutout corresponding to the interior of the transducer. It should be noted that, in some cases, an object that is further from the point-of-view location can be associated with a higher priority identifier than an object that is closer to the point-of-view location. Continuing with the example above, such a scenario can result in a rendering that includes the medical image and a portion of a selected surface of the transducer that excludes a cutoff region corresponding to the region of the transducer that intersects with, or is within the interior of, the medical image.

[0170] As described herein, fragments can be blended for display at a pixel. In some cases, at least some of the fragments can be at least partially transparent. For example, the beginning- and/or ending-surface of an object may be selected to be rendered transparently. In examples such as these, the system can select the transparent transducer fragment, as well as a fragment of another object if one happens to overlap at that pixel. Each of the opaque and transparent surface fragments may be composited (for example, accumulated in terms of color and transparency) in depth order. Thus, the fragments can become blended such that both the transducer and the object would be visible at that pixel (for example, the object would be shown through the transducer). In some cases, depth order and compositing formulas may help create the appearance that beginning-surface is in front of (or closer to the point-of-view location than) the ending-surface, and/or that the ultrasound is in front of the other display object.

[0171] A number of rendering techniques can be used to generate this visualization including, but not limited to depth peeling (for example, an order independent transparency solution that involves rendering a scene multiple times and each time 'peeling away' layers of the image in depth order), fragment sorting to identify beginning- and ending-surfaces, rendering those objects intended to be transparent to off-screen buffers and transparently compositing those over the main view, ray-casting, or a Binary Space Partition (BSP) Tree algorithm.

Flow Diagrams

[0172] FIG. 10 is a flow diagram illustrative of an embodiment of a routine implemented by the system for providing improved perception of a display object in a virtual 3D scene for medical device navigation. One skilled in the relevant art will appreciate that the elements outlined for routine 1000 can be implemented by one or more computing devices/ components that are associated with the system 100, such as

the position sensing unit **130**, the image guidance unit **150**, surgical system **180**, a head-mounted display, and/or the imaging unit **160**. Accordingly, routine **1000** has been logically associated as being generally performed by the system **100**. However, the following illustrative embodiment should not be construed as limiting. Furthermore, it will be understood that the various blocks described herein with reference to FIG. **10** can be implemented in a variety of orders. For example, the system **100** can implement some blocks concurrently or change the order as desired. Furthermore, it will be understood that fewer, more, or different blocks can be used as part of the routine **1000**. For example, in some embodiments, one or more of blocks **1002**, **1004**, **1006**, **1008**, **1010**, **1012**, **1014**, or **1016** are not implemented. However, it will be understood that any of the blocks (and more or different blocks) can be implemented as part of routine **1000**.

[0173] At block **1002**, the system **100** receives first emplacement data associated with a first emplacement sensor and/or a first medical device. The first emplacement data can be generated by the first emplacement sensor and/or by the position sensing unit **130**. In some embodiments, the first emplacement sensor can be associated with the first medical device. For example, the first emplacement sensor can be associated with and/or attached to a single-axis device, such as a medical needle (for example, an ablation needle), a scalpel, a catheter, a stent, or a laparoscopic camera, or a multi-axis device, such as a stapler, a grasper, a transecting device, a resecting device, or a vessel sealer. In some embodiments, the first emplacement sensor can be associated with and/or attached to an imaging device such as an ultrasound transducer.

[0174] At block **1004**, the system **100** receives second emplacement data associated with a second emplacement sensor and/or a second medical device. The second emplacement data can be generated by the second emplacement sensor and/or by the position sensing unit **130**. In some embodiments, the second emplacement sensor can be associated with the second medical device. For example, the second emplacement sensor can be associated with and/or attached to a single-axis device, such as a medical needle (for example, an ablation needle), a scalpel, a catheter, a stent, or a laparoscopic camera, or a multi-axis device, such as a stapler, a grasper, a transecting device, a resecting device, or a vessel sealer. In some embodiments, the second emplacement sensor can be associated with and/or attached to an imaging device such as an ultrasound transducer.

[0175] At block **1006**, the system **100** can determine an emplacement of a first virtual medical device corresponding to the first medical device based at least in part on the received first emplacement data. As described above, the first virtual medical device can correspond to one or more of an ultrasound transducer, a medical needle, a grasper, a stapler, a vessel sealer, an electrocautery device, a resecting device, a transecting device, a scalpel, a catheter, a stent, or a laparoscopic camera.

[0176] In some embodiments, the system **100** can use the first emplacement data and one or more characteristics of the associated first medical device (or a corresponding virtual medical device) to determine the emplacement of at least a portion of the first medical device. For example, characteristics such as shape, size, model, or the like may aid in the determination of an emplacement of the virtual medical device.

[0177] In certain embodiments, the system **100** can determine the emplacement of the first medical device in one or more coordinate systems by mapping the first emplacement data, from one coordinate system to a second coordinate system. For example, the first emplacement data may be received with respect to a first coordinate system, such as a position sensing coordinate system, and then mapped to a second coordinate system, such as a 3D scene coordinate system and/or a screen coordinate system. The emplacement of the first medical device can be determined with respect to one or more of the coordinate systems. For example, the emplacement of the first medical device can be determined after the first emplacement data has been mapped to the second coordinate system, such as the 3D scene coordinate system and/or the screen coordinate system, or the emplacement of the first medical device can be determined for the first coordinate system, such as the position sensing coordinate system, and then mapped to the 3D scene coordinate system and/or the screen coordinate system.

[0178] In certain embodiments, the system **100** can utilize point-of-view location, as described herein, to determine the emplacement of the first medical device for viewing. For example, the point-of-view location can include one or more of an actual location of a user, an expected location of a user, a fixed location relative to one or more displays, or a dynamic location. For example, the system can track a user in real time and determine the point-of-view location based at least in part on the tracked location of the user.

[0179] In certain embodiments, the system **100** can use an offset to determine the emplacement of the first virtual medical device for viewing. For example, the system **100** can determine an initial emplacement of the first medical device in the 3D scene coordinate system and/or the screen coordinate system, and then apply an offset to the initial emplacement and/or the system **100** can determine an initial emplacement of the first medical device in the position sensing coordinate system and apply an offset to the initial emplacement prior to mapping the emplacement of the first medical device in the position sensing coordinate system to the 3D scene coordinate system and/or the screen coordinate system.

