US 20250265714A1

(19) United States
(12) Patent Application Publication
(10) Pub. No.: US 2025/0265714 A1
(43) Pub. Date: Aug. 21, 2025
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(54) **PHYSICAL MEDICAL ELEMENT SIZING SYSTEMS AND METHODS**

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(21) Appl. No.: **19/199,851**

(22) Filed: **May 6, 2025**

Related U.S. Application Data

(63) Continuation of application No. 17/639,676, filed on Mar. 2, 2022, filed as application No. PCT/US2020/054295 on Oct. 5, 2020, now Pat. No. 12,322,089.

(60) Provisional application No. 62/911,851, filed on Oct. 7, 2019.

Publication Classification

(51) **Int. Cl.**

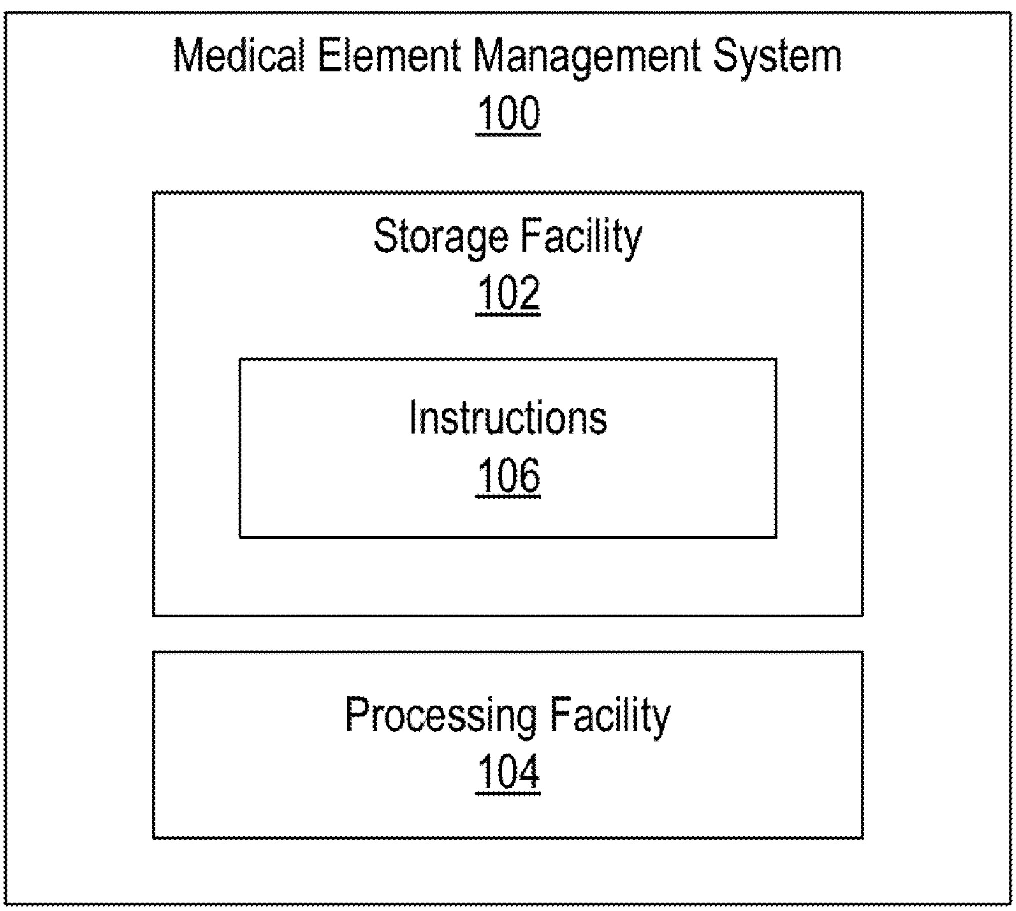
G06T 7/00	(2017.01)
A61B 34/20	(2016.01)
G06T 7/11	(2017.01)
G06T 19/00	(2011.01)
G06T 19/20	(2011.01)

(52) **U.S. Cl.**

CPC ***G06T 7/0012*** (2013.01); ***A61B 34/20*** (2016.02); ***G06T 7/11*** (2017.01); ***G06T 19/006*** (2013.01); ***G06T 19/20*** (2013.01); *G06T 2207/10081* (2013.01); *G06T 2210/41* (2013.01); *G06T 2219/2012* (2013.01); *G06T 2219/2016* (2013.01); *G06T 2219/2021* (2013.01)

(57) **ABSTRACT**

An illustrative system is configured to instruct a display device to render a virtual medical element representative of a physical medical element over a target region within an image of an internal space of a patient, the target region depicting an anatomical surface to be covered by the physical medical element; receive, while the virtual medical element is rendered over the target region, user input that sets at least one of a pose of the virtual medical element within the image or a size of the virtual medical element; and determine, based on the user input and on depth data representative of a depth map for the internal space, physical dimensions for the physical medical element.



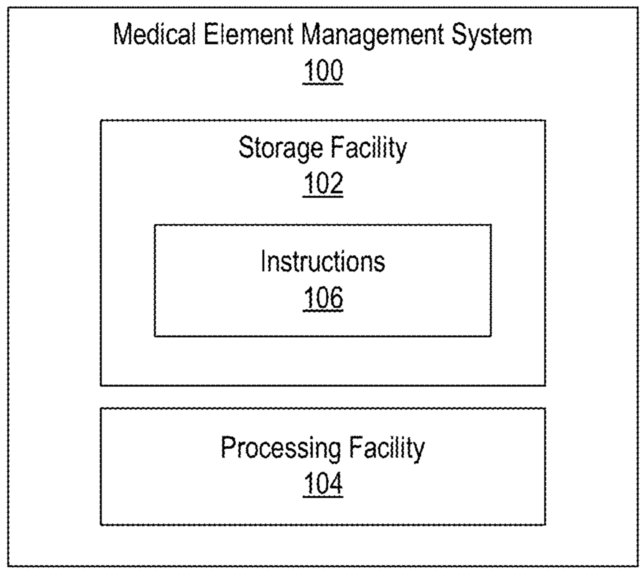

Medical Element Management System
100
Storage Facility
102
Instructions
106
Processing Facility
104

Fig. 1

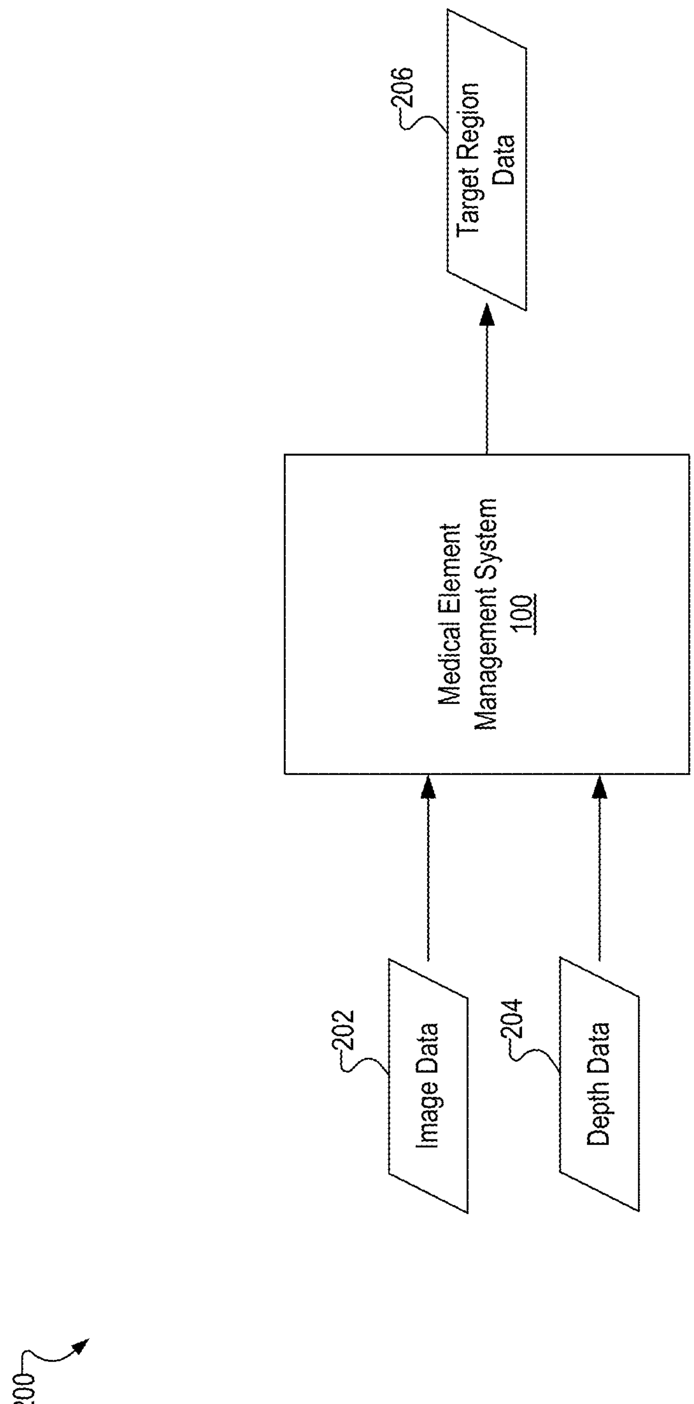
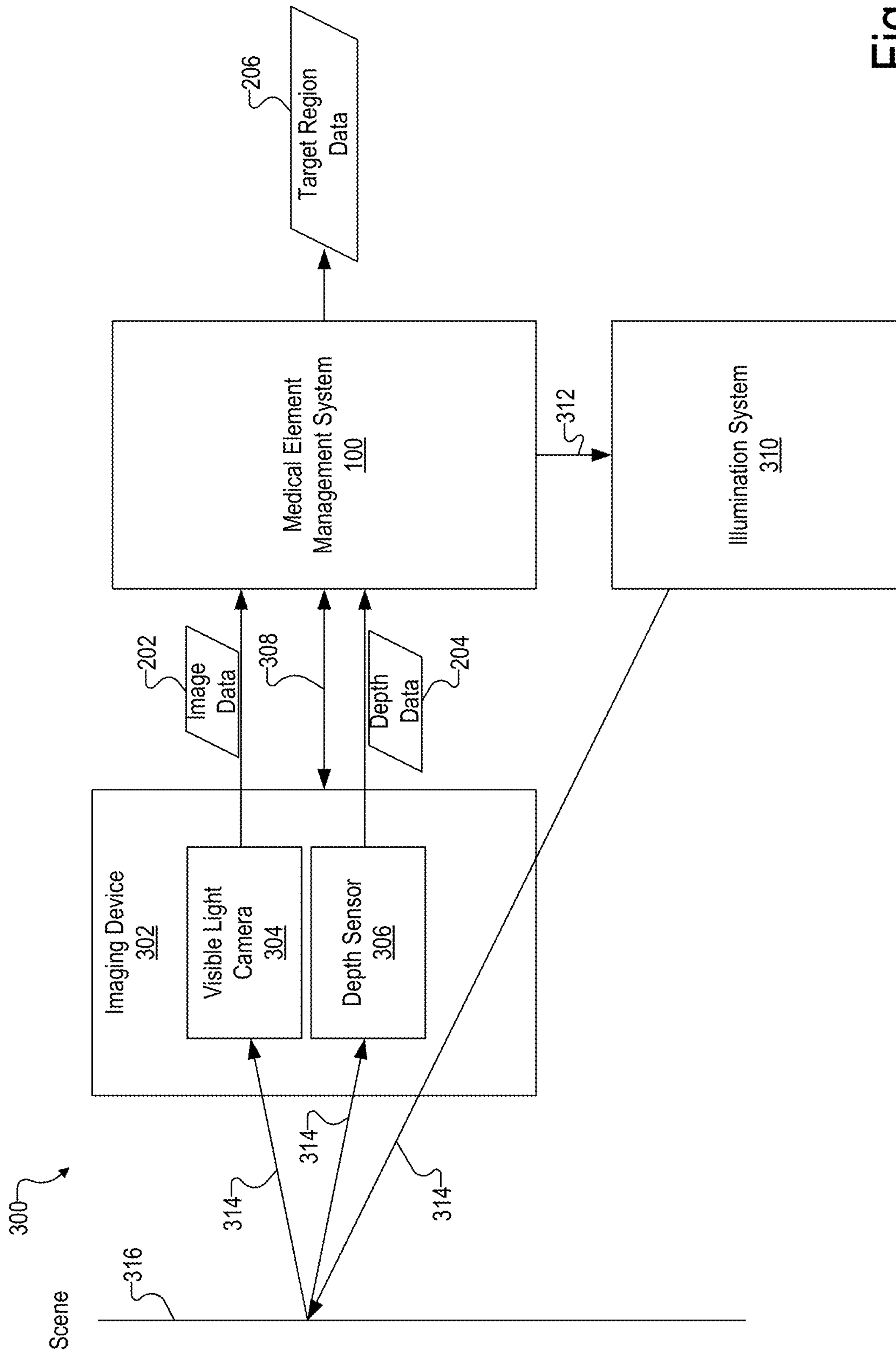

206
Target Region Data
Medical Element Management System
100
202
Image Data
204
Depth Data
200

Fig. 2



300
Scene
316
314
314
314
Imaging Device
302
Visible Light Camera
304
Depth Sensor
306
Image Data
202
308
Depth Data
204
Medical Element Management System
100
312
Illumination System
310
Target Region Data
206

Fig. 3

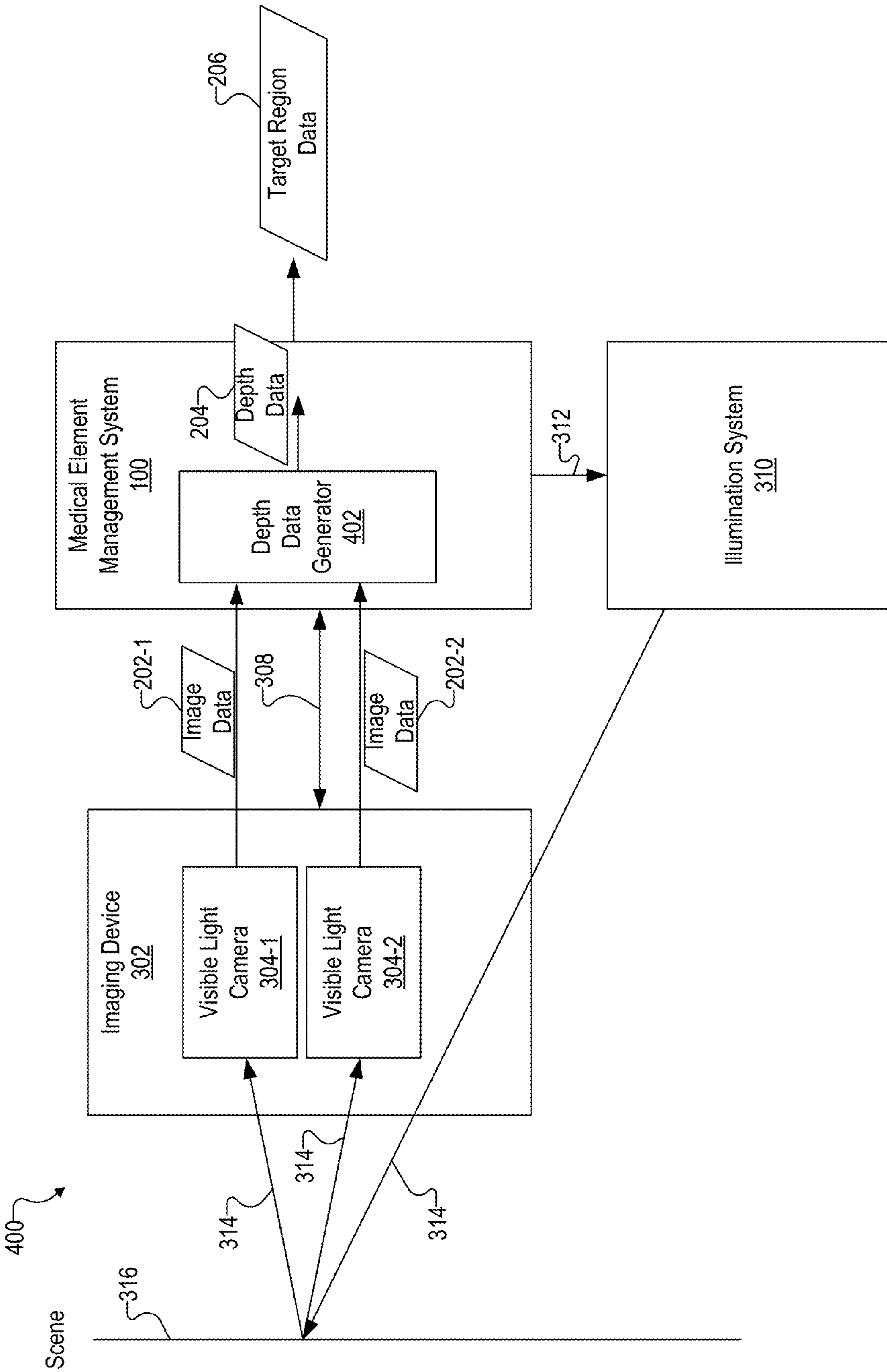

400
Scene
316
314
314
314
Imaging Device
302
Visible Light
Camera
304-1
Visible Light
Camera
304-2
202-1
Image
Data
308
Image
Data
202-2
Medical Element
Management System
100
Depth
Data
Generator
402
204
Depth
Data
312
Illumination System
310
206
Target Region
Data