[0180] The offset can be made in one, or a combination of, coordinate systems, and/or with respect to one, or a combination of, axes. In certain embodiments, the offset can be made along a y-axis (up/down) of the position sensing coordinate system, the 3D scene coordinate system and/or the screen coordinate system. For example, the system **100** can adjust the y-coordinate (up/down coordinate) of the determined emplacement of the first medical device (or the first emplacement sensor(s)) in the position sensing coordinate system by the offset amount. When mapped to the 3D scene coordinate system and/or the screen coordinate system, the system **100** can use the adjusted emplacement. As yet another example, the system **100** can adjust the y-coordinate (up/down coordinate) of the determined emplacement of the first medical device (or the first emplacement sensor (s)) in the 3D scene coordinate system and/or the screen coordinate system by the offset amount. Any combination of the above-referenced examples can be used as desired. Furthermore, it will be understood that the offset can be made in any one or any combinations of the coordinate systems and with reference to any one or any combination of the axes. For example, the adjustment can be made along any one or any combination of the x-axis, y-axis, or z-axis.

[0181] Furthermore, the offset can be a predetermined offset and/or a dynamic offset. In some embodiments, a predetermined offset can be used. For example, the system **100** can use a static offset based on an average height of males and/or females or average distance between elbows and hands, the height of the user, a distance between the user's elbow and eyes, expected location of a user with respect to the imaged volume, etc. In certain embodiments, the system **100** can use a dynamic offset, such as a determined emplacement of a head-mounted display (HMD) relative to one or more emplacement sensors, position sensing region, and/or position sensing unit coordinate system. For example, the system **100** can determine the emplacement of an HMD relative to a medical device or imaged area and adjust the offset such that the medical image is always in view on the displays of an HMD. With continued reference to the example, if the wearer crouches down or turns to the side, the system **100** can determine the change in relative emplacement between the HMD and the medical device or imaged area and adjust the offset such that the medical image remains in view in substantially the same emplacement.

[0182] In addition, it will be understood that the offset described herein with reference to the first medical device can be applied to any one or any combination of the objects to be displayed and/or to all contents of the virtual 3D scene. In some embodiments, the offset can be applied to some objects to be displayed but not to others.

[0183] At block **1008**, as described above with respect to block **1006**, the system **100** can determine an emplacement of a second virtual medical device corresponding to the second medical device based at least in part on the received second emplacement data. As described above, the second virtual medical device can correspond to an imaging device, such as an ultrasound transducer.

[0184] At block **1010**, the system **100** can determine an emplacement of a medical image associated with the second medical device based at least in part on received second emplacement data. The medical image can be an intra-operative and/or real-time medical image, such as a live ultrasound or intra-operative CT scan, or can be a pre-operative image, such as a pre-operative CT or MRI scan image. A real-time medical image (or real-time medical imaging stream) can refer to a medical image (or real-time medical imaging stream) received in real-time. The medical image received in real-time can correspond to a live image, such as a live medical image generated by an ultrasound or other image, such as a pre-operative or intra-operative CT image or MRI image that is communicated in real-time.

[0185] In some embodiments, the system **100** can use the second emplacement data and one or more characteristics of the second emplacement sensor or associated second medical device (or a corresponding second virtual medical device) to determine the emplacement of the medical image. For example, the characteristics may indicate an emplacement of the medical image relative to the second emplacement sensor or associated second medical device (or second virtual medical imaging device).

[0186] The system **100** can determine the emplacement of the medical image relative to the second emplacement sensor and/or associated second medical device (or second virtual medical imaging device). For example, the system **100** can use a known relationship between the second emplacement data and the emplacement of the medical image (non-limiting example: the medical image begins 2 cm. away from the of the second emplacement data location in a particular direction and ends 5 cm. away) and/or use a known relationship between the emplacement of the second emplacement sensor and/or associated second medical device (or second virtual medical imaging device) and the emplacement of the medical image (non-limiting examples: the medical image begins 4 cm. from the tip of the second medical device (or second virtual medical imaging device) and ends at the tip of the second medical device (or second virtual medical imaging device), or the medical image extends 2 cm. in either direction from the ends of the second emplacement sensor).

[0187] In certain embodiments, the system **100** can determine the emplacement of the medical image in one or more coordinate systems by mapping the first emplacement data, from one coordinate system to a second coordinate system. For example, the second emplacement data may be received with respect to a first coordinate system, such as a position sensing coordinate system, and then mapped to a second coordinate system, such as a 3D scene coordinate system and/or a screen coordinate system. The emplacement of the medical image can be determined with respect to one or more of the coordinate systems. For example, the emplacement of the medical image can be determined after the second emplacement data has been mapped to the second coordinate system, such as the 3D scene coordinate system and/or the screen coordinate system, or the emplacement of the medical image can be determined for the first coordinate system, such as the position sensing coordinate system, and then mapped to the 3D scene coordinate system and/or the screen coordinate system. In certain embodiments, the system **100** can also use point-of-view location to determine the emplacement of the medical image.

[0188] As described above with respect to block **1006**, in certain embodiments, the system **100** can also use an offset to determine the emplacement of the medical image for viewing. For example, the system **100** can determine an initial emplacement of the medical image in the 3D scene coordinate system and/or the screen coordinate system, and then apply an offset to the initial emplacement and/or the system **100** can determine an initial emplacement of the medical image in the position sensing coordinate system and apply an offset to the initial emplacement prior to mapping the emplacement of the medical image in the position sensing coordinate system to the 3D scene coordinate system and/or the screen coordinate system.

[0189] The offset can be made in one, or a combination of, coordinate systems, and/or with respect to one, or a combination of, axes. In certain embodiments, the offset can be made along a y-axis (up/down) of the position sensing coordinate system, the 3D scene coordinate system and/or the screen coordinate system. For example, the system **100** can adjust the y-coordinate (up/down coordinate) of the determined emplacement of the medical image (or the first emplacement sensor) in the position sensing coordinate system by the offset amount. When mapped to the 3D scene coordinate system and/or the screen coordinate system, the system **100** can use the adjusted emplacement. As yet another example, the system **100** can adjust the y-coordinate (up/down coordinate) of the determined emplacement of the medical image (or the first emplacement sensor) in the 3D scene coordinate system and/or the screen coordinate system by the offset amount. Any combination of the above-refer-

enced examples can be used as desired. Furthermore, it will be understood that the offset can be made in any one or any combinations of the coordinate systems and with reference to any one or any combination of the axes. For example, the adjustment can be made along any one or any combination of the x-axis, y-axis, or z-axis.