Fig. 4

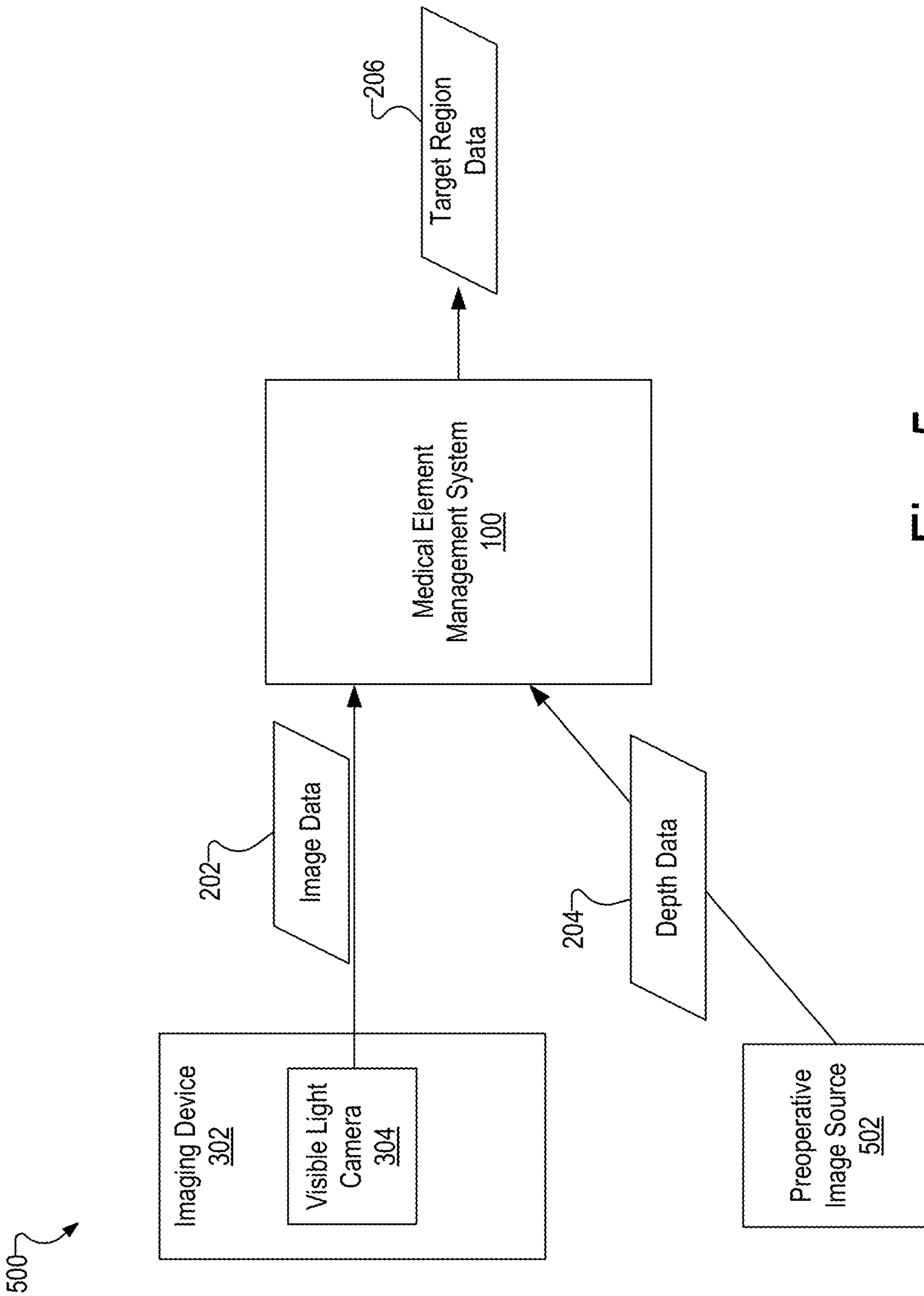

500
Imaging Device
302
Visible Light
Camera
304
Preoperative
Image Source
502
202
Image Data
204
Depth Data
Medical Element
Management System
100
206
Target Region
Data

Fig. 5

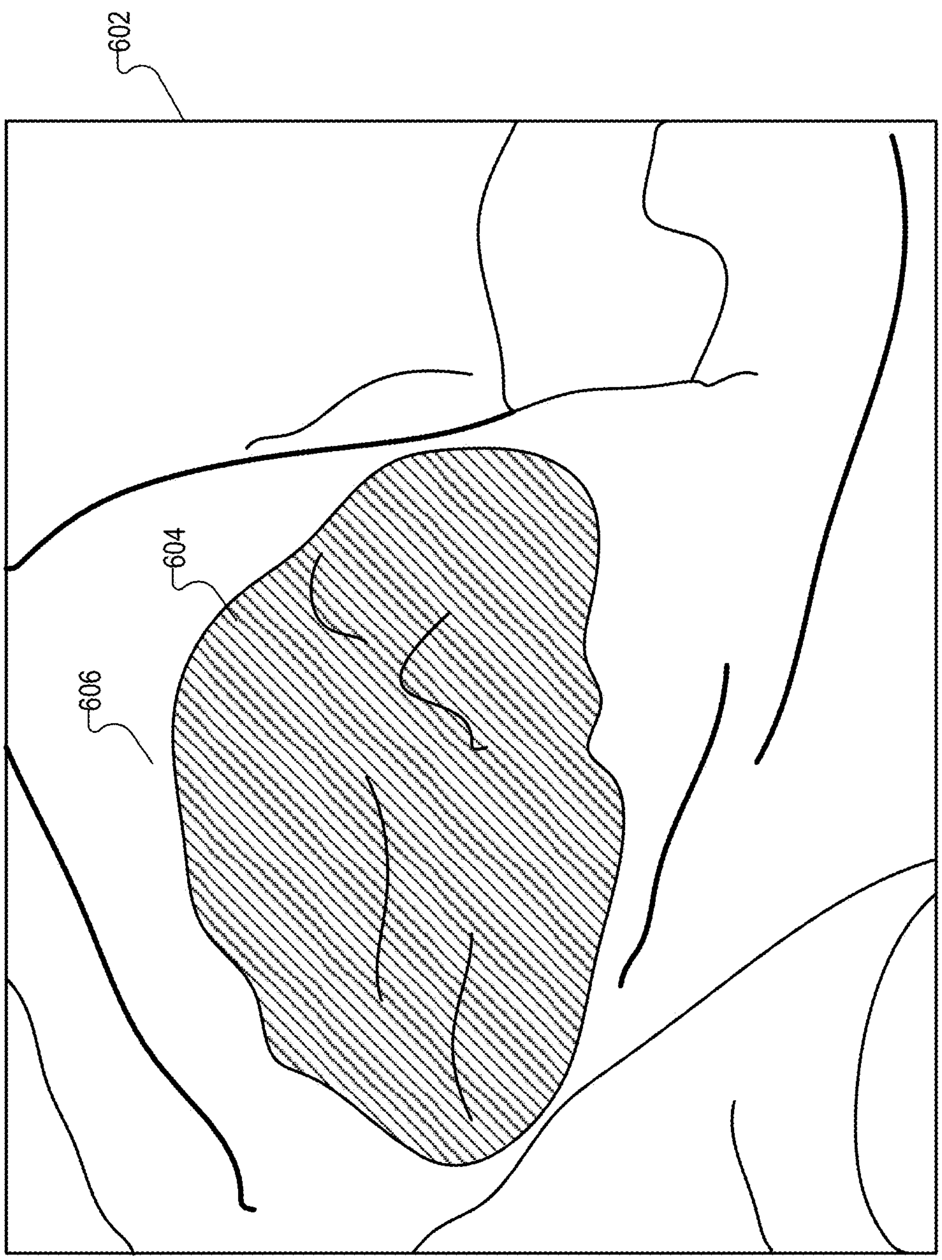


Fig. 6

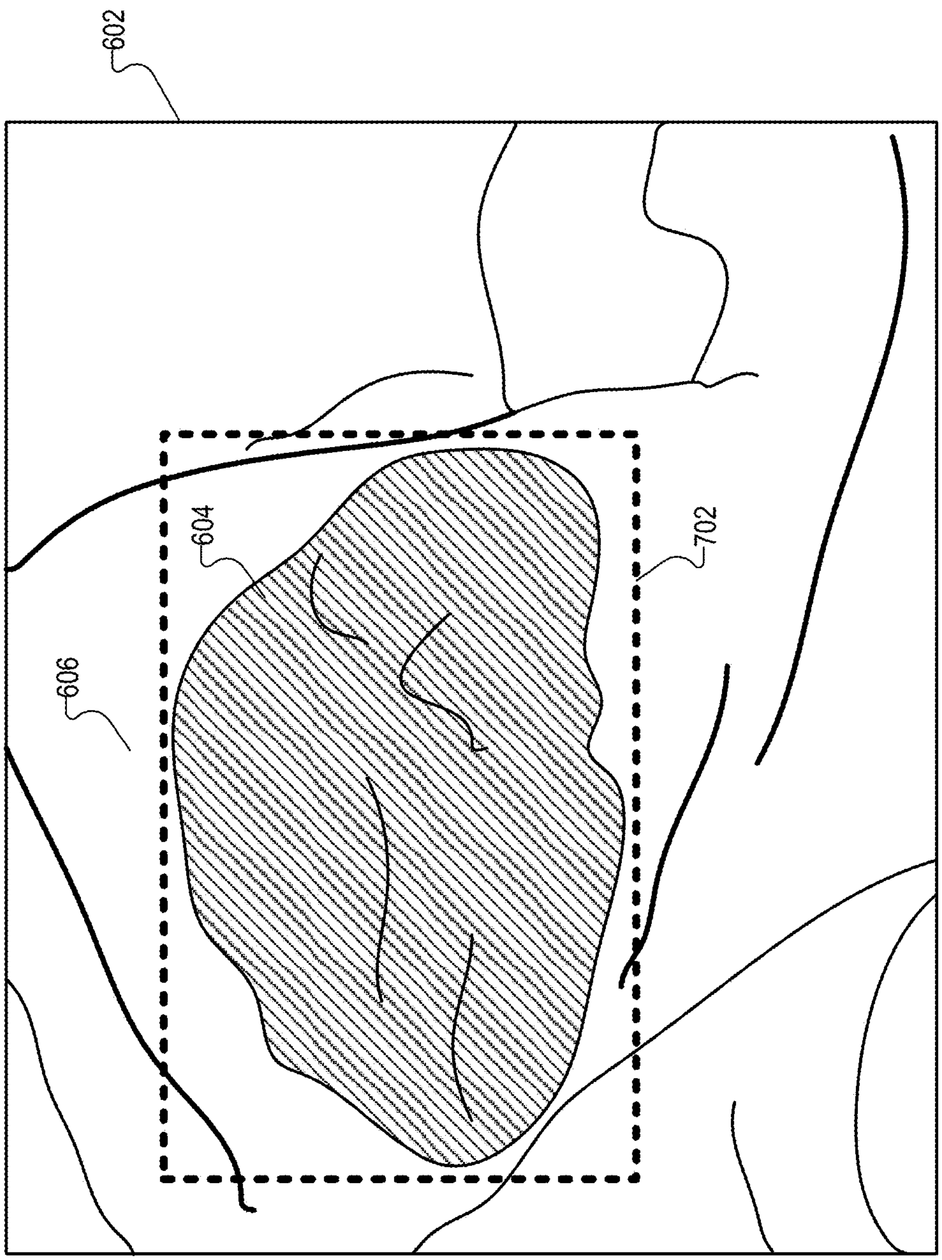


Fig. 7

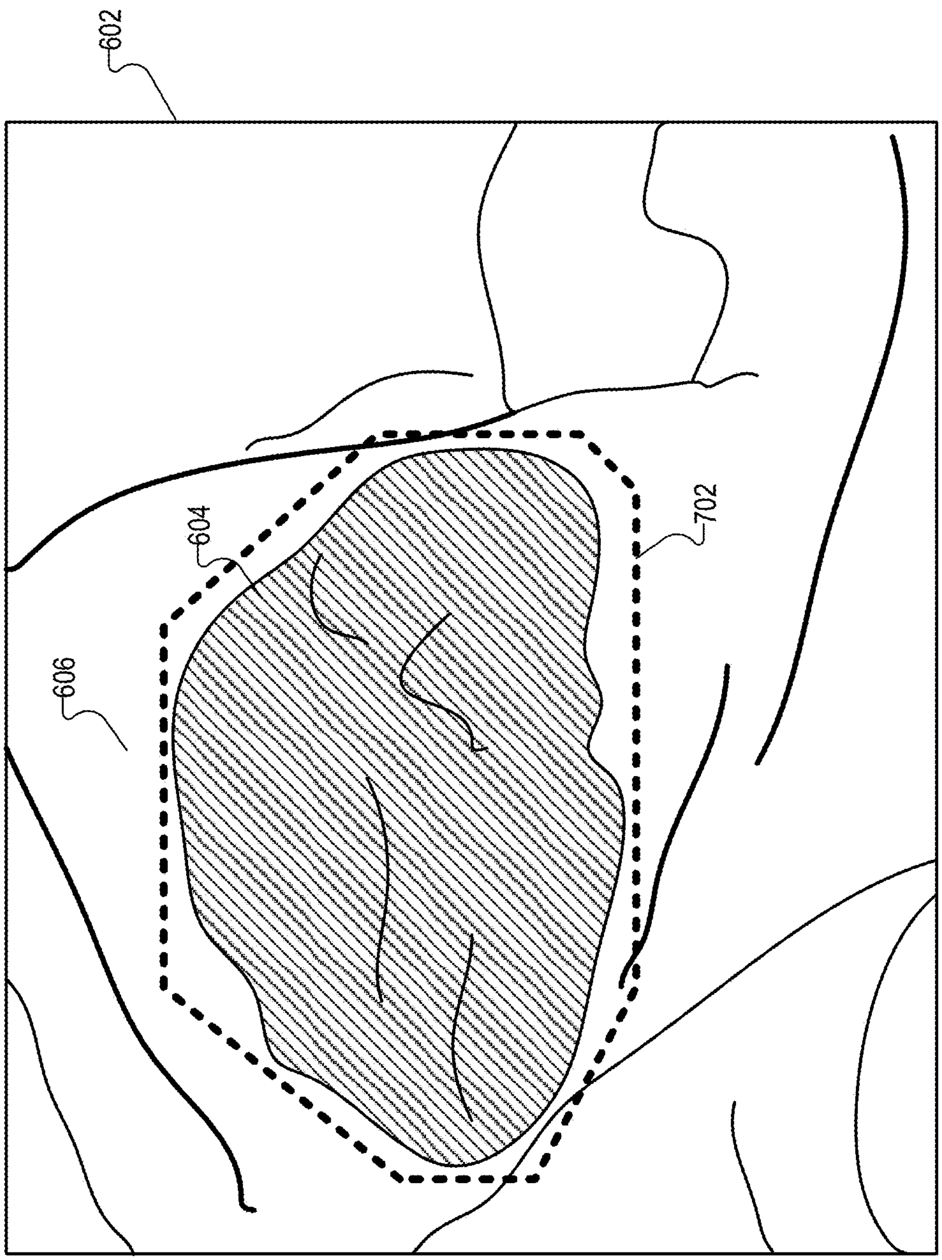


Fig. 8

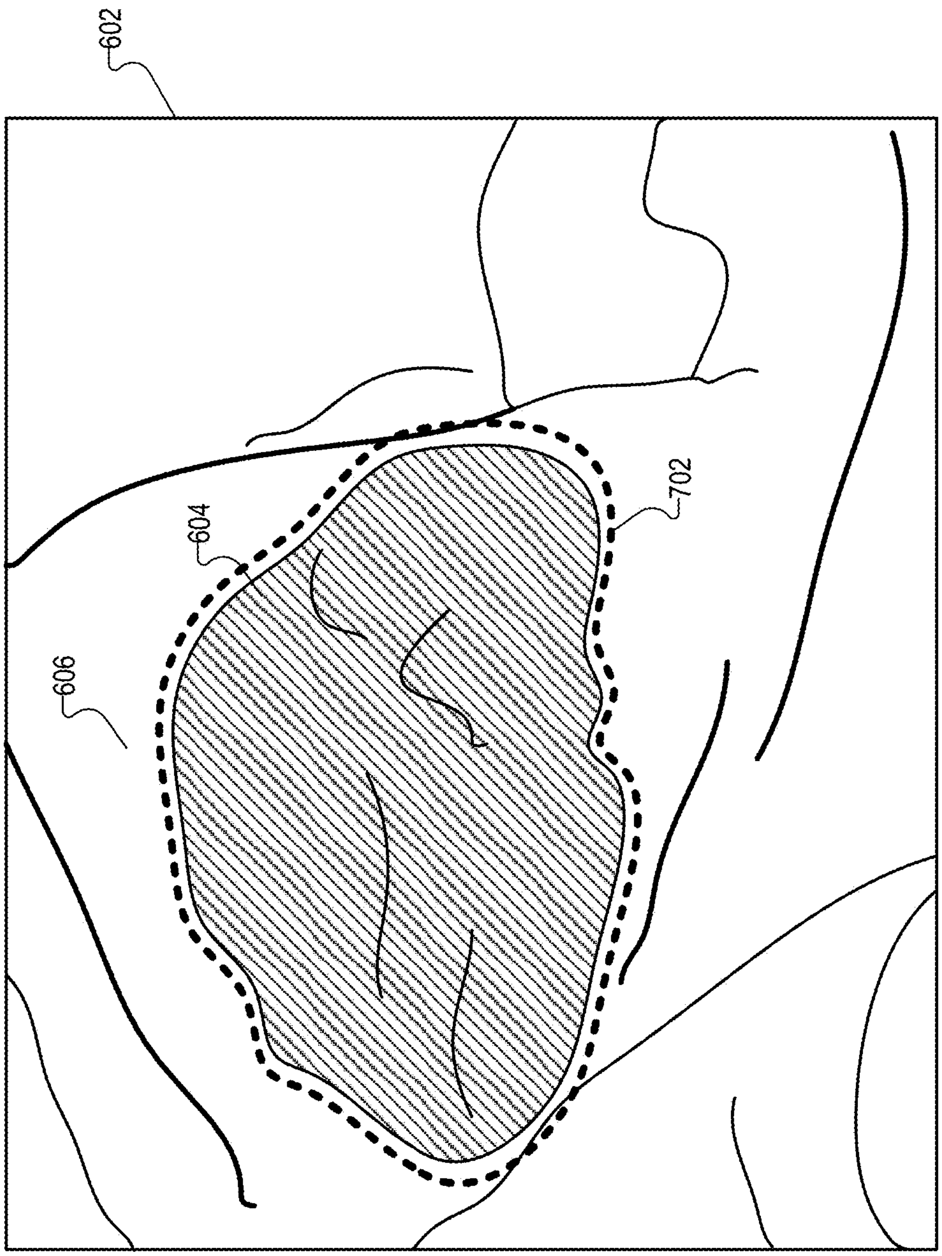


Fig. 9

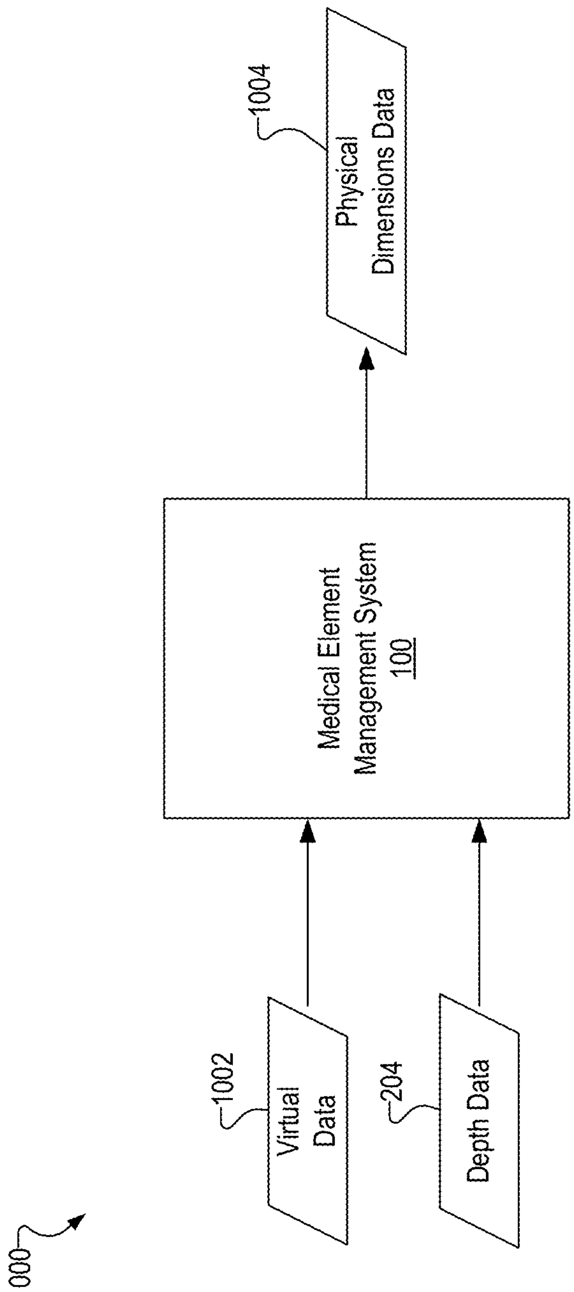

1000
Virtual Data
1002
Depth Data
204
Medical Element Management System
100
Physical Dimensions Data
1004

Fig. 10

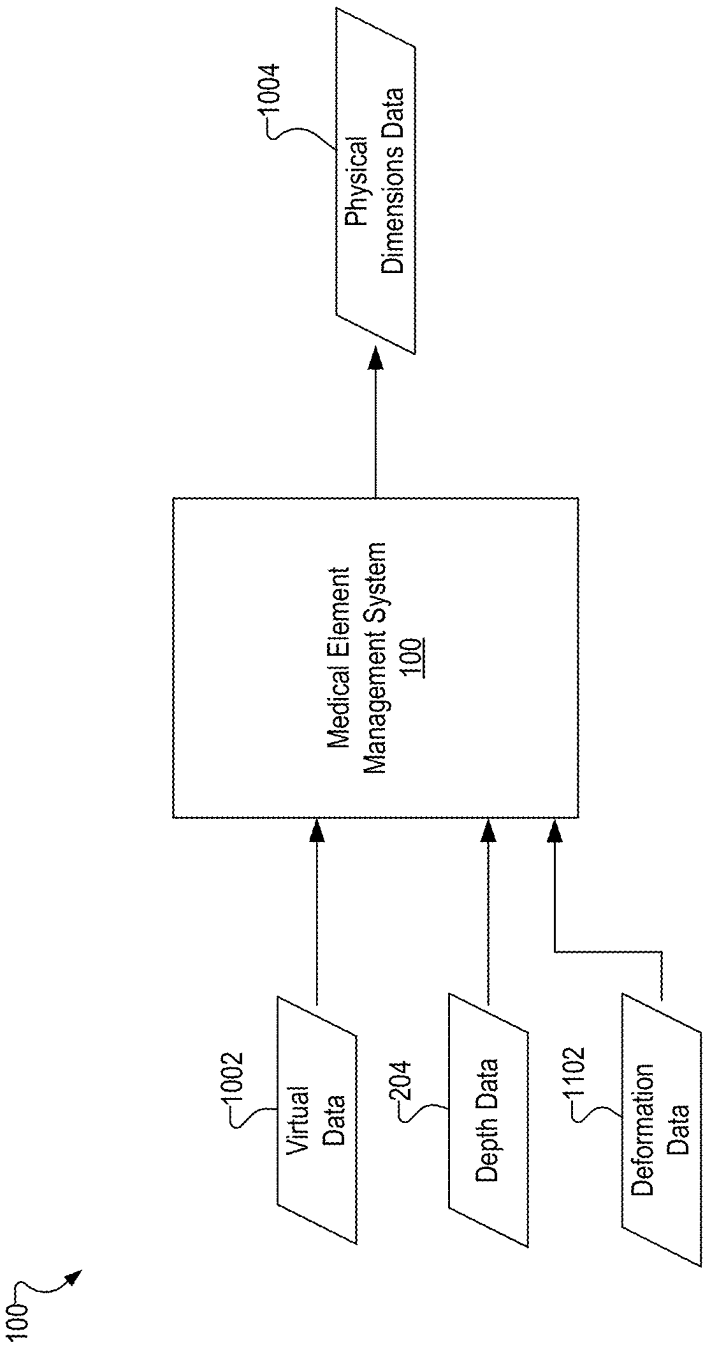

1100
1002
Virtual Data
204
Depth Data
1102
Deformation Data
Medical Element Management System 100
1004
Physical Dimensions Data

Fig. 11

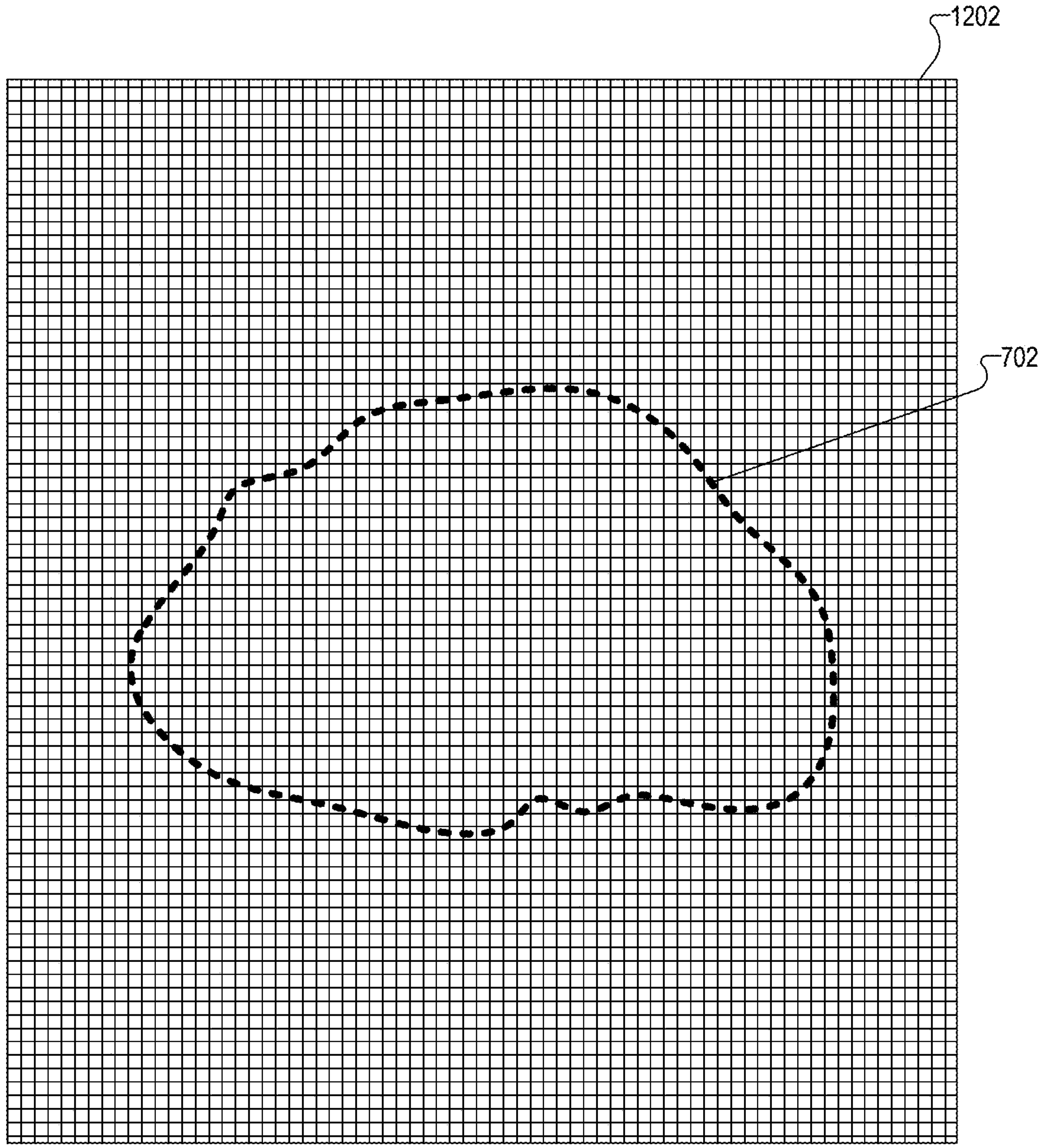


Fig. 12

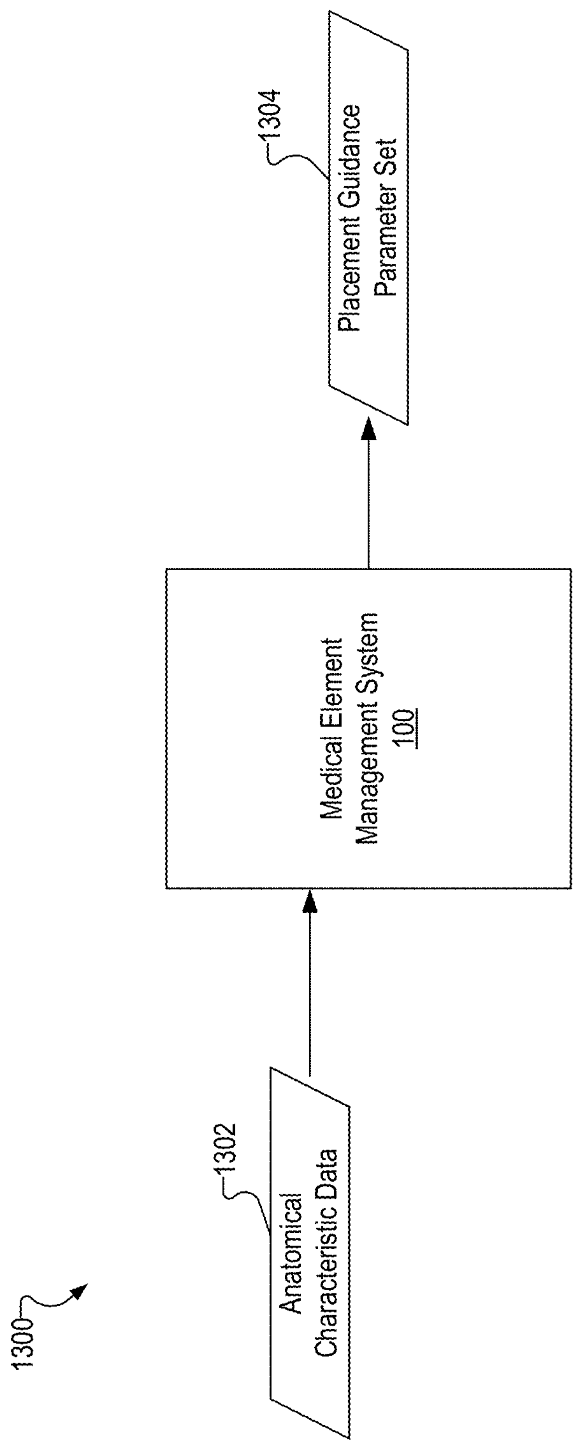

1300
1302
Anatomical Characteristic Data
Medical Element Management System
100
1304
Placement Guidance Parameter Set