[0190] Furthermore, the offset can be a predetermined offset and/or a dynamic offset. In some embodiments, a predetermined offset can be used. For example, the system 100 can use a static offset based on an average height of males and/or females or average distance between elbows and hands, the height of the user, a distance between the user's elbow and eyes, expected location of a user with respect to the imaged volume, etc. In certain embodiments, the system 100 can use a dynamic offset, such as a determined emplacement of an HMD relative to one or more emplacement sensors, position sensing region, and/or position sensing unit coordinate system. For example, the system 100 can determine the emplacement of an HMD relative to a medical device or imaged area and adjust the offset such that the medical image is always in view on the displays of an HMD. With continued reference to the example, if the wearer crouches down or turns to the side, the system 100 can determine the change in relative emplacement between the HMD and the medical device or imaged area and adjust the offset such that the medical image remains in view in substantially the same emplacement.

[0191] In addition, it will be understood that the offset described herein with reference to the medical image can be applied to any one or any combination of the objects to be displayed and/or to all contents of the virtual 3D scene. In some embodiments, the offset can be applied to some objects to be displayed but not others.

[0192] At block 1012, the system 100 can identify a selected surface of the second virtual medical device based at least in part on a point-of-view location. As described herein, the selected surface can include the beginning-surface, the ending-surface, the front-surface, the back-surface, the exterior surface, a side-surface, or other surfaces, or one or more portions thereof.

[0193] In some cases, the one or more surfaces can be identified using one or more view-rays, as described herein. For example, imagine a plurality of view-rays extending from the point-of-view location to the second virtual medical device. As described herein, in some cases, the beginning-surface of second virtual medical device can be identified by determining, for multiple or all view-rays, the view-ray's first entry point or first intersection with the second virtual medical device. To determine the beginning-surface, the system can aggregate a first entry point or first intersection from multiple view rays. In addition or alternatively, as described herein, in some cases, the ending-surface of second virtual medical device can be identified by determining, for multiple view-rays, the final exit point or last intersection with the second virtual medical device. To determine the ending-surface, the system can aggregate the final exit point from multiple view-rays. In some cases, the view-rays can extend from a plane of reference, rather than a point-of-reference. For example, the view-rays can extend orthogonally or obliquely from a plane of reference and a subset of the view-rays can intersect with the second virtual medical device, as described above. In this implementation, the beginning-surface can be identified by aggregating the initial entry points from multiple or all of the view-rays,

and/or the ending-surface can be identified by aggregating the final exit points from multiple or all of the view-rays.

[0194] In some cases, the one or more surfaces can be identified based at least in part on the orientation of the second virtual medical device relative to the point-of-view location. For example, in some cases, a front-surface of the second virtual medical device can be identified by selecting or identifying surfaces, edges, or other portions of the second virtual medical device that are facing the point-of-view location. Similarly, in some cases, a back-surface of the second virtual medical device can be identified by selecting or identifying surfaces, edges, or other portions of the second virtual medical device that are not facing the point-of-view location.

[0195] Furthermore, in some cases, a beginning-surface of the second virtual medical device can be identified by selecting or identifying surfaces, edges, or other portions of the second virtual medical device that are facing the point-of-view location and that are not occluded from view by the second virtual medical device's shape. For example, to identify the beginning-surface, the system can determine portions of the second virtual medical device that face, or are oriented towards, the point-of-view location. In other words, the system can determine a front-surface of the second virtual medical device. From those portions that face the point-of-view location (or from the front-surface), the system can select, identify, or determine surfaces, edges, or other portions of the second virtual medical device that are not obstructed from view when viewed from the point-of-view location.

[0196] In some cases, the one or more surfaces can be identified based at least in part on the point-of-view location. For example, the beginning-surface of the second virtual medical device be identified by selecting or identifying surfaces, edges, or other portions of the second virtual medical device that are visible from a point-of-view location.

[0197] At block 1014, the system 100 can cause a display to display a view of a virtual 3D scene including a rendering of at least a portion of the first virtual medical device based at least in part on the determined emplacement of the first virtual medical device. In some embodiments, the display of the first virtual medical device can be based at least in part on dimensions of a corresponding real medical device (non-limiting examples: size, shape, or other appearance). As a non-limiting example, the first virtual medical device can include a medical needle. Thus, in some embodiments, the rendering of at least a portion of the first virtual medical device includes at least a portion of a medical needle. However, it will be understood that the rendering of at least a portion of the first virtual medical device can include any portions of the first virtual device.

[0198] In addition or alternatively, at block 1014, the system 100 can cause a display to display a view of a virtual 3D scene including a rendering of at least a portion of the medical image based at least in part on the determined emplacement of the second virtual medical device. In some cases, the rendering can include perspective rendering, an orthographic projection, or any other camera projection or viewpoint.

[0199] As described above, the view or rendering of the medical image or first virtual medical device can be determined and displayed based at least in part on a point-of-view location. The point-of-view location can be a fixed point-

of-view location or a dynamic point-of-view location. For example, the point-of-view location can be set with respect to a specific location in front of the display and/or can be based on a tracked location of the display, the HMD, or the user. In some embodiments, the point-of-view location is determined based at least in part on the relative emplacement of an HMD or user with respect to the position sensing region or imaged volume, or the emplacement of an HMD within a position sensing coordinate system. In embodiments, in which the point-of-view location is based on a tracked location, the system **100** can enable the user to view different views of the virtual 3D scene based on the changing emplacement of the tracked object (HMD, user) relative to the medical devices **140, 145** or the position sensing region.

[0200] In certain embodiments, the system **100** can determine multiple emplacements for the first virtual medical device or medical image. For example, the system **100** can determine the emplacement for the medical image for a right-eye view and a left-eye view of a stereoscopic display, such as a HMD. In this way, each display for the HMD can display the medical image from a slightly different perspective corresponding to a right-eye view and a left-eye view, etc.

[0201] At block **1016**, the system **100** can cause the display to display a selective-transparency rendering of at least a portion of the selected surface(s) of the second virtual medical device. This rendering can be based at least in part on the determined emplacement of the second virtual medical device. Furthermore, the rendering can be based at least in part on the identification of the selected surface(s) at block **1012**.

[0202] As described herein, the selective-transparency rendering of the selected surface(s) of the second virtual medical device can include a display of the selected surface at varying transparency levels, with other portions of the second virtual medical device, such as the non-selected surfaces being omitted, not shown, or completely transparent. It will be understood that multiple surfaces can be used as part of a selective-transparency rendering. For example, a selective-transparency surface rendering can include a beginning-surface, ending-surface, front-surface, rear-facing surface, side-facing surface, etc.

[0203] The selective-transparency rendering of the selected surface can be implemented with the selected surface becoming less transparent as it gets closer to an edge. In this way, image guidance data, such as the first virtual medical device, the medical image, or image guidance cues can be visible through the second virtual medical device, and the spatial relationships between each of the first virtual medical device, second virtual medical device, medical image, and image guidance cues can be accurately identified. In some embodiments, the selective-transparency rendering of the selected surface of the second virtual medical device can reduce the number of displayed lines and improve a user's ability to properly understand the correct orientation of the second virtual medical device.

[0204] It will be understood that the selective-transparency of the selected surface can be implemented in a variety of ways. For example, the selective-transparency can include displaying the selected surface at the same transparency level, displaying edges of the surface opaquely or as solid or dashed lines (non-limiting example: wire frame) and the rest of the selected surface transparently or vice versa, displaying portions of the surface that are in front of another

display object transparently or more transparently than portions of the selected surface that are not in front of another display object, etc.

[0205] Moreover, when a selective-transparency rendering includes multiple surfaces, each surface can be rendered using the same selective-transparency or different selective transparencies. For example, a beginning-surface can be rendered such that portions of the beginning-surface that are closer to an edge are rendered at a different opacity (for example, more opaquely) than portions that are farther away from an edge. As another example, an ending-surface can be rendered such that the entire surface has a single level of transparency or alternatively can be rendered such that only edges of the ending-surface are rendered opaquely, while other portions of the ending-surface are render with a diminished opacity or are completely transparent.

[0206] Furthermore, as described herein, the selected surfaces can be rendered selectively transparent in a variety of ways. For example, the system can render portions of the selected surface of the second virtual medical device that overlap with other display objects (for example, the first virtual medical device or the medical image) transparently or more transparently than non-overlapping portions of the second virtual medical device, which can be rendered opaquely (for example, like the transducer **106** as illustrated in FIG. **3**). In certain embodiments, the non-overlapping portions of the second virtual medical device can be displayed at one or more different transparency levels similar to the overlapping portions of the selected surface.

[0207] In some embodiments, the rendering of the second virtual medical device can include shading and other visualization techniques to illustrate contours of the second medical device. For example, in some cases, surface shading can be added to the selected surface rendering of the second virtual medical device, which can make the second virtual medical device more salient and easier to see, despite its transparency.

[0208] As described herein, in some cases, rendering the selective-transparency rendering of the selected surface of the second virtual medical device can include omitting, ignoring, rendering transparently or otherwise not showing portions of the second virtual medical device that are not portions of the selected surface(s). For example, portions that are not part of the selected surface can include the beginning-surface, ending-surface, back-surface, front-surface, interior, one or more sides, or the like.

[0209] It will be understood that the various blocks described herein can be implemented in a variety of orders, and that the system **100** can implement one or more of the blocks concurrently and/or change the order, as desired. For example, the system **100** can concurrently receive the emplacement data from different sources, concurrently receive the medical image, or receive the data in any order. Similarly, the system **100** can concurrently determine the emplacement of the medical image and/or one or more virtual medical devices, etc.

[0210] Furthermore, it will be understood that fewer, more, or different blocks can be used as part of the routine **1000**. For example, the routine **1000** can include blocks for receiving emplacement data associated with additional emplacement sensors or medical devices, determining emplacements of one or more medical devices, corresponding virtual medical devices, other display objects, displays, and/or users. In some embodiments, the routine **1000** can

include determining an emplacement of a medical device associated with the medical image and determining the emplacement of the medical image based at least in part on the determined emplacement of the medical device (or corresponding virtual medical device), and display the virtual medical device concurrently with the medical image. Furthermore, the system **100** can determine and display a variety of image guidance cues, such as trajectory indicators, affected region indicators, intersection indicators, or medical devices in different states or configurations.

[0211] Furthermore, similar to the identification of the selected surface of the second virtual medical device, the system can identify a selected surface of other image guidance data, such as the first second virtual medical device or the medical image based at least in part on the point-of-view location, the system can render those one or more selected surfaces. For example, it can be advantageous for the physician to see at least the selected surface of every display object. Accordingly, in some cases, each display object (or portion of each display object) that is not blocked by another display object (with respect to the point-of-view location) can be rendered with a selective-transparency rendering of the selected surface. For instance, referring to the illustrated embodiment of FIG. **4**, a portion of the virtual needle **102** overlaps with a portion of the medical image **104**. In some cases, at least one of the selected surfaces of the virtual needle **102** or the medical image **104** can be displayed using a selective-transparency rendering such that each selected surface portion of every portion of image guidance data is visible to the physician. Furthermore, in some embodiments, all of the image guidance data, or a subset thereof, can be displayed using a selective-transparency rendering.

[0212] Furthermore, in some cases, as described herein, the system can identify and/or selectively display one or more fragments corresponding to the display objects. For example, the system can determine what is to be displayed at the different pixels of the display **170** by fragmenting the display objects or treating a display object as a combination of fragments. For example, multiple fragments of the same display object or different display objects can be mapped to the same pixel (non-limiting example: located at the same vertical and horizontal coordinate of the screen **170**). When this occurs, the system can determine which fragment, or combination thereof, to display at the pixel.