Fig. 13

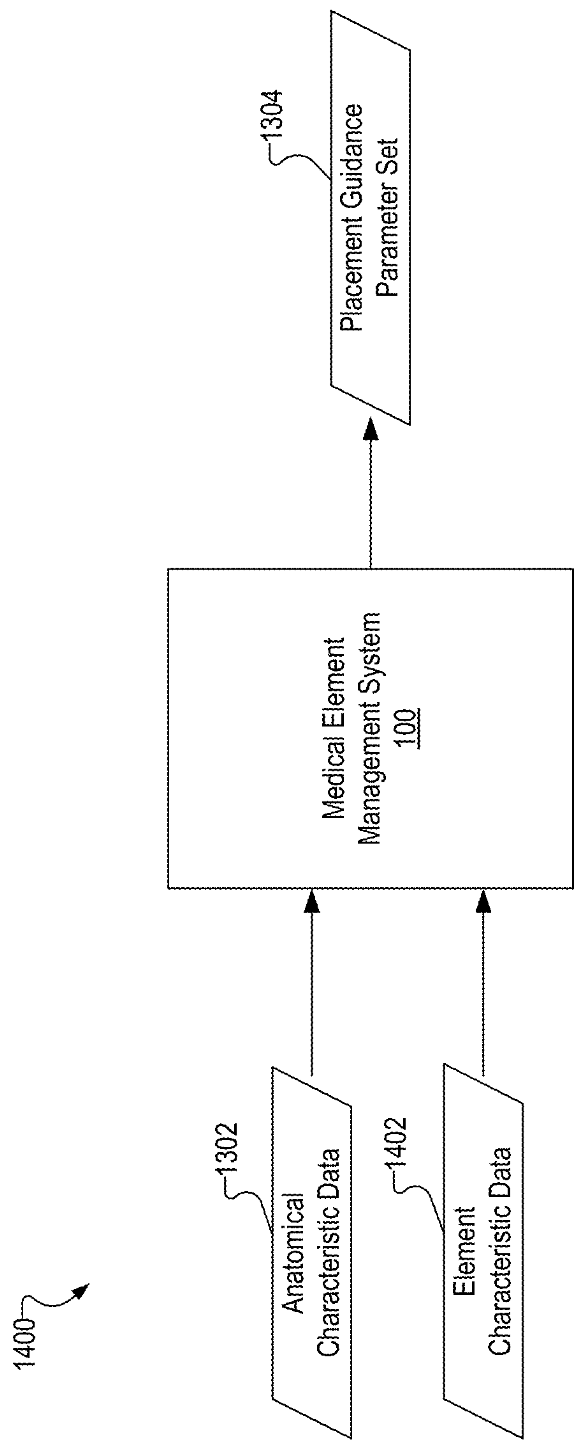

1400
1302
Anatomical Characteristic Data
1402
Element Characteristic Data
Medical Element Management System
100
1304
Placement Guidance Parameter Set

Fig. 14

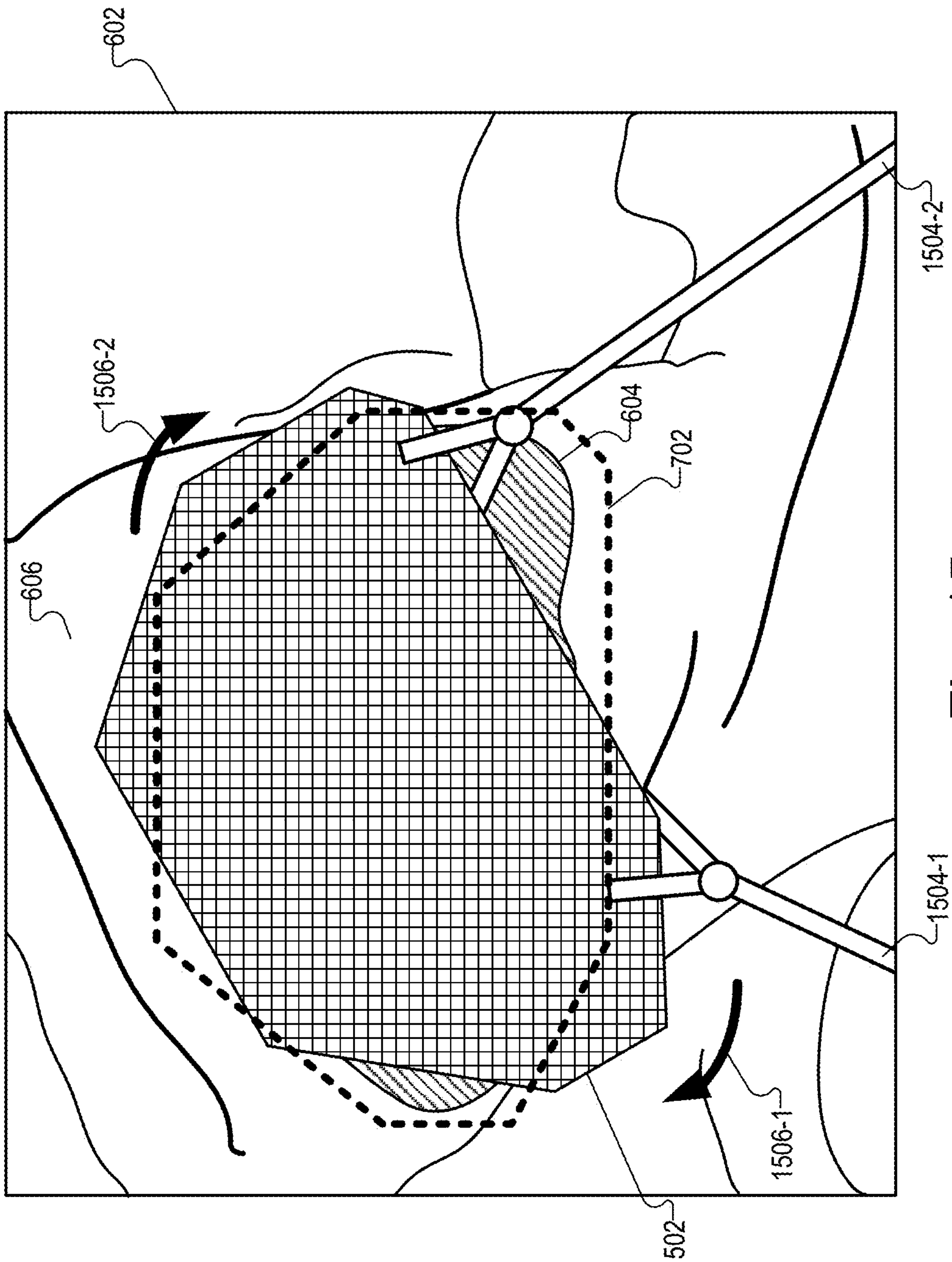


Fig. 15

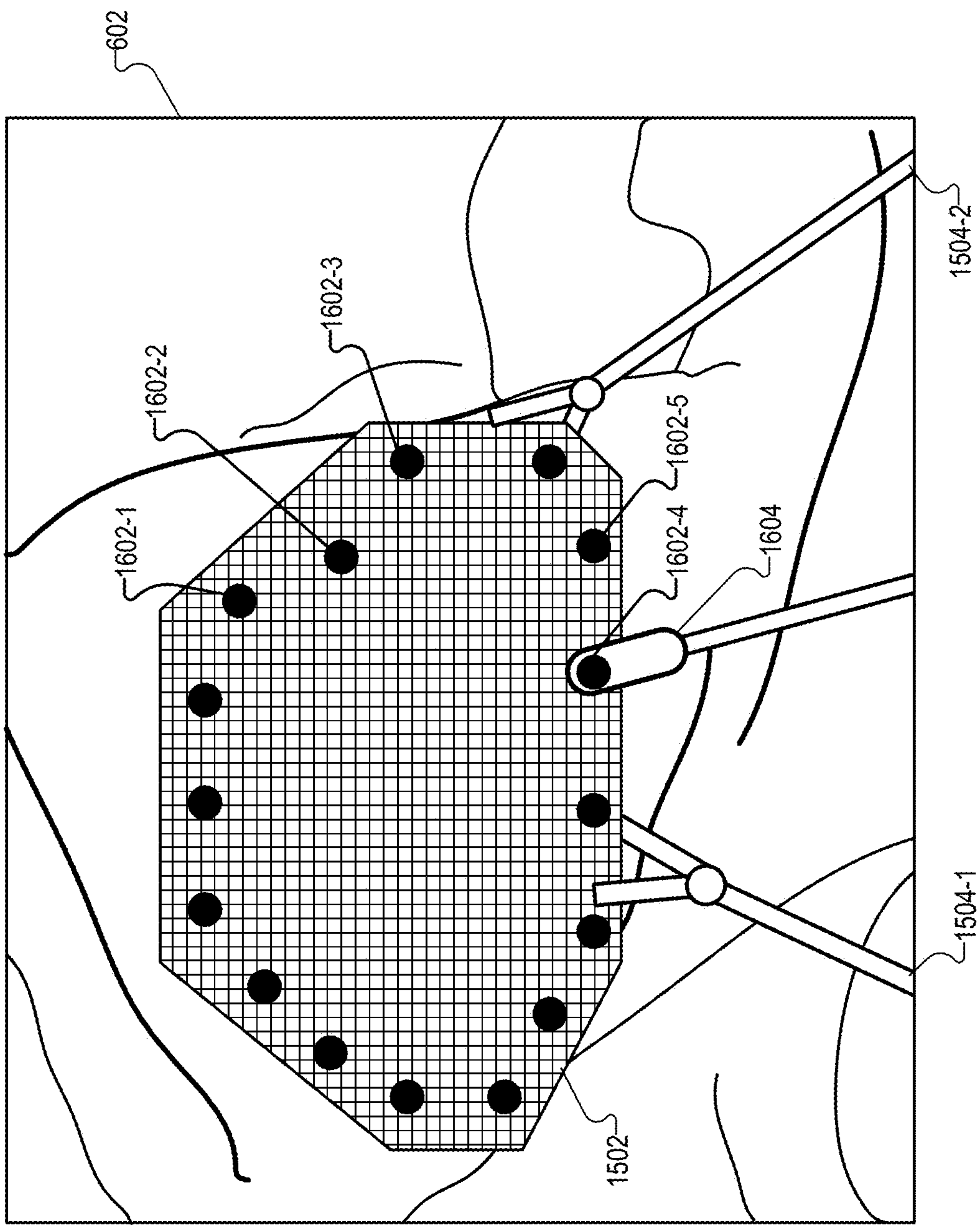


Fig. 16

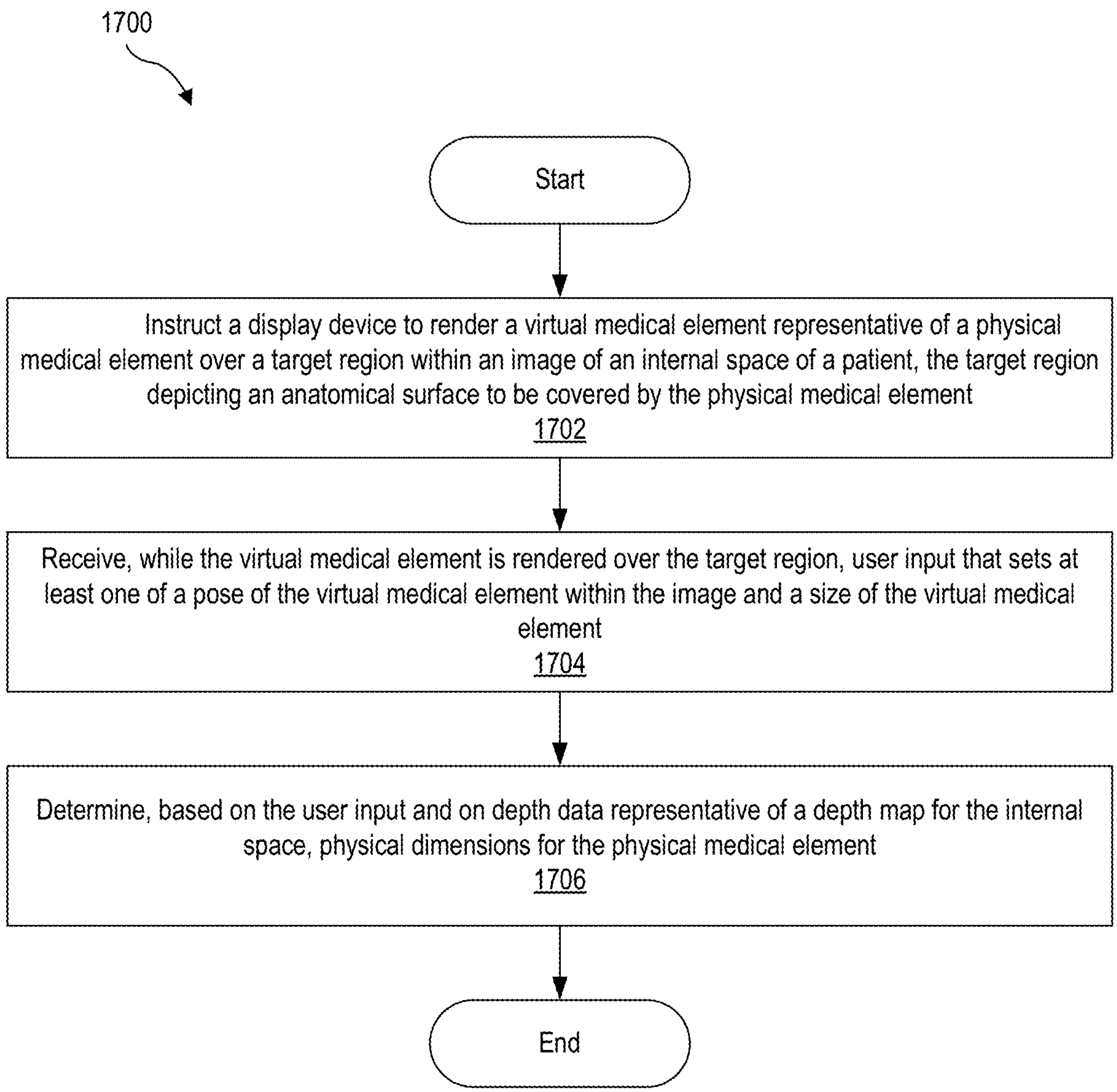

1700
Start
Instruct a display device to render a virtual medical element representative of a physical medical element over a target region within an image of an internal space of a patient, the target region depicting an anatomical surface to be covered by the physical medical element
1702
Receive, while the virtual medical element is rendered over the target region, user input that sets at least one of a pose of the virtual medical element within the image and a size of the virtual medical element
1704
Determine, based on the user input and on depth data representative of a depth map for the internal space, physical dimensions for the physical medical element
1706
End

Fig. 17

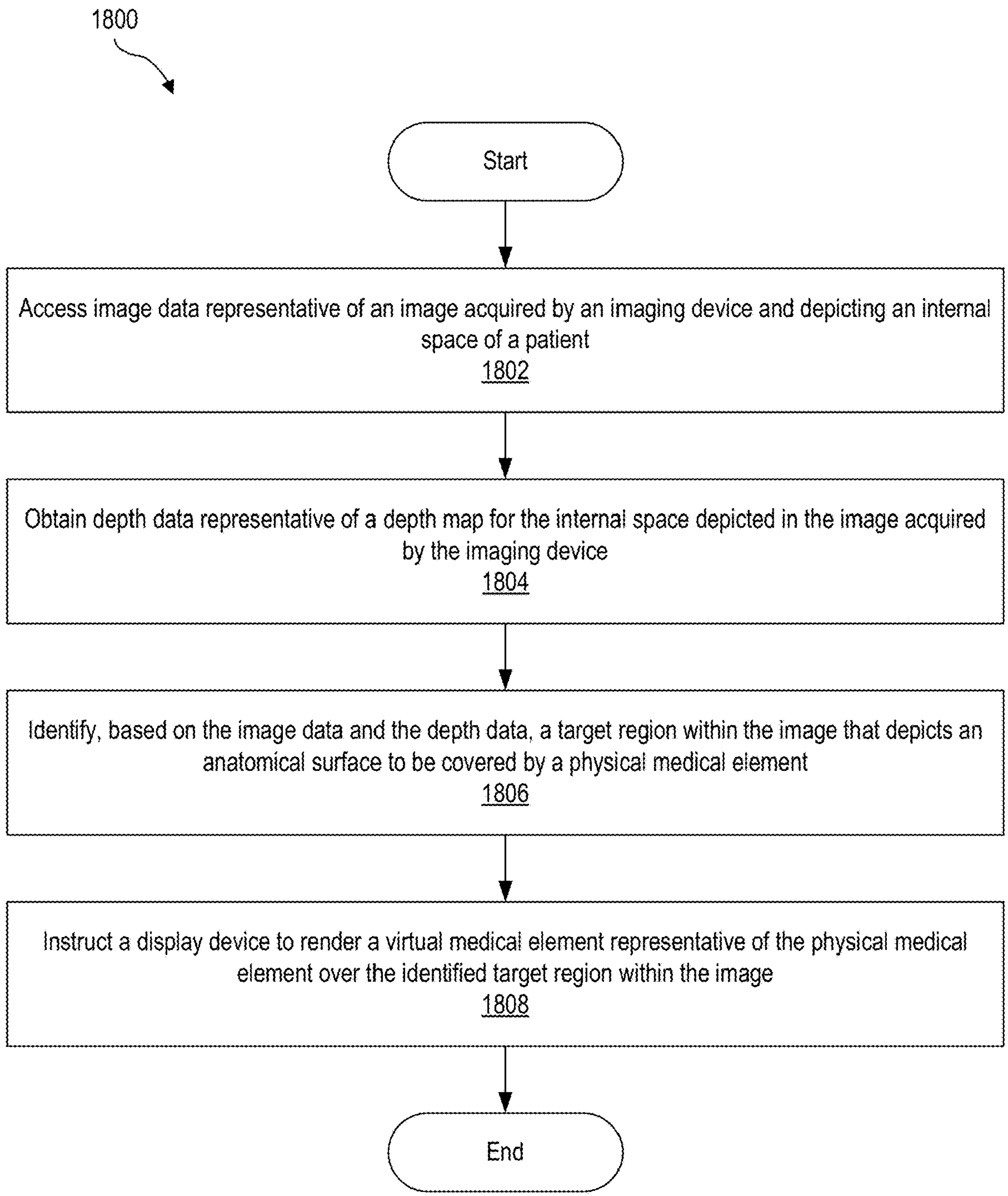

1800
Start
Access image data representative of an image acquired by an imaging device and depicting an internal space of a patient
1802
Obtain depth data representative of a depth map for the internal space depicted in the image acquired by the imaging device
1804
Identify, based on the image data and the depth data, a target region within the image that depicts an anatomical surface to be covered by a physical medical element
1806
Instruct a display device to render a virtual medical element representative of the physical medical element over the identified target region within the image
1808
End