[0213] As described herein, the system can use a variety of techniques to determine which fragment or combination of fragments are to be displayed at the pixel, such as, but not limited to, depth order, a fragment identifier, a priority identifier, and/or transparency level, etc. For example, in some cases, the system can display use the fragment(s) corresponding to the display object that is closest to the point-of-view location to determine what is to be displayed at the pixel, and discard fragments from other display objects. In certain cases, the system can use the fragment with the highest priority identifier or level to determine what is to be displayed at the pixel. For example, if fragments for an image guidance cue (having the highest priority identifier), medical image (having the lowest priority identifier), and transducer are mapped to the same pixel, the system can use the image guidance cue fragment to determine what to display at the pixel and discard the transducer and medical image fragments. In another instance and with reference to the same example, the system can use a combination of the image guidance cue and transducer to determine what to

display at the pixel, etc. In some embodiments, the system can use a combination of features to determine what is to be displayed at the pixel. For example, the system can use depth order and a priority identifier to determine which fragments to use for a pixel.

[0214] In addition, in some cases, the routine **1000** can omit certain blocks, such as, but not limited to, blocks **1002**, **1004**, **1006**, **1010**, and/or **1014**. For example, in some embodiments, the system may not determine emplacement of and/or may not display a portion of the first virtual medical device or a portion of the medical image.

[0215] FIG. **11** is a flow diagram illustrative of an embodiment of a routine implemented by the system for improved perception of a display object in a virtual 3D scene for medical device navigation. One skilled in the relevant art will appreciate that the elements outlined for routine **1100** can be implemented by one or more computing devices/components that are associated with the system **100**, such as the position sensing unit **130**, the image guidance unit **150**, surgical system **180**, an HMD, and/or the imaging unit **160**. Accordingly, routine **1100** has been logically associated as being generally performed by the system **100**. However, the following illustrative embodiment should not be construed as limiting. Furthermore, it will be understood that the various blocks described herein with reference to FIG. **11** can be implemented in a variety of orders. For example, the system **100** can implement some blocks concurrently or change the order as desired. Furthermore, it will be understood that fewer, more, or different blocks can be used as part of the routine **1100**. However, it will be understood that any of the blocks (and more or different blocks) can be implemented as part of routine **1100**.

[0216] At block **1102**, as described similarly above with reference to block **1008** of FIG. **10**, the system **100** can determine an emplacement of a first display object. This determination can be based at least in part on received emplacement data. As described herein, display objects can include virtual medical device, medical images, or the like. In some cases, this routine can be implemented for image guidance data other than display objects, such as image guidance cues like trajectory indicators, affected region indicators, or intersection indicators.

[0217] At block **1104**, as described similarly above with reference to block **1012** of FIG. **10**, the system **100** can identify a first selected surface of the display object relative to a point-of-view location. As described herein, the first selected surface can include the beginning-surface, the ending-surface, the front-surface, the back-surface, the exterior surface, a side-surface, or other surfaces, or one or more portions thereof.

[0218] At block **1104**, the system **100** can identify a second selected surface of the display object that is different from the first selected surface. In some embodiments, the second selected surface can be identified in a manner similar to the first selected surface. As described herein, the second selected surface can include the beginning-surface, the ending-surface, the front-surface, the back-surface, the exterior surface, a side-surface, or other surfaces, or one or more portions thereof, and can be different from the first selected surface.

[0219] At block **1108**, as similarly described above with respect to block **1016** of FIG. **10**, the system **100** can display a selective-transparency surface rendering of the first selected surface of the display object.

[0220] As a non-limiting example, the first selected surface can include the beginning-surface of the display object. As described herein, the selective-transparency beginning-surface rendering of the display object can include a display of the beginning-surface at varying transparency levels, with other portions of the display object, such as the back-, ending-, interior, or sides being omitted, shown differently, not shown, or shown completely transparently. In some cases, the selective-transparency beginning-surface rendering can be implemented with the beginning-surface becoming less transparent as it gets closer to an edge. In this way, image guidance data, such as another display object or image guidance cues can be visible through the display object, and the spatial relationships between each of the display object and other image guidance data can be accurately identified. In some embodiments, the selective-transparency beginning-surface rendering of the display object can reduce the number of displayed lines and improve a user's ability to properly understand the correct orientation of the display object.

[0221] It will be understood that the selective-transparency beginning-surface rendering can be implemented in a variety of ways. For example, the selective-transparency can include displaying the beginning-surface at a single transparency level, displaying edges of the surface opaquely or as solid or dashed lines (non-limiting example: wire frame) and the rest of the beginning-surface transparently or vice versa, displaying portions of the beginning-surface that are in front of another display object transparently or more transparently than portions of the beginning-surface that are not in front of another display object, etc.

[0222] Furthermore, as described herein, the beginning-surface can be rendered selectively transparent in a variety of ways. For example, the system can render portions of the beginning-surface of the display object that overlap with other display objects (for example, another display object or image guidance cues) transparently or more transparently than non-overlapping portions of the display object, which can be rendered opaquely (for example, like the transducer 106 as illustrated in FIG. 3). In certain embodiments, the non-overlapping portions of the display object can be displayed at one or more different transparency levels similar to the overlapping portions of the beginning-surface.

[0223] In some embodiments, the rendering of the beginning-surface can include shading and other visualization techniques to illustrate contours of the second medical device. For example, in some cases, surface shading can be added to the beginning-surface rendering of the second virtual medical device, which can make the second virtual medical device more salient and easier to see, despite its transparency.

[0224] As described herein, in some cases, the selective-transparency beginning-surface rendering can include omitting, ignoring, rendering transparently or otherwise not showing portions of the display object that are not portions of the beginning-surface. For example, portions that are not part of the beginning-surface can include the ending-surface, back-surface, interior, one or more sides, or the like.

[0225] At block 1110, as similarly described above with respect to blocks 1108, the system 100 can cause the display to display a selective surface rendering of at least a portion of the second selected surface of the display object.

[0226] As a non-limiting example, the second selected surface can include the ending-surface of the display object.

When a selective-transparency surface rendering includes multiple surfaces, such as a first and second surface or a beginning- and ending-surface, each surface can be rendered using the same selective-transparency or different selective transparencies. For example, a beginning-surface can be rendered such that portions of the beginning-surface that are closer to an edge are rendered at a different opacity (for example, more opaquely) than portions that are farther away from an edge. As another example, an ending-surface can be rendered such that the entire surface has a single level of transparency or alternatively can be rendered such that only edges of the ending-surface are rendered opaquely, while other portions of the ending-surface are render with a diminished opacity or are completely transparent.