Fig. 18

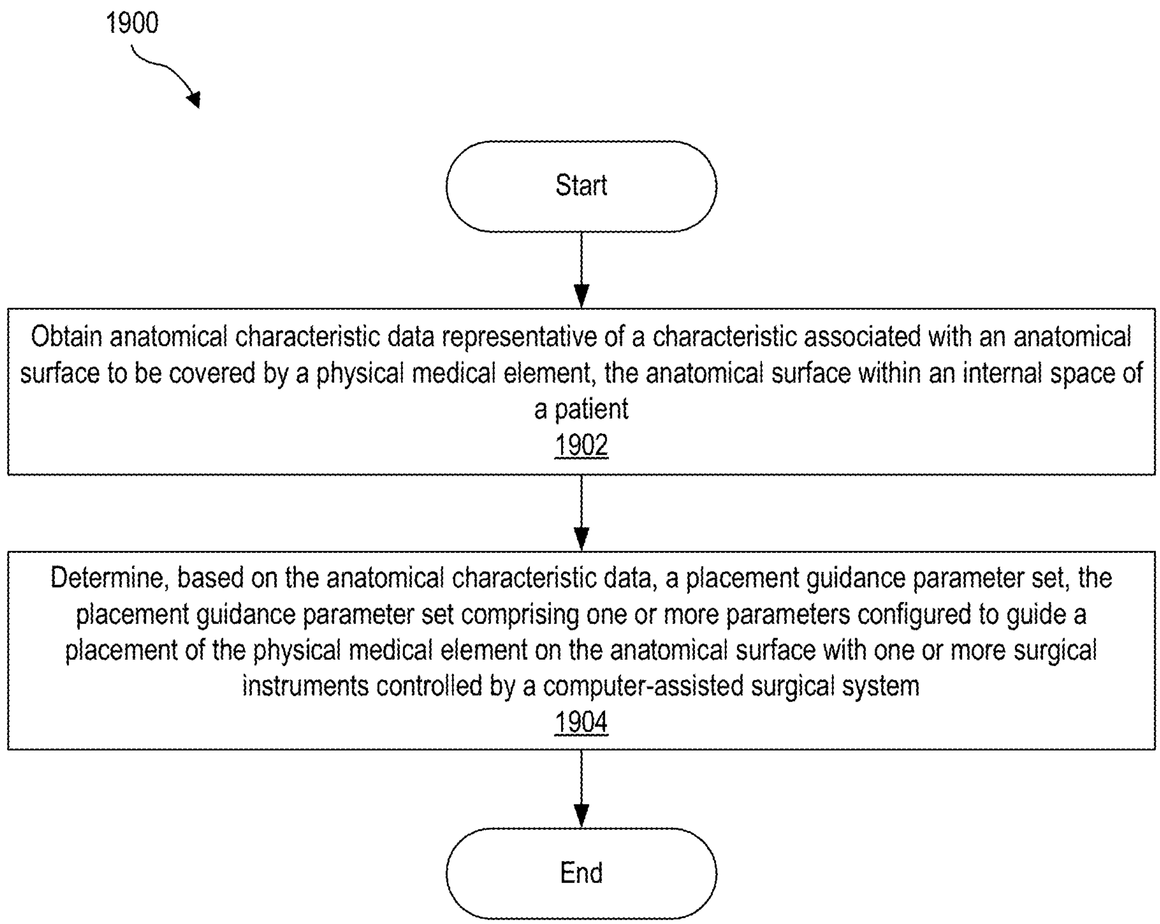

1900
Start
Obtain anatomical characteristic data representative of a characteristic associated with an anatomical surface to be covered by a physical medical element, the anatomical surface within an internal space of a patient
1902
Determine, based on the anatomical characteristic data, a placement guidance parameter set, the placement guidance parameter set comprising one or more parameters configured to guide a placement of the physical medical element on the anatomical surface with one or more surgical instruments controlled by a computer-assisted surgical system
1904
End

Fig. 19

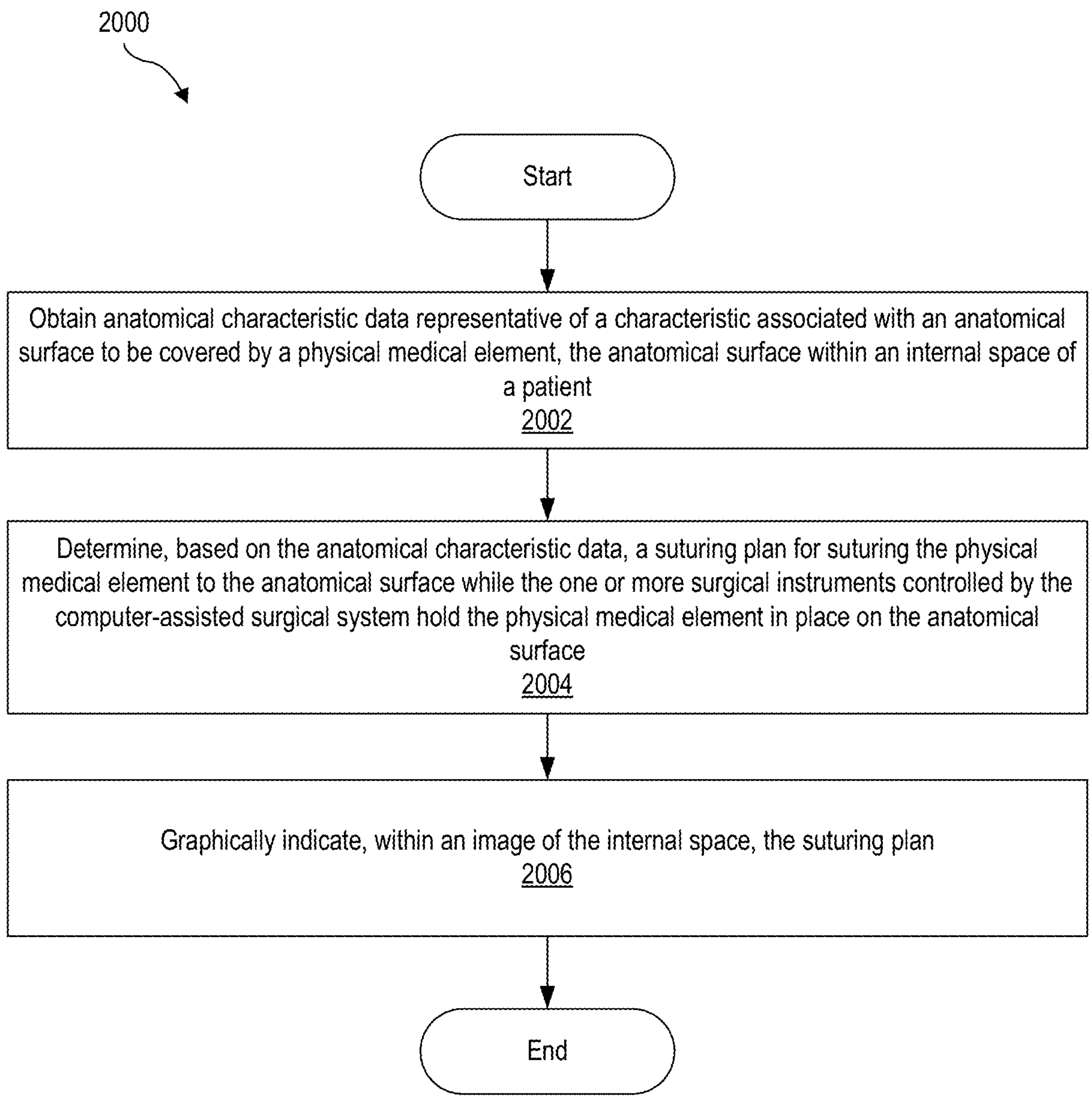

2000
Start
Obtain anatomical characteristic data representative of a characteristic associated with an anatomical surface to be covered by a physical medical element, the anatomical surface within an internal space of a patient
2002
Determine, based on the anatomical characteristic data, a suturing plan for suturing the physical medical element to the anatomical surface while the one or more surgical instruments controlled by the computer-assisted surgical system hold the physical medical element in place on the anatomical surface
2004
Graphically indicate, within an image of the internal space, the suturing plan
2006
End

Fig. 20

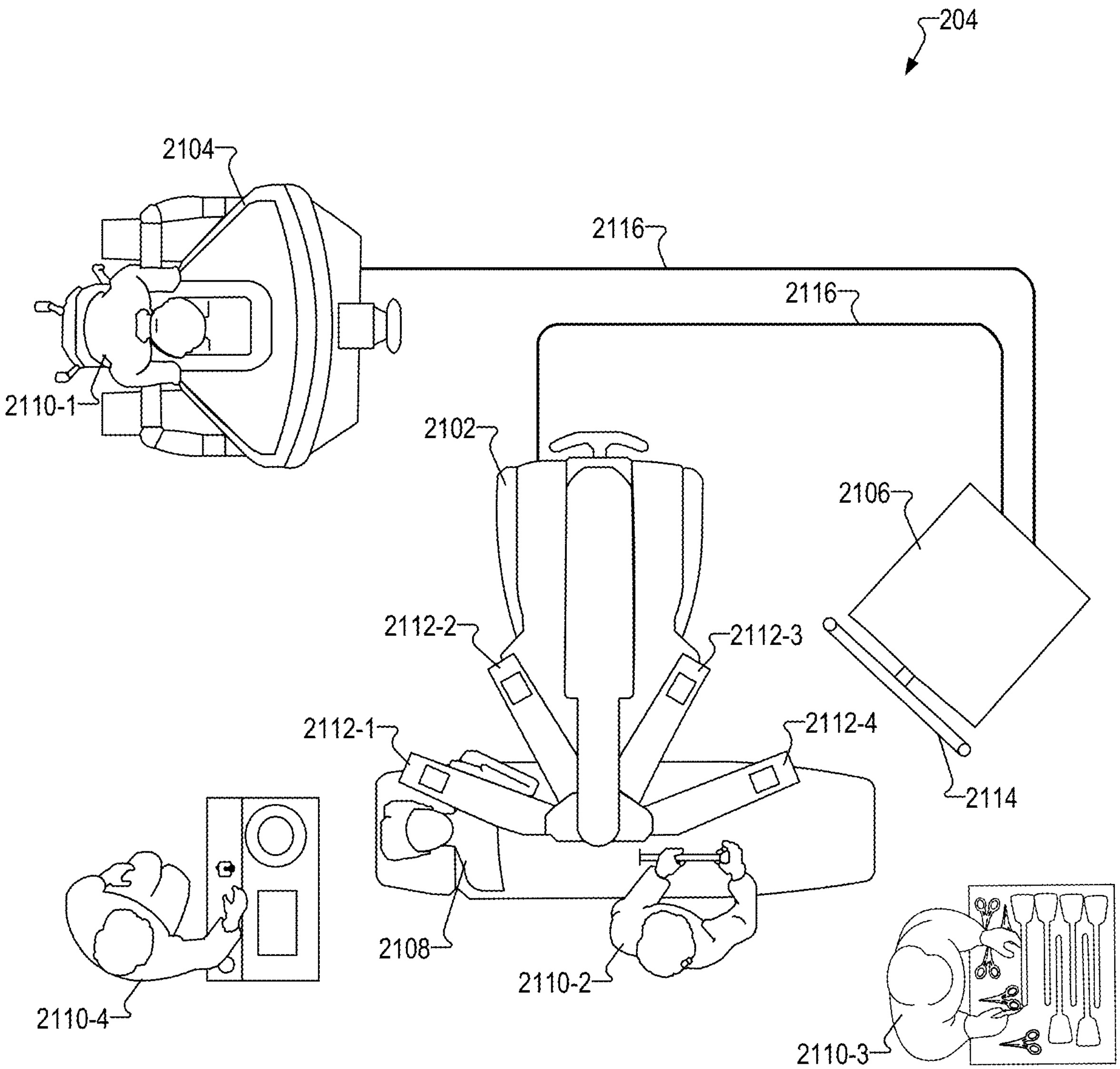

204
2104
2116
2116
2110-1
2102
2106
2112-2
2112-3
2112-1
2112-4
2114
2108
2110-2
2110-4
2110-3

Fig. 21

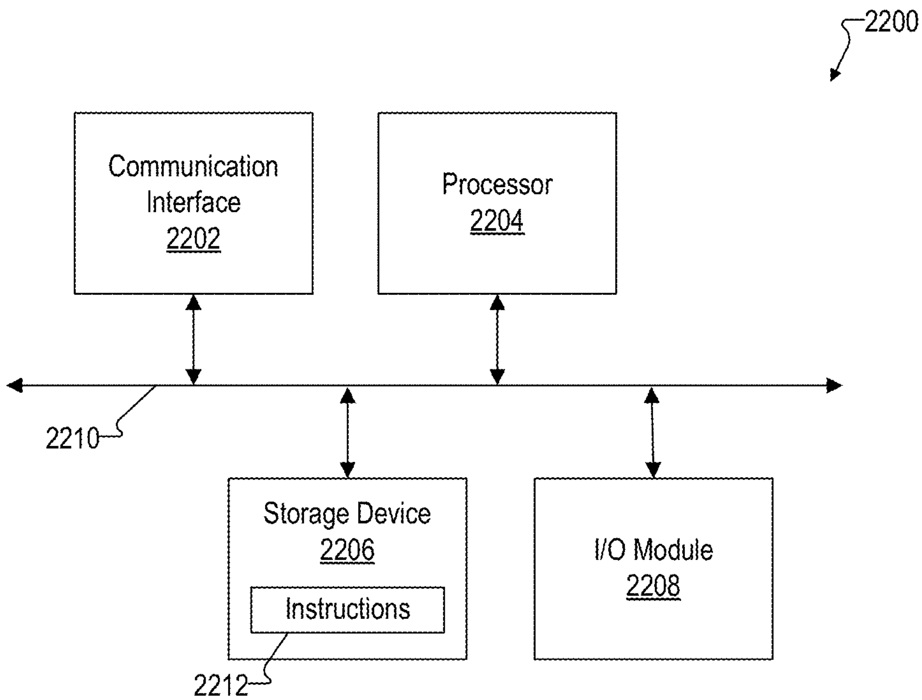

2200
Communication Interface 2202
Processor 2204
2210
Storage Device 2206
Instructions
2212
I/O Module 2208

Fig. 22

PHYSICAL MEDICAL ELEMENT SIZING SYSTEMS AND METHODS

RELATED APPLICATIONS

[0001] The present application is a continuation of U.S. patent application Ser. No. 17/639,676, filed Mar. 2, 2022, which is a U.S. National Stage Application under 35 U.S.C. § 371 of International Application No. PCT/US2020/054295, filed Oct. 5, 2020, which claims priority to U.S. Provisional Patent Application No. 62/911,851, filed Oct. 7, 2019, each of which is hereby incorporated by reference in its entirety.

BACKGROUND INFORMATION

[0002] A computer-assisted surgical system is often used to perform a hernia repair procedure within a patient. As part of the hernia repair procedure, a mesh patch may be placed over the hernia and attached (e.g., sutured) to tissue surrounding the hernia. The mesh patch may provide support for the damaged tissue as the tissue heals.

[0003] During a hernia repair procedure, a surgeon interacting with the computer-assisted surgical system must determine an appropriate size for the mesh patch. Once the mesh patch has been sized (e.g., by cutting the mesh patch out of a mesh material), the surgeon must place the mesh patch at an appropriate location within the patient. These and other types of operations that involve determining suitable physical dimensions for a medical element that is to be introduced into a patent may be time-intensive and tedious.

SUMMARY

[0004] The following description presents a simplified summary of one or more aspects of the systems and methods described herein. This summary is not an extensive overview of all contemplated aspects and is intended to neither identify key or critical elements of all aspects nor delineate the scope of any or all aspects. Its sole purpose is to present one or more aspects of the systems and methods described herein as a prelude to the detailed description that is presented below.

[0005] An exemplary system includes a memory storing instructions and a processor communicatively coupled to the memory and configured to execute the instructions to instruct a display device to render a virtual medical element representative of a physical medical element over a target region within an image of an internal space of a patient, the target region depicting an anatomical surface to be covered by the physical medical element; receive, while the virtual medical element is rendered over the target region, user input that sets at least one of a pose of the virtual medical element within the image and a size of the virtual medical element; and determine, based on the user input and on depth data representative of a depth map for the internal space, physical dimensions for the physical medical element.

[0006] An exemplary system includes a memory storing instructions and a processor communicatively coupled to the memory and configured to execute the instructions to access image data representative of an image acquired by an imaging device and depicting an internal space of a patient; obtain depth data representative of a depth map for the internal space depicted in the image acquired by the imaging device; identify, based on the image data and the depth data, a target region within the image that depicts an anatomical surface to be covered by a physical medical element; and instruct a display device to render a virtual medical element representative of the physical medical element over the identified target region within the image.

[0007] An exemplary method includes instructing, by a medical element management system, a display device to render a virtual medical element representative of a physical medical element over a target region within an image of an internal space of a patient, the target region depicting an anatomical surface to be covered by the physical medical element; receiving, by the medical element management system while the virtual medical element is rendered over the target region, user input that sets at least one of a pose of the virtual medical element within the image and a size of the virtual medical element; and determining, by the medical element management system based on the user input and on depth data representative of a depth map for the internal space, physical dimensions for the physical medical element.

[0008] An exemplary method includes accessing, by a medical element management system, image data representative of an image acquired by an imaging device and depicting an internal space of a patient; obtaining, by the medical element management system, depth data representative of a depth map for the internal space depicted in the image acquired by the imaging device; identifying, by the medical element management system based on the image data and the depth data, a target region within the image that depicts an anatomical surface to be covered by a physical medical element; and instructing, by the medical element management system, a display device to render a virtual medical element representative of the physical medical element over the identified target region within the image.

[0009] An exemplary non-transitory computer-readable medium stores instructions that, when executed, direct a processor of a computing device to instruct a display device to render a virtual medical element representative of a physical medical element over a target region within an image of an internal space of a patient, the target region depicting an anatomical surface to be covered by the physical medical element; receive, while the virtual medical element is rendered over the target region, user input that sets at least one of a pose of the virtual medical element within the image and a size of the virtual medical element; and determine, based on the user input and on depth data representative of a depth map for the internal space, physical dimensions for the physical medical element.

[0010] An exemplary non-transitory computer-readable medium stores instructions that, when executed, direct a processor of a computing device to access image data representative of an image acquired by an imaging device and depicting an internal space of a patient; obtain depth data representative of a depth map for the internal space depicted in the image acquired by the imaging device; identify, based on the image data and the depth data, a target region within the image that depicts an anatomical surface to be covered by a physical medical element; and instruct a display device to render a virtual medical element representative of the physical medical element over the identified target region within the image.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The accompanying drawings illustrate various embodiments and are a part of the specification. The illustrated embodiments are merely examples and do not limit the scope of the disclosure. Throughout the drawings, identical or similar reference numbers designate identical or similar elements.

[0012] FIG. **1** illustrates an exemplary medical element management system according to principles described herein.

[0013] FIG. **2** illustrates an exemplary configuration in which a system is configured to identify a target region within an image acquired by an imaging device and that depicts an anatomical surface to be covered by a physical medical element according to principles described herein.

[0014] FIG. **3** illustrates an exemplary configuration in which an imaging device includes a visible light camera and a depth sensor according to principles described herein.

[0015] FIG. **4** illustrates an exemplary configuration in which a depth sensor is implemented by visible light cameras according to principles described herein.

[0016] FIG. **5** shows an exemplary configuration in which a system obtains depth data from a preoperative image source according to principles described herein.

[0017] FIG. **6** shows an exemplary image that may be captured by an imaging device according to principles described herein.

[0018] FIGS. **7-9** show an exemplary virtual medical element rendered over an identified target region within an image according to principles described herein.

[0019] FIGS. **10-11** illustrate exemplary configurations in which a system generates physical dimensions data according to principles described herein.

[0020] FIG. **12** shows an exemplary physical material from which a physical medical element is to be cut according to principles described herein.

[0021] FIGS. **13-14** illustrate exemplary configurations in which a system determines a placement guidance parameter set according to principles described herein.

[0022] FIGS. **15-16** show an exemplary scenario in which a physical medical element is being placed on an anatomical surface that includes a tissue defect and a portion of non-defective tissue according to principles described herein.

[0023] FIGS. **17-20** illustrate exemplary methods according to principles described herein.

[0024] FIG. **21** illustrates an exemplary computer-assisted surgical system according to principles described herein.

[0025] FIG. **22** illustrates an exemplary computing device according to principles described herein.

DETAILED DESCRIPTION

[0026] Physical medical element sizing systems and methods are described herein. As described herein, an exemplary medical element management system may instruct a display device to render a virtual medical element (e.g., a virtual mesh patch) representative of a physical medical element (e.g., a mesh patch for a hernia) over a target region within an image of an internal space of a patient, where the target region depicts an anatomical surface to be covered by the physical medical element. The medical element management system may receive, while the virtual medical element is rendered over the target region, user input that sets at least one of a pose of the virtual medical element within the image and a size of the virtual medical element. Based on the user input and on depth data representative of a depth map for the internal space, the medical element management system may determine physical dimensions for the physical medical element.

[0027] The systems and methods described herein advantageously facilitate optimal sizing of a physical medical element that is to be introduced into a body of a patient and placed over an anatomical surface within the body during a medical procedure. Moreover, by basing the determination of the physical dimensions for the physical medical element on depth data representative of a depth map for the internal space, the systems and methods described herein advantageously account for peaks, valleys, contours, and/or other variations in depth of the anatomical surface when determining the optimal size of the physical medical element. Such depth variations may not be visually apparent in an image of the internal space, and may affect the size of the physical medical element. For example, a large variation in depth between portions of the anatomical surface that is to be covered by the physical medical element may necessitate a larger size for the physical medical element than what may be visually ascertainable in the image of the internal space.

[0028] As an illustration, if a user manually adjusts a size of a virtual medical element displayed within an image that depicts an anatomical surface so that the virtual medical element appears to cover the anatomical surface, the size of the virtual medical element may not actually correspond to the actual size needed for the physical medical element unless depth data representative of the three-dimensional contours of the anatomical surface. Hence, the systems and methods described herein base the size of the anatomical surface on depth data that is indicative of such contours.

[0029] The systems and methods described herein may also advantageously determine where within an image of an internal space of a patient that the virtual medical element is to be initially rendered. This may facilitate relatively fast determination of an optimal size of the physical medical element represented by the virtual medical element, as will be described in more detail herein.

[0030] These and other advantages and benefits of the systems and methods described herein will be made apparent herein.

[0031] As used herein, a physical medical element refers to any element foreign to a patient's body that is configured to be placed on and cover an anatomical surface within the patient's body. For example, a physical medical element may be implemented by a patch (e.g., a mesh or wire patch) configured to cover a tissue defect (e.g., a hernia, cut, or other type of lesion) within the patient. Other examples of physical medical elements that may be used in connection with the systems and methods described herein include, but are not limited to, gauze, bandages, plates, prostheses (e.g., artificial discs, joint implants such as knee implants, etc.), specimen containment bags, bone putty, fasteners (e.g., clips, clamps, staples, etc.), etc. A physical medical element may be placed on an anatomical surface in any suitable manner. For example, the physical medical element may be sutured, anchored, or otherwise affixed to the anatomical surface.

[0032] FIG. **1** illustrates an exemplary medical element management system **100** ("system **100**") configured to perform various operations described herein. As shown, system **100** may include, without limitation, a storage facility **102**

and a processing facility **104** selectively and communicatively coupled to one another. Facilities **102** and **104** may each include or be implemented by hardware and/or software components (e.g., processors, memories, communication interfaces, instructions stored in memory for execution by the processors, etc.). For example, facilities **102** and/or **104** may be implemented by any component in a computer-assisted surgical system configured to perform a medical procedure in which a physical medical element is introduced into a body of a patient and placed on an anatomical surface within the body of the patient. As another example, facilities **102** and/or **104** may be implemented by a computing device separate from and communicatively coupled to a computer-assisted surgical system. In some examples, facilities **102** and **104** may be distributed between multiple devices and/or multiple locations as may serve a particular implementation.

[0033] Storage facility **102** may maintain (e.g., store) executable data used by processing facility **104** to perform one or more of the operations described herein. For example, storage facility **102** may store instructions **106** that may be executed by processing facility **104** to perform one or more of the operations described herein. Instructions **106** may be implemented by any suitable application, software, code, and/or other executable data instance. Storage facility **102** may also maintain any data received, generated, managed, used, and/or transmitted by processing facility **104**.

[0034] Processing facility **104** may be configured to perform (e.g., execute instructions **106** stored in storage facility **102** to perform) various operations described herein.

[0035] For example, processing facility **104** may be configured to instruct a display device to render a virtual medical element representative of a physical medical element over a target region within an image of an internal space of a patient, the target region depicting an anatomical surface to be covered by the physical medical element, receive, while the virtual medical element is rendered over the target region, user input that sets at least one of a pose of the virtual medical element within the image and a size of the virtual medical element, and determine, based on the user input and on depth data representative of a depth map for the internal space, physical dimensions for the physical medical element. As described herein, the physical dimensions may define a surface area for the physical medical element.

[0036] As another example, processing facility **104** may be configured to access image data representative of an image acquired by an imaging device and depicting an internal space of a patient, obtain depth data representative of a depth map for the internal space depicted in the image acquired by the imaging device, identify, based on the image data and the depth data, a target region within the image that depicts an anatomical surface to be covered by a physical medical element, and instruct a display device to render a virtual medical element representative of the physical medical element over the identified target region within the image.

[0037] As another example, processing facility **104** may be configured to obtain anatomical characteristic data representative of a characteristic associated with an anatomical surface to be covered by a physical medical element, the anatomical surface within an internal space of a patient and determine, based on the anatomical characteristic data, a placement guidance parameter set. As described herein, the placement guidance parameter set may include one or more parameters configured to guide a placement of the physical medical element on the anatomical surface with one or more surgical instruments controlled by a computer-assisted surgical system.

[0038] As another example, processing facility **104** may be configured to obtain anatomical characteristic data representative of a characteristic associated with an anatomical surface to be covered by a physical medical element, the anatomical surface within an internal space of a patient, determine, based on the anatomical characteristic data, a suturing plan (or any other type of affixation plan) for suturing the physical medical element to the anatomical surface while the one or more surgical instruments controlled by the computer-assisted surgical system hold the physical medical element in place on the anatomical surface, and graphically indicate, within an image of the internal space, the suturing plan.

[0039] These and other operations that may be performed by system **100** (e.g., processing facility **104**) are described herein.

[0040] FIG. **2** illustrates an exemplary configuration **200** in which system **100** is configured to identify a target region within an image acquired by an imaging device and that depicts an anatomical surface to be covered by a physical medical element. As shown, system **100** may access image data **202** representative of an image acquired by an imaging device and depicting an internal space of a patient. System **100** may also obtain depth data **204** representative of a depth map for the internal space depicted in the image acquired by the imaging device. Based on image data **202** and depth data **204**, system **100** may identify a target region within the image that depicts an anatomical surface to be covered by a physical medical element and output target region data **206** representative of the identified target region.

[0041] Target region data **202** may be in any suitable format. For example, target region data **202** may include two or three-dimensional pixel coordinates representative of pixels that depict the anatomical surface that is to be covered by the physical medical element.

[0042] Exemplary manners in which image data **202** and depth data **204** may be generated will now be described.

[0043] FIG. **3** illustrates an exemplary configuration **300** in which an imaging device **302** includes a visible light camera **304** configured to generate and output image data **202** and a depth sensor **306** configured to generate and output depth data **204**.

[0044] Imaging device **302** may be implemented by an endoscope or other camera device configured to capture images of a scene. In some examples, imaging device **302** may be configured to be attached to and controlled by a computer-assisted surgical system. In alternative examples, imaging device **302** may be hand-held and operated manually by an operator (e.g., a surgeon).

[0045] In some examples, the scene captured by imaging device **302** may include a surgical area associated with a patient. The surgical area may, in certain examples, be entirely disposed within the patient and may include an area within the patient at or near where a surgical procedure is planned to be performed, is being performed, or has been performed. For example, for a minimally invasive surgical procedure being performed on tissue internal to a patient, the surgical area may include the tissue, anatomy underlying the tissue, as well as space around the tissue where, for example, surgical instruments used to perform the surgical procedure are located. In certain example implementations, the surgical area entirely disposed within the patient may be referred to as an "internal space." As described herein, any internal anatomy of the patient (e.g., vessels, organs, and/or tissue) and/or surgical instruments located in the internal space may be referred to as objects and/or structures.

[0046] Visible light camera **304** ("camera **304**") is configured to generate image data **202** representative of a two-dimensional visible light image of a scene. Camera **304** may be implemented by any suitable image sensor, such as a charge coupled device ("CCD") image sensor, a complementary metal-oxide semiconductor ("CMOS") image sensor, a hyperspectral camera, a multispectral camera, or the like.

[0047] Depth sensor **306** may be implemented by any suitable sensor configured to generate depth data **204**. For example, depth sensor **306** may be implemented by a time-of-flight sensor, a structured light sensor, an interferometer, a hyperspectral camera, a multispectral camera, and/or any other suitable sensor configured to acquire depth data as may serve a particular implementation. In cases where depth sensor **306** is implemented by a time-of-flight sensor, the time-of-flight sensor may be implemented by one or more photodetectors (e.g., one or more single photon avalanche diode ("SPAD") detectors), CCD sensors, CMOS sensors, and/or any other suitable configuration. In the example of FIG. **3**, depth sensor **306** is separate from (i.e., physically distinct from) camera **304**.

[0048] In configuration **300**, system **100** may obtain image data **202** by directing camera **304** to acquire image data **202** and receiving image data **202** from camera **304**. Likewise, system **100** may obtain depth data **204** by directing depth sensor **306** to acquire depth data **204** and receiving depth data **204** from depth sensor **306**.

[0049] To this end, in configuration **300**, system **100** is communicatively coupled to imaging device **302** by way of a bidirectional communication link **308** and to an illumination system **310** by way of a communication link **312**. Communication links **308** and **312** may each be implemented by any suitable wired and/or wireless communication medium as may serve a particular implementation. System **100** may use communication links **308** and **312** to direct camera **304** and depth sensor **306** to acquire image data **202** and depth data **204** and receive image data **202** and depth data **204**, as described herein.

[0050] Illumination system **310** may be configured to emit light **314** (e.g., at the direction of system **100**) used to illuminate a scene to be imaged by imaging device **302**. The light **314** emitted by illumination system **310** may include visible light and/or non-visible light (e.g., infrared light). As shown, light **314** may travel to the scene through imaging device **302** (e.g., by way of an illumination channel within imaging device **302** that may be implemented by one or more optical fibers, light guides, lenses, etc.).

[0051] As shown, light **314** emitted by illumination system **310** may reflect off a surface **316** within a scene being imaged by imaging device **302**. In cases where imaging device **302** is aimed at an internal space of the patient, surface **316** represents a surface (e.g., an anatomical surface) within the internal space.