[0227] It will be understood that the various blocks described herein can be implemented in a variety of orders, and that the system 100 can implement one or more of the blocks concurrently and/or change the order, as desired. For example, the system 100 can concurrently receive the emplacement data from different sources, concurrently receive the medical image, or receive the data in any order. Similarly, the system 100 can concurrently determine the emplacement of the medical image and/or one or more virtual medical devices, etc.

[0228] Furthermore, it will be understood that fewer, more, or different blocks can be used as part of the routine 1100. For example, the routine 1100 can include blocks for receiving emplacement data associated with additional emplacement sensors or medical devices, determining emplacements of one or more medical devices, corresponding virtual medical devices, other display objects, displays, and/or users. In some embodiments, the routine 1100 can include receiving emplacement data or determining an emplacement of a medical device associated with the medical image and determining the emplacement of the medical image based at least in part on the determined emplacement of the medical device (or corresponding virtual medical device), and display the virtual medical device concurrently with the medical image. Furthermore, the system 100 can determine and display a variety of image guidance cues, such as trajectory indicators, affected region indicators, as described above. In addition, in some cases, the routine 1100 can omit certain blocks, such as, but not limited to, blocks 1104 and 1108, or 1106 and 1110. For example, in some embodiments, the system may not identify or display a beginning-surface of the display object. Similarly, in some embodiments, the system may not identify or display an ending-surface of the display object.

[0229] In some cases, multiple display objects can be displayed using the same or different selective-transparency renderings. For example, if two or more objects overlap, the closest display object or portion thereof (relative to the point-of-view location) can be displayed using a first selective-transparency rendering, and the second closest display object or portion thereof (relative to the point-of-view location) can be displayed using a second selective-transparency rendering. In some cases, the first and second selective-transparency renderings of the first and second display objects can be different. For example, the second display object can use a different selective-transparency scheme, such as more transparent or a single transparency level. In some cases, using different selective-transparency rendering schemes to display different display object can allow overlapping portions of different display objects to be

visible to the user, and can enable the user to understand the spatial relationships between each display object, or other image guidance data.

[0230] Furthermore, in some cases, as described herein, the system can identify and/or selectively display one or more fragments corresponding to the display objects. For example, the system can determine what is to be displayed at the different pixels of the display **170** by fragmenting the display objects or treating a display object as a combination of fragments. For example, multiple fragments of the same display object or different display objects can be mapped to the same pixel (non-limiting example: located at the same vertical and horizontal coordinate of the screen **170**). When this occurs, the system can determine which fragment, or combination thereof, to display at the pixel.

[0231] As described herein, the system can use a variety of techniques to determine which fragment or combination of fragments are to be displayed at the pixel, such as, but not limited to, depth order, a fragment identifier, a priority identifier, and/or transparency level, etc. For example, in some cases, the system can display use the fragment(s) corresponding to the display object that is closest to the point-of-view location to determine what is to be displayed at the pixel, and discard fragments from other display objects. In certain cases, the system can use the fragment with the highest priority identifier or level to determine what is to be displayed at the pixel. For example, if fragments for an image guidance cue (having the highest priority identifier), medical image (having the lowest priority identifier), and transducer are mapped to the same pixel, the system can use the image guidance cue fragment to determine what to display at the pixel and discard the transducer and medical image fragments. In another instance and with reference to the same example, the system can use a combination of the image guidance cue and transducer to determine what to display at the pixel, etc. In some embodiments, the system can use a combination of features to determine what is to be displayed at the pixel. For example, the system can use depth order and a priority identifier to determine which fragments to use for a pixel.

[0232] In addition, it will be understood that the various blocks described herein with reference to FIG. **11** can be implemented in routine **1100**, in a variety of orders. For example, the system **100** can implement some or all of various blocks of FIG. **11** in routine **1100** concurrently or change the order as desired. In addition or alternatively, it will be understood that any of the various blocks described herein with reference to FIG. **10** can be implemented in routine **1100**, in a variety of orders. For example, the system **100** can implement some or all of various blocks of FIG. **10** in routine **1100** concurrently or change the order as desired.

Terminology

[0233] Conditional language, such as, among others, "can," "could," "might," or "may," unless specifically stated otherwise, or otherwise understood within the context as used, is generally intended to convey that certain embodiments include, while other embodiments do not include, certain features, elements, and/or steps. Thus, such conditional language is not generally intended to imply that features, elements and/or steps are in any way required for one or more embodiments or that one or more embodiments necessarily include logic for deciding, with or without user input or prompting, whether these features, elements and/or steps are included or are to be performed in any particular embodiment.

[0234] Unless the context clearly requires otherwise, throughout the description and the claims, the words "comprise," "comprising," and the like are to be construed in an inclusive sense, as opposed to an exclusive or exhaustive sense; that is to say, in the sense of "including, but not limited to." As used herein, the terms "connected," "coupled," or any variant thereof means any connection or coupling, either direct or indirect, between two or more elements; the coupling or connection between the elements can be physical, logical, or a combination thereof. Additionally, the words "herein," "above," "below," and words of similar import, when used in this application, refer to this application as a whole and not to any particular portions of this application. Where the context permits, words in the above Detailed Description using the singular or plural number may also include the plural or singular number respectively. The word "or" in reference to a list of two or more items, covers all of the following interpretations of the word: any one of the items in the list, all of the items in the list, and any combination of the items in the list. Likewise the term "and/or" in reference to a list of two or more items, covers all of the following interpretations of the word: any one of the items in the list, all of the items in the list, and any combination of the items in the list.

[0235] Depending on the embodiment, certain operations, acts, events, or functions of any of the algorithms described herein can be performed in a different sequence, can be added, merged, or left out altogether (non-limiting example: not all are necessary for the practice of the algorithms). Moreover, in certain embodiments, operations, acts, functions, or events can be performed concurrently, non-limiting examples: through multi-threaded processing, interrupt processing, or multiple processors or processor cores or on other parallel architectures, rather than sequentially.