[0052] Camera **304** and depth sensor **306** may each detect the reflected light **314**. Camera **304** may be configured to generate, based on the detected light, image data **202** representative of a two-dimensional visible light image of the scene including surface **316**. Depth sensor **306** may be configured to generate, based on the detected light, depth data **204**. Image data **202** and depth data **204** may each have any suitable format.

[0053] To generate a stereoscopic image of a scene, system **100** may direct illumination system **310** to emit light **314**. System **100** may also activate (e.g., turn on) visible light camera **304** and depth sensor **306**. Light **314** travels to the scene and reflects off of surface **316** (and, in some examples, one or more other surfaces in the scene). Camera **304** and depth sensor **306** both detect the reflected light **314**.

[0054] Camera **304** (and/or other circuitry included in imaging device **302**) may generate, based on detected light **314**, image data **202** representative of a two-dimensional visible light image of the scene. This may be performed in any suitable manner. Visible light camera **304** (and/or other circuitry included imaging device **302**) may transmit image data **202** to system **100**. This may also be performed in any suitable manner.

[0055] Depth sensor **306** may generate, based on detected light **314**, depth data **204** representative of a depth map of the scene (e.g., a depth map of surface **316**). This may be performed in any suitable manner. For example, depth sensor **306** may measure an amount of time that it takes for a photon of light **314** to travel from illumination system **310** to depth sensor **306**. Based on this amount of time, depth sensor **306** may determine a depth of surface **316** relative to a position of depth sensor **306**. Data representative of this depth may be represented in depth data **204** in any suitable manner. For example, the depth map represented by depth data **204** may include an array of depth values (e.g., Z-buffer values) corresponding to each pixel in an image.

[0056] Depth sensor **306** (and/or other circuitry included imaging device **302**) may transmit depth data **204** to system **100**. This may be performed in any suitable manner.

[0057] System **100** may receive image data **202** and depth data **204** and perform one or more processing operations on image data **202** and depth data **204**. For example, as will be described in more detail below, system **100** may generate target region data **206** based on image data **202** and depth data **204**.

[0058] As another example, system **100** may generate, based on image data **202** and depth data **204**, a right-side perspective image of the scene and a left-side perspective image representative of the scene. This may be performed in any suitable manner. System **100** may then direct display devices to concurrently display the right and left-side perspective images in a manner that forms a stereoscopic image of the scene. In some examples, the display devices are included in and/or communicatively coupled to computer-assisted surgical system **204**.

[0059] FIG. **4** illustrates an exemplary configuration **400** in which depth sensor **402** is implemented by visible light cameras **304-1** and **304-2** included in imaging device **302**. In configuration **400**, system **100** may obtain depth data **204** by directing camera **304-1** to acquire a first image (e.g., a first two-dimensional image) of an internal space of a patient, directing camera **304-2** to acquire a second image (e.g., a second two-dimensional image) of the internal space of the patient, and generating, based on the first and second images, the depth map represented by depth data **204**.

[0060] In FIG. **4**, the first image acquired by camera **304-1** is represented by image data **202-1** and the second image acquired by camera **304-2** is represented by image data

202-2. As shown, image data **202-1** and **202-2** are transmitted to a depth data generator **402** implemented by system **100**. Depth data generator **402** may use any visible image-based technique to determine depth data **204** based on image data **202-1** and **202-2**.

[0061] Other configurations of imaging device **302** are possible in accordance with the systems and methods described herein. For example, imaging device **302** may include multiple cameras **304** and/or multiple depth sensors **306**. To illustrate, imaging device **302** may include two cameras **304** in combination with a separate depth sensor **306**. In these embodiments, depth data may be generated based on the images acquired by both cameras **304**. Depth data generated by depth sensor **304** may be used to fine tune or otherwise enhance the depth data generated based on the images acquired by both cameras **304**.

[0062] In some examples, system **100** may obtain depth data **204** by accessing a preoperative image registered to the image from a source other than imaging device **204**. For example, FIG. **5** shows an exemplary configuration **500** in which system **100** obtains depth data **204** from a preoperative image source **502**. Source **502** may be implemented by a computer-aided tomography (CT) scanner, a magnetic resonance imaging (MRI) device, an ultrasound device, a three-dimensional scanning (LIDAR) device, and/or any other suitable alternative imaging device configured to generate a preoperative image of the patient. The preoperative image may be registered with the image represented by image data **202** and thereby provide depth data **204**.

[0063] System **100** may identify the target region based on image data **202** and depth data **204** in any suitable manner. For example, based on image data **202** and depth data **204**, system **100** may identify a region within the image represented by image data **202** that depicts tissue in need of being covered by the physical medical element and then designate the identified region as the target region.

[0064] System **100** may identify a region of an image that depicts tissue in need of being covered by the physical medical element in any suitable manner. For example, based on image data **202** and depth data **204**, system **100** may segment the image (e.g., by classifying different portions of the image as corresponding to different types of tissue) and identify the region based on the segmentation.

[0065] Additionally or alternatively, system **100** may identify a region that depicts tissue in need of being covered by the physical medical element by inputting image data **202** and depth data **204** into a machine learning model configured to identify a tissue anomaly. The machine learning model may be trained and/or used in any suitable manner.

[0066] In some examples, system **100** may determine a stage within a surgical procedure being performed with respect to the patient and further based the identification of the region that depicts tissue in need of being covered by the physical medical element on the determined stage. For example, system **100** may receive input from a surgeon that the surgeon is attempting to locate a tissue defect within the patient by scanning an internal space of the patient with an imaging device. Based on this input, system **100** may initiate a region identification heuristic that utilizes image data **202** and depth data **204** to automatically identify a region within the image acquired by imaging device that depicts tissue in need of being covered by the physical medical element.

[0067] Once the target region that depicts an anatomical surface to be covered by the physical medical element is identified, system **100** may instruct a display device to render a virtual medical element representative of the physical medical element over the identified target region within the image. This may be performed in any suitable manner.

[0068] By way of illustration, FIG. **6** shows an exemplary image **602** that may be captured by an imaging device aimed at an internal space of a patient and that may be represented by image data **202**. As shown, image **602** depicts a tissue defect **604** surrounded by non-defective tissue **606**. Tissue defect **604** may be a hernia, cut, or other type of lesion. Non-defective tissue **606** may include, for example, healthy tissue not affected by tissue defect **604**.

[0069] System **100** may, based on image data **202** and/or depth data **204**, identify a target region within image **602** that depicts an anatomical surface that is to be covered by a physical medical element. This may be performed in any of the ways described herein. In some examples, the anatomical surface to be covered by the physical medical element includes at least a portion of tissue defect **604**. The anatomical surface to be covered by the physical medical element may, in some instances, also include at least a portion of non-defective tissue **606**. For example, the anatomical surface to be covered by the physical medical element may include the entire tissue defect **604** and an overlap region made up of non-defective tissue **606** surrounding tissue defect **604**. The overlap region may have any suitable width (e.g., between one and five centimeters), and may be used to attach the physical medical element to the anatomical surface, as described herein.

[0070] Tissue defect **604** and the non-defective tissue **606** may have varying relative depths. For example, tissue defect **604** and the non-defective tissue surrounding tissue defect **604** may have various ridges, peaks, valleys, contours, and/or otherwise uneven surfaces. However, such variations in depth may not be visually ascertainable within image **602**, especially if image **602** is two-dimensional. Hence, as described herein, system **100** may take such depth variations into account when determining the physical dimensions of the physical medical element that will be cover tissue defect **604** and the overlap region made up of non-defective tissue **606** surrounding tissue defect **604**.

[0071] System **100** may instruct the display device to render a virtual medical element representative of the physical medical element over the identified target region within image **602**. For example, FIG. **7** shows an exemplary virtual medical element **702** rendered over the identified target region within image **602**. In the example of FIG. **7**, virtual medical element **702** includes the dashed line as well as a region enclosed by the dashed line. Moreover, in the example of FIG. **7**, the identified target region corresponds directly with (i.e., is completely covered by) virtual medical element **702**.

[0072] While virtual medical element **702** is illustrated as being a dashed rectangle positioned over tissue defect **604** and a portion of non-defective tissue **606**, it will be recognized that virtual medical element **702** may alternatively be rendered in any other suitable manner. For example, virtual medical element **702** may be at least partially transparent to allow visualization by the user of the target region and/or tissue defect **604** while virtual medical element **702** is rendered over the target region.

[0073] While virtual medical element **702** is rendered over the target region, a user may provide user input that sets a pose and/or size of virtual medical element **702**. For example, if the user determines that the initially determined pose and size of virtual medical element **702** is adequate (e.g., if virtual medical element **702** sufficiently covers the depiction of tissue defect **604**), the user may provide user input that confirms that the pose and size of virtual medical element **702** are correct. Such user input may be provided in any suitable manner. For example, such user input may be provided by the user selecting an option displayed in image **602**, by the user selecting a user input button on a component of a computer-assisted surgical system, by the user providing a verbal command, and/or in any other manner.

[0074] In some cases, the user may determine that the initially determined pose and/or size of virtual medical element **702** needs further refinement. For example, the user may desire to enlarge or shrink virtual medical element **702**, reposition one or more edges of virtual medical element **702**, and/or otherwise adjust a pose and/or size of virtual medical element **702**. In these cases, the user input that sets the pose and/or size of virtual medical element **702** may include one or more user input commands that adjust the pose and/or size of virtual medical element **702**. Such user input may be provided in any suitable manner. For example, the user input may be provided by the user interacting with virtual handles displayed as part of virtual medical element **702**, providing one or more input commands by way of a graphical user interface within which image **602** is included, providing one or more keyboard or other input device commands, and/or in any other suitable manner. System **100** may dynamically adjust, in response to receiving the user input that adjusts the pose and/or size of virtual medical element **702**, the rendering of virtual medical element **702** in substantially real time to depict at least one of the pose and the size of the virtual medical element as adjusted by the user input.

[0075] To illustrate, FIG. **8** shows virtual medical element **702** after a user has adjusted a shape (and therefore size) of virtual medical element **702**. As shown, the shape and size of virtual medical element **702** as illustrated in FIG. **8** conforms more closely with the actual shape and size of tissue defect **604** than did virtual medical element **702** prior to being adjusted by the user (FIG. **7**).

[0076] In some examples, the initial shape of virtual medical element **702** is a standard size used for a particular type of physical medical element. For example, the initial shape of virtual medical element **702** may be rectangular, as shown in FIG. **7**, for physical medical elements that are typically rectangular in shape.

[0077] Alternatively, the initial shape of virtual medical element **702** may conform more closely with the actual shape of the anatomical surface to be covered by the physical medical element. For example, FIG. **9** shows an exemplary implementation where virtual medical element **702** has a contoured shape that follows an outer edge of tissue defect **604**.

[0078] The initial shape of virtual medical element **702** may be determined automatically based on one or more attributes of the physical medical element that is to cover the anatomical surface. Additionally or alternatively, the initial shape of virtual medical element **702** may be specified by a user by providing one or more user input commands.

[0079] Based on the user input that sets the pose and/or size of virtual medical element **702** and on depth data **204**, system **100** may determine physical dimensions for the physical medical element that is to cover the anatomical surface. For example, FIG. **10** illustrates an exemplary configuration **1000** in which system **100** accesses virtual data **1002** and depth data **204** and generates physical dimensions data **1004** based on virtual data **1002** and depth data **204**. Virtual data **1002** may be representative of the pose, size, and/or positioning of virtual medical element **702** as set by the user. Depth data **204**, as explained herein, is representative of a depth map for the internal space depicted in image **602**. Physical dimensions data **1004** is representative of physical dimensions for the physical medical element as determined by system **100**. As described herein, the physical dimensions may represent a surface area for the physical medical element.

[0080] System **100** may generate physical dimensions data **1004** based on virtual data **1002** and depth data **204** in any suitable manner. For example, system **100** may identify, based on the pose and the size of the virtual medical element as represented by virtual data **1002**, a plurality of pixels within image **602** that are covered by virtual medical element **702**. System **100** may determine a two-dimensional pixel area of the plurality of pixels. System **100** may determine, based on depth data **204**, depth values for each of the plurality of pixels that are covered by virtual medical element **702**. Based on the two-dimensional pixel area and the depth values, system **100** may determine a surface area and/or other dimensions of the anatomical surface to be covered by the physical medical element. System **100** may base the physical dimensions of the physical medical element on the surface area of the anatomical surface. Each of these operations may be performed in any suitable manner.

[0081] As mentioned, the systems and methods described herein may be used to determine physical dimensions for a mesh patch used to cover a hernia. As another example, virtual medical element **702** may be representative of a fastener (e.g., a clip or staple) and placed over an image of two tissue sections that are to be fastened together. Based on a sizing and/or change in pose of virtual medical element **702**, system **100** may determine physical dimensions for an actual fastener that is to be used to fasten the two tissue sections. As another example, virtual medical element **702** may be representative of bone putty or another type of material that is to be used to fill in a void in a bone. Based on a sizing and/or change in pose of virtual medical element **702**, system **100** may determine physical dimensions (e.g., a volume) for actual bone putty that is to be used to fill in the void. These examples are merely illustrative of the many different ways in which system **100** may determine physical dimensions for a medical element that is to be introduced into a patient.

[0082] Because of the variations in depth that the anatomical surface may have, the surface area for the physical medical element as defined by the physical dimensions of virtual medical element **702** may, in some cases, be greater than a physical area represented by the two-dimensional pixel area. For example, the physical medical element may be made out of a material configured to "shrink wrap" or otherwise adhere to all of the surface area of the anatomical surface. In this example, if the anatomical surface has protruding ridge that needs to be covered by the physical medical element, this variation in depth may result in the surface area defined by the physical dimensions of the physical medical element as determined by system **100** being larger than a physical area represented by the two-dimensional pixel area of virtual medical element **702**.

[0083] FIG. **11** shows an exemplary configuration **1100** in which system **100** further bases the generation of physical dimensions data **1004** on deformation data **1102** in addition to virtual data **1002** and depth data **204**. Deformation data **1102** is representative of a deformation model of the physical medical element. The deformation model may indicate one or more physical attributes of a physical medical element that affect an ability of the physical medical element to deform (e.g., stretch, compress, etc.) in response to force applied to the physical medical element. For example, the deformation model may indicate a type of material from which the physical medical element is made, a tensile strength of the material, and/or any other metric representative of deformation as may serve a particular implementation.

[0084] System **100** may determine the physical dimensions of the physical medical element based on deformation data **1102** in any suitable manner. For example, if deformation data **1102** indicates that the physical medical element is relatively resistant to stretching, system **100** may specify that the physical dimensions are to be relatively smaller than a different type of physical medical element that exhibits a high degree of stretching.

[0085] System **100** may obtain deformation data **1102** in any suitable manner. For example, system **100** may maintain or access a database that includes deformation data **1102** for various types of physical medical elements. System **100** may ascertain which particular physical medical element is to be used to cover the anatomical surface by receiving user input indicating which physical medical element is to be used, automatically determining which physical medical element is to be used based on tracked tendencies of a particular user and/or a particular type of surgical procedure being performed, and/or in any other suitable manner.

[0086] System **100** may output data representative of the physical dimensions in any suitable manner. For example, system **100** may output data representative of the physical dimensions by displaying the physical dimensions within image **602** or within any other suitable user interface. Additionally or alternatively, system **100** may output data representative of the physical dimensions by outputting physical measurements (e.g., a width and length in centimeters) of the physical medical element. Additionally or alternatively, system **100** may output data representative of the physical dimensions by outputting data representative of a pattern to be used to cut the physical medical element out of a material.

[0087] In some examples, system **100** may project virtual medical element **702** onto a physical material from which the physical medical element is to be cut. In this manner, virtual medical element **702** may guide a user in cutting the physical medical element out of the physical material.

[0088] To illustrate, FIG. **12** shows an exemplary physical material **1202** from which the physical medical element is to be cut. In the example of FIG. **12**, physical material **1202** is a mesh material from which patches for hernias and/or other types of tissue defects may be cut. As shown, system **100** has projected the virtual medical element **702** onto physical material **1202**. Virtual medical element **702** may be projected onto physical material **1202** in any suitable manner.

[0089] Once a physical medical element is ready to be introduced into the patient, system **100** may be configured to provide placement guidance configured to guide and/or assist a user in placing the physical medical element on the anatomical surface. This placement guidance may be provided in a number of different ways.

[0090] For example, FIG. **13** illustrates exemplary configuration **1300** in which system **100** obtains anatomical characteristic data **1302** representative of a characteristic associated with an anatomical surface to be covered by a physical medical element and determines, based on anatomical characteristic data **1302**, a placement guidance parameter set **1304**. Placement guidance parameter set **1304** includes one or more parameters configured to guide a placement of the physical medical element on the anatomical surface with one or more surgical instruments controlled by a computer-assisted surgical system.