[0236] The various illustrative logical blocks, modules, routines, and algorithm steps described in connection with the embodiments disclosed herein can be implemented as electronic hardware, or as a combination of electronic hardware and executable software. To clearly illustrate this interchangeability, various illustrative components, blocks, modules, and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware, or as software that runs on hardware, depends upon the particular application and design constraints imposed on the overall system **100**. The described functionality can be implemented in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the disclosure.

[0237] Moreover, the various illustrative logical blocks and modules described in connection with the embodiments disclosed herein can be implemented or performed by a machine, such as a processor device, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A processor device can be a microprocessor, but in the alternative, the processor device can be a controller, microcontroller, or combinations of the same, or the like. A processor device can

include electrical circuitry configured to process computer-executable instructions. In another embodiment, a processor device includes an FPGA or other programmable device that performs logic operations without processing computer-executable instructions. A processor device can also be implemented as a combination of computing devices, non-limiting examples: a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration. Although described herein primarily with respect to digital technology, a processor device may also include primarily analog components. For example, some or all of the signal processing algorithms described herein may be implemented in analog circuitry or mixed analog and digital circuitry. A computing environment can include any type of computer system, including, but not limited to, a computer system based on a microprocessor, a mainframe computer, a digital signal processor, a portable computing device, a device controller, or a computational engine within an appliance, to name a few.

[0238] The elements of a method, process, routine, or algorithm described in connection with the embodiments disclosed herein can be embodied directly in hardware, in a software module executed by a processor device, or in a combination of the two. A software module can reside in RAM memory, flash memory, ROM memory, EPROM memory, EEPROM memory, registers, hard disk, a removable disk, a CD-ROM, or any other form of a non-transitory computer-readable storage medium. An exemplary storage medium can be coupled to the processor device such that the processor device can read information from, and write information to, the storage medium. In the alternative, the storage medium can be integral to the processor device. The processor device and the storage medium can reside in an ASIC. The ASIC can reside in a user terminal. In the alternative, the processor device and the storage medium can reside as discrete components in a user terminal.

[0239] Further, the processing of the various components of the illustrated systems can be distributed across multiple machines, networks, and other computing resources. In addition, two or more components of a system can be combined into fewer components. Various components of the illustrated systems can be implemented in one or more virtual machines, rather than in dedicated computer hardware systems and/or computing devices.

[0240] Virtualization technologies allow a single physical computing device to host one or more instances of a virtual machine, which virtual machine instance appears to a user as an independent computing device. With virtualization, the host computing device can create, maintain, delete, or otherwise manage virtual machines instances in a dynamic manner. In turn, users can request computing resources, including single computing devices or a configuration of networked computing devices, and be provided with virtual machine instances that provide the requested computing resources.

[0241] An instance of a virtual machine may be configured to provide specific functionality. For example, a virtual machine instance may be associated with different combinations of software applications and operating systems or operating system configurations to enable a virtual machine to provide different desired functionalities, or to provide similar functionalities more efficiently.

[0242] Any patents and applications and other references noted above, including any that may be listed in accompanying filing papers, are incorporated herein by reference. Aspects of the invention can be modified, if necessary, to employ the systems, functions, and concepts of the various references described above to provide yet further implementations of the invention.

[0243] These and other changes can be made to the invention in light of the above Detailed Description. While the above description describes certain examples of the invention, and describes the best mode contemplated, no matter how detailed the above appears in text, the invention can be practiced in many ways. Details of the system may vary considerably in its specific implementation, while still being encompassed by the invention disclosed herein. As noted above, particular terminology used when describing certain features or aspects of the invention should not be taken to imply that the terminology is being redefined herein to be restricted to any specific characteristics, features, or aspects of the invention with which that terminology is associated. In general, the terms used in the following claims should not be construed to limit the invention to the specific examples disclosed in the specification, unless the above Detailed Description section explicitly defines such terms. Accordingly, the actual scope of the invention encompasses not only the disclosed examples, but also all equivalent ways of practicing or implementing the invention under the claims.

[0244] To reduce the number of claims, certain aspects of the invention are presented below in certain claim forms, but the applicant contemplates the various aspects of the invention in any number of claim forms. For example, while only one aspect of the invention may be recited as a means-plus-function claim under 35 U.S.C sec. 108(f) (AIA), other aspects may likewise be embodied as a means-plus-function claim, or in other forms, such as being embodied in a computer-readable medium. Any claims intended to be treated under 35 U.S.C. § 108(f) will begin with the words "means for", but use of the term "for" in any other context is not intended to invoke treatment under 35 U.S.C. § 108(f). Accordingly, the applicant reserves the right to pursue additional claims after filing this application, in either this application or in a continuing application.

[0245] Disjunctive language such as the phrase "at least one of X, Y, or Z," unless specifically stated otherwise, is otherwise understood with the context as used in general to present that an item, term, etc., may be either X, Y, or Z, or any combination thereof (non-limiting examples: X, Y, and/or Z). Thus, such disjunctive language is not generally intended to, and should not, imply that certain embodiments require at least one of X, at least one of Y, or at least one of Z to each be present.

[0246] Unless otherwise explicitly stated, articles such an "a" or "an" should generally be interpreted to include one or more described items. Accordingly, phrases such as "a device configured to" are intended to include one or more recited devices. Such one or more recited devices can also be collectively configured to carry out the stated recitations. For example, "a processor configured to carry out recitations A, B and C" can include a first processor configured to carry out recitation A working in conjunction with a second processor configured to carry out recitations B and C.

[0247] While the above detailed description has shown, described, and pointed out novel features as applied to

various embodiments, it can be understood that various omissions, substitutions, and changes in the form and details of the devices or algorithms illustrated can be made without departing from the spirit of the disclosure. As can be recognized, certain embodiments described herein can be embodied within a form that does not provide all of the features and benefits set forth herein, as some features can be used or practiced separately from others. The scope of certain embodiments disclosed herein is indicated by the appended claims rather than by the foregoing description. All changes which come within the meaning and range of equivalency of the claims are to be embraced within their scope.