[0091] Anatomical characteristic data **1302** may be representative of one or more characteristics associated with the anatomical surface to be covered by the physical medical element. For example, anatomical characteristic data **1302** may be representative of a type of tissue that constitutes the anatomical surface, a size of the anatomical surface, and/or a location of the anatomical surface within the patient. These characteristics may affect the way in which the physical medical element is placed on the anatomical surface. For example, if the anatomical surface is located in a vicinity of an organ, system **100** may generate one or more parameters for inclusion in placement guidance parameter set **1304** that indicate that the anatomical surface is near the organ and that may be used to identify a suturing plan for attaching the physical medical element to the anatomical surface in a manner that does not damage or otherwise affect the organ. As another example, if the tissue that constitutes the anatomical surface is relatively weak, system **100** may generate one or more parameters for inclusion in the placement guidance parameter set **1304** that may be used to increase the relative number of sutures are used to attach the physical medical element to the anatomical surface.

[0092] System **100** may obtain anatomical characteristic data **1302** in any suitable manner. For example, system **100** may obtain anatomical characteristic data **1302** by accessing image data **202**, obtaining depth data **204**, and determining, based on image data **202** and depth data **204**, anatomical characteristic data **1302**. To illustrate, image data **202** and depth data **204** may be used to determine a location of the anatomical surface, a size of the anatomical surface, and/or any other characteristic of the anatomical surface.

[0093] In some examples, system **100** may use image data **202** and depth data **204** to segment the image represented by image data **202**. The segmentation may include classifying different portions of the image as corresponding to different items (e.g., types of tissue). Based on the segmentation, system **100** may determine one or more characteristics of the anatomical surface, such as tissue type, etc.

[0094] FIG. **14** illustrates exemplary configuration **1400** in which system **100** obtains element characteristic data **1402** in addition to anatomical characteristic data **1302**. As shown, in configuration **1400**, system **100** generates placement guidance parameter set **1304** based on both anatomical characteristic data **1302** and element characteristic data **1402**. In alternative examples, system **100** generates placement guidance parameter set **1304** based only on element characteristic data **1402** (and not anatomical characteristic data **1302**).

[0095] Element characteristic data **1402** is representative of one or more characteristics associated with the physical medical element that will cover the anatomical surface. For example, element characteristic data **1402** may be representative of physical dimensions of the physical medical element, a type of material used for the physical medical element, a tensile strength of the physical medical element, and/or a deformation characteristic of the physical medical element.

[0096] System **100** may access element characteristic data **1402** in any suitable manner. For example, system **100** may maintain or access a database that includes element characteristic data **1402**. As another example, system **100** may access element characteristic data **1402** by receiving user input representative of the access element characteristic data **1402**.

[0097] In some examples, placement guidance parameter set **1304** includes one or more parameters configured to specify an optimal orientation for the physical medical element as the physical medical element is being placed on the anatomical surface with one or more surgical instruments controlled by a computer-assisted surgical system. In these examples, system **100** may indicate the optimal orientation for the physical medical element to a user in any suitable manner.

[0098] For example, system **100** may be configured to indicate the optimal orientation for the physical medical element to a user by graphically indicating, within an image (e.g., image **602**) of the internal space, the optimal orientation. To illustrate, FIG. **15** shows an exemplary scenario in which a physical medical element **1502** is being placed on an anatomical surface that includes tissue defect **604** and a portion of non-defective tissue **606**.

[0099] As shown, physical medical element **1502** is being placed on the anatomical surface by surgical instruments **1504-1** and **1504-2** ("surgical instruments **1504**"). Surgical instruments **1504** may include any suitable grasping tool configured to hold and guide physical medical element **1502** into place. In some examples, surgical instruments **1504** are controlled by a computer-assisted surgical system (e.g., in response to user input commands provided by a surgeon or other user).

[0100] As shown, system **100** may render virtual medical element **702** within image **602** while the user is using surgical instruments **1504** to place physical medical element **1502** on the anatomical surface. In this configuration, virtual medical element **702** graphically indicates the optimal orientation of physical medical element. In addition, graphical arrows **1506-1** and **1506-2** may be rendered by system **100** within image **602** to indicate a direction in which the user should rotate physical medical element **1502** to arrive at the optimal orientation. System **100** may additionally or alternatively present any other suitable virtual, audible, and/or graphical assistance indicative of the optimal orientation of physical medical element **1502** as may serve a particular implementation.

[0101] In some examples, placement guidance parameter set **1304** includes one or more parameters configured to specify an optimal insertion path within the internal space that surgical instruments **1504** are to follow while bringing physical medical element **1502** from outside the patient to being in contact with the anatomical surface. In these examples, system **100** may indicate the optimal insertion path for physical medical element **1502** to a user in any suitable manner. For example, system **100** may be configured to indicate the optimal insertion path for the physical medical element by graphically indicating, within an image (e.g., image **602**) of the internal space, the optimal insertion path. System **100** may additionally or alternatively present any other suitable virtual, audible, and/or graphical assistance indicative of the optimal insertion path as may serve a particular implementation.

[0102] The optimal insertion path specified by the one or more parameters in placement guidance parameter set **1304** may be defined such that surgical instruments **1504** and/or physical medical element **1502** avoid collision with tissue and/or other objects (e.g., other surgical instruments) in the internal space while physical medical element **1502** is brought from outside the patient to being in contact with the anatomical surface.

[0103] In some examples, placement guidance parameter set **1304** includes one or more parameters configured to specify a suturing plan for suturing physical medical element **1502** to the anatomical surface while the surgical instruments **1504** hold physical medical element **1502** in place on the anatomical surface. The suturing plan may include information specifying a suture pattern to be used to suture physical medical element **1502** to the anatomical surface, a spacing to be used between sutures used to suture physical medical element **1502** to the anatomical surface, a type of thread to be used to suture physical medical element **1502** to the anatomical surface, a length of thread needed to suture physical medical element **1502** to the anatomical surface, and/or any other aspect of a suturing plan as may serve a particular implementation. While exemplary suturing plans are described herein, it will be recognized that placement guidance parameter set **1304** may alternatively include one or more parameters configured to specify any other type of affixation plan that may be used to affix physical medical element **1502** to the anatomical surface.

[0104] By way of example, an exemplary suturing plan that may be specified by one or more parameters in placement guidance parameter set **1304** may indicate a recommended suture pattern, suture spacing, thread type, and/or thread length for a particular type of tissue as indicated in anatomical characteristic data **1302**, a particular type and/or size of tissue defect **604** as indicated in anatomical characteristic data **1302**, a proximity of other objects (e.g., organs) to tissue defect **604** as indicated in anatomical characteristic data **1302**, and/or any other characteristic of the anatomical surface as indicated in anatomical characteristic data **1302**. Additionally or alternatively, an exemplary suturing plan that may be specified by one or more parameters in placement guidance parameter set **1304** may indicate a recommended suture pattern, suture spacing, thread type, and/or thread length for one or more of the characteristics of physical medical element **1502** as indicated in element characteristic data **1402**.

[0105] In some examples, system **100** may be configured to graphically indicate the suturing plan within image **602**. For example, FIG. **16** shows physical medical element **1502** prior to being sutured to the anatomical surface. System **100** may graphically indicate the suturing plan within image **602** by presenting virtual markers (e.g., virtual markers **1602-1** through **1602-5**) representative of locations where sutures are to be placed to attach physical medical element **1502** to the anatomical surface. The position and spacing of each virtual marker **1602** may be determined based on anatomical characteristic data **1302** and/or element characteristic data **1402**. For example, the majority of virtual markers **1602** are positioned approximately the same distance from an outer edge of physical medical element **1502**. However, in this example, virtual marker **1602-2** is offset with respect to its adjacent virtual markers **1602-1** and **1602-3** (i.e., virtual marker **1602-2** is further away from the edge of physical medical element **1502** than virtual markers **1602-1** and **1602-3**). This may be because anatomical characteristic data **1302** may indicate that the tissue in the vicinity of the location on physical medical element **1502** that corresponds to virtual marker **1602-2** is relatively weak, thereby necessitating a larger gap between the suture location and the edge of physical medical element **1502**.

[0106] In some examples, a user may provide user input configured to modify the suturing plan graphically indicated within image **602**. For example, a user may provide input that adjusts a position of one or more of virtual markers **1602**, removes a particular virtual marker **1602**, adds a new virtual marker, and/or otherwise modifies the suturing plan. In response to this user input, system **100** may dynamically adjust the suturing plan in accordance with the user input. For example, based on a repositioning by a user of a particular virtual marker **1602**, system **100** may update an amount of thread needed to perform the suturing, adjust a positioning of a suturing device and/or one or more other surgical instruments, and/or otherwise adjust the suturing plan.

[0107] FIG. **16** also shows a suturing device **1604** positioned at a location on physical medical element **1502** that corresponds to a particular virtual marker **1602-4**. Suturing device **1604** may be configured to suture physical medical element **1502** to the anatomical surface in any suitable manner. For example, suturing device **1604** may apply a running suture (or any other type of suture) around a perimeter of physical medical element **1502** at various locations corresponding to virtual markers **1602**.

[0108] In some examples, suturing device **1604** is controlled by a computer-assisted surgical system (e.g., by being connected to a manipulator arm of the computer-assisted surgical system). In these examples, suturing device **1604** may be referred to as a certain type of surgical instrument coupled to and controlled by the computer-assisted surgical system. In alternative examples, suturing device **1604** is not controlled by a computer-assisted surgical system. In these alternative examples, suturing device **1604** may be manually held and/or otherwise controlled by a user.

[0109] In cases where suturing device **1604** is controlled by a computer-assisted surgical system, a positioning and/or operation of suturing device **1604** may be set in response to user input (e.g., a user may provide input commands that move and/or operate suturing device **1604**). For example, the user may provide input commands that direct the computer-assisted surgical system to move suturing device **1604** from suturing location to suturing location as guided by the suturing plan represented by virtual markers **1602**. For example, after suturing device **1604** is used to suture physical medical element **1502** to the anatomical surface at a suture location corresponding to virtual marker **1602-4**, the user may provide input commands (e.g., by manipulating master controls that are a part of the computer-assisted surgical system) that cause suturing device **1604** to move to a suture location that corresponds to virtual marker **1602-5**. Once at this location, suturing device **1604** may be used to suture physical medical element **1502** to the anatomical surface at the suture location corresponding to virtual marker **1602-5**. Such repositioning of suturing device **1604** may alternatively be performed automatically by the computer-assisted surgical system without specific user input that controls a positioning and/or operation of suturing device **1604**.

[0110] In some examples, system **100** may direct, in accordance with placement guidance parameter set **1304**, a computer-assisted surgical system to use one or more surgical instruments (e.g., surgical instruments **1504** and/or suturing device **1604**) to automatically place a physical medical element (e.g., physical medical element **1502**) on the anatomical surface without a user providing user input that controls a movement of the one or more surgical instrument while the physical medical element is being placed on the anatomical surface by the one or more surgical instruments. For example, system **100** may direct a computer-assisted surgical system to use surgical instruments **1504** to guide physical medical element **1502** to a proper orientation and positioning over the anatomical surface. System **100** may then direct the computer-assisted surgical system to use suturing device **1604** to automatically suture physical medical element **1502** to the anatomical surface.

[0111] In some examples, system **100** may track a relative pose of suturing device **1604** and/or surgical instruments **1504** with respect to physical medical element **1502**. System **100** may use the tracked pose to direct suturing device **1604** to properly perform the suturing of physical medical element **1502** to the anatomical surface and/or surgical instruments **1504** to properly grasp and hold physical medical element **1502**.

[0112] FIG. **17** illustrates an exemplary method **1700** that may be performed by a medical element management system (e.g., system **100** and/or any implementation thereof). While FIG. **17** illustrates exemplary operations according to one embodiment, other embodiments may omit, add to, reorder, and/or modify any of the operations shown in FIG. **17**.

[0113] In operation **1702**, a medical element management system instructs a display device to render a virtual medical element representative of a physical medical element over a target region within an image of an internal space of a patient, the target region depicting an anatomical surface to be covered by the physical medical element. Operation **1702** may be performed in any of the ways described herein.

[0114] In operation **1704**, the medical element management system receives, while the virtual medical element is rendered over the target region, user input that sets at least one of a pose of the virtual medical element within the image and a size of the virtual medical element. Operation **1704** may be performed in any of the ways described herein.

[0115] In operation **1706**, the medical element management system determines, based on the user input and on depth data representative of a depth map for the internal space, physical dimensions for the physical medical element. In some examples, the physical dimensions may specify a surface area, a volume, or any other suitable dimension for the physical medical element. Operation **1706** may be performed in any of the ways described herein.

[0116] FIG. **18** illustrates another exemplary method **1800** that may be performed by a medical element management system (e.g., system **100** and/or any implementation thereof). While FIG. **18** illustrates exemplary operations according to one embodiment, other embodiments may omit, add to, reorder, and/or modify any of the operations shown in FIG. **18**.

[0117] In operation **1802**, a medical element management system accesses image data representative of an image acquired by an imaging device and depicting an internal space of a patient. Operation **1802** may be performed in any of the ways described herein.

[0118] In operation **1804**, the medical element management system obtains depth data representative of a depth map for the internal space depicted in the image acquired by the imaging device. Operation **1804** may be performed in any of the ways described herein.

[0119] In operation **1806**, the medical element management system identifies, based on the image data and the depth data, a target region within the image that depicts an anatomical surface to be covered by a physical medical element. Operation **1806** may be performed in any of the ways described herein.

[0120] In operation **1808**, the medical element management system instructs a display device to render a virtual medical element representative of the physical medical element over the identified target region within the image. Operation **1808** may be performed in any of the ways described herein.

[0121] FIG. **19** illustrates another exemplary method **1900** that may be performed by a medical element management system (e.g., system **100** and/or any implementation thereof). While FIG. **19** illustrates exemplary operations according to one embodiment, other embodiments may omit, add to, reorder, and/or modify any of the operations shown in FIG. **19**.

[0122] In operation **1902**, a medical element management system obtains anatomical characteristic data representative of a characteristic associated with an anatomical surface to be covered by a physical medical element, the anatomical surface within an internal space of a patient. Operation **1902** may be performed in any of the ways described herein.

[0123] In operation **1904**, the medical element management system determines, based on the anatomical characteristic data, a placement guidance parameter set, the placement guidance parameter set comprising one or more parameters configured to guide a placement of the physical medical element on the anatomical surface with one or more surgical instruments controlled by a computer-assisted surgical system. Operation **1904** may be performed in any of the ways described herein.

[0124] FIG. **20** illustrates another exemplary method **2000** that may be performed by a medical element management system (e.g., system **100** and/or any implementation thereof). While FIG. **20** illustrates exemplary operations according to one embodiment, other embodiments may omit, add to, reorder, and/or modify any of the operations shown in FIG. **20**.

[0125] In operation **2002**, a medical element management system obtains anatomical characteristic data representative of a characteristic associated with an anatomical surface to be covered by a physical medical element, the anatomical surface within an internal space of a patient. Operation **2002** may be performed in any of the ways described herein.

[0126] In operation **2004**, the medical element management system determines, based on the anatomical characteristic data, a suturing plan for suturing the physical medical element to the anatomical surface while the one or more surgical instruments controlled by the computer-assisted surgical system hold the physical medical element in place on the anatomical surface. Operation **2004** may be performed in any of the ways described herein.

[0127] In operation **2006**, the medical element management system graphically indicates, within an image of the internal space, the suturing plan. Operation **2006** may be performed in any of the ways described herein.

[0128] The systems and methods described herein may be used in connection with and/or implemented by a computer-assisted surgical system used to perform a surgical procedure with respect to a patient. FIG. **21** illustrates an exemplary computer-assisted surgical system **2100** ("surgical system **2100**"). As shown, surgical system **2100** may include a manipulating system **2102**, a user control system **2104**, and an auxiliary system **2106** communicatively coupled one to another. Surgical system **2100** may be utilized by a surgical team to perform a computer-assisted surgical procedure on a patient **2108**. As shown, the surgical team may include a surgeon **2110-1**, an assistant **2110-2**, a nurse **2110-3**, and an anesthesiologist **2110-4**, all of whom may be collectively referred to as "surgical team members **2110**." Additional or alternative surgical team members may be present during a surgical session as may serve a particular implementation.

[0129] While FIG. **21** illustrates an ongoing minimally invasive surgical procedure, it will be understood