[0248] The previous description of the disclosed implementations is provided to enable a person skilled in the art to make or use the present invention. Various modifications to these implementations will be readily apparent to those skilled in the art, and the generic principles defined herein can be applied to other implementations without departing from the spirit or scope of the invention. Furthermore, although described above with reference to medical devices and procedures, it will be understood that the embodiments described herein can be applied to other systems in which non-medical objects are tracked and non-medical image streams are received, and virtual representations are displayed on a display and/or systems in which multiple objects are displayed on a display within a virtual space, such as within a virtual 3D space. Thus, the present invention is not intended to be limited to the implementations shown herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

I claim:

1. A method for providing image guidance, the method comprising:

receiving first emplacement data associated with a first device tracker associated with a first medical device;

receiving second emplacement data associated with a second device tracker associated with a second medical device;

determining an emplacement of a first virtual medical device corresponding to the first medical device based at least in part on the first emplacement data;

determining an emplacement of a second virtual medical device corresponding to the second medical device based at least in part on the second emplacement data;

determining an emplacement of a medical image associated with the second medical device based at least in part on the second emplacement data;

identifying a selected surface of the second virtual medical device based at least in part on a point-of-view location;

causing one or more displays to concurrently display:

a 3D rendering of at least a portion of the first virtual medical device based at least in part on the determined emplacement of the first virtual medical device,

a 3D rendering of at least a portion of the medical image based at least in part on the determined emplacement of the medical image, and

a selective-transparency rendering of the selected surface.

2. The method of claim 1, wherein the selected surface comprises a beginning-surface of the second virtual medical device or an ending-surface of the second virtual medical device.

3. The method of claim 1, wherein said identifying the selected surface of the second virtual medical device comprises identifying regions of the second virtual medical device that are visible from the point-of-view location.

4. The method of claim 1, wherein said identifying the selected surface of the second virtual medical device comprises:

determining surfaces of the second virtual medical device that face the point-of-view location; and

identifying, from the surfaces that face the point-of-view location, portions of the second virtual medical device that are not obstructed from view when viewed from the point-of-view location.

5. The method of claim 2, wherein said identifying the selected surface of the second virtual medical device comprises discarding portions of the second virtual medical device that are not visible from the point-of-view location.

6. The method of claim 2, wherein the selected surface of the second virtual medical device corresponds to a plurality of view-rays extending from the point-of-view location to the second virtual medical device, wherein said identifying the selected surface of the second virtual medical device comprises:

determining, for multiple view-rays of the plurality of view-rays, a first entry point into the second medical device; and

aggregating that first entry points of the multiple view-rays.

7. The method of claim 2, further comprising:

determining, based at least in part on the emplacement of the second virtual medical device and the emplacement of the medical image, that a section of the medical image intersects with a section of the second virtual medical device; and

selecting the at least a portion of the medical image such that it excludes the section of the medical image that intersects with the section of the second virtual medical device.

8. The method of claim 2, further comprising:

determining, based at least in part on the emplacement of the first virtual medical device and the emplacement of the second virtual medical device, that a portion of image guidance cues corresponding to the first virtual medical device intersects with a section of the second virtual medical device; and

causing one or more displays to concurrently display the image guidance cues, wherein the portion of image guidance cues that intersects with the section of the second virtual medical device is displayed at a different opacity than other portions of the image guidance cues that do not intersect with the section of the second virtual medical device.

9. The method of claim 1, further comprising determining that the second virtual medical device is proximate to the point-of-view location relative to the first virtual medical device and the medical image based at least in part on the determined emplacements of the first virtual medical device, the second virtual medical device, or the medical image.

10. The method of claim 1, where the selected surface is a beginning-surface of the second virtual medical device,

wherein the selective-transparency is a first selective-transparency, wherein the method further comprises:

identifying an ending-surface of the second virtual medical device based at least in part on a point-of-view location; and

causing one or more displays to concurrently display a second selective-transparency rendering of the ending-surface.

11. The method of claim 1, wherein the point-of-view location comprises at least one of an actual location of a user, an expected location of user, or a fixed location relative to the one or more displays.

12. The method of claim 1, wherein the first medical device and the second medical device comprise at least one of an ultrasound transducer, a medical needle, a grasper, a stapler, a vessel sealer, an electrocautery device, a resecting device, a transecting device, a scalpel, a catheter, a stent, or a laparoscopic camera.

13. A method for providing image guidance, the method comprising:

receiving emplacement information associated with a medical device;

determining an emplacement of a display object associated with the medical device relative to a point-of-view location;

identifying a selected surface of the display object based at least in part on the point-of-view location; and

causing a display to display a selective-transparency surface rendering of the selected surface of the display object.

14. The method of claim 13, wherein the selected surface comprises a beginning-surface of the display object or an ending-surface of the display object.

15. The method of claim 13, wherein the selected surface is a first selected surface, wherein the selective-transparency is a first selective-transparency, the method further comprising:

identifying a second selected surface of the display object based at least in part on the point-of-view location; and

causing a display to display a second selective-transparency surface rendering of the selected surface of the display object, wherein the second selected surface is different from the first selected surface.

16. The method of claim 13, wherein the first selected surface comprises a beginning-surface of the display object, wherein the second selected surface comprises an ending-surface of the display object.

17. The method of claim 13, wherein the selective-transparency comprises displaying edges of the selected surface opaquely and displaying non-edges of the selected surface transparently.

18. The method of claim 13, wherein the selective-transparency comprises displaying portions of the selected surface that are closer to an edge of the display object at a different opacity than portions of the selected surface that are farther away from an edge of the display object.

19. The method of claim 13, wherein the medical device comprises at least one of an ultrasound transducer, a medical needle, a grasper, a stapler, a vessel sealer, an electrocautery device, a resecting device, a transecting device, a scalpel, a catheter, a stent, or a laparoscopic camera.

20. A system, comprising:

a display; and

one or more processors in communication with the display and configured to:

receive emplacement information from a tracking device associated with a medical device;

determine an emplacement of a display object associated with the medical device relative to a point-of-view location;

identify a selected surface of the display object based at least in part on the point-of-view location; and

cause the display to display a selective-transparency surface rendering of the selected surface of the display object.

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摘要(译)

一种用于图像引导的系统和方法，其提供对用于医疗设备导航的渲染场景中的显示对象的改进的感知。该系统可以接收与医疗设备相关联的安放信息，并确定与医疗设备相关联的显示对象的安放。该系统可以进一步识别显示对象的选定表面并使显示器显示所选表面的选择性透明度渲染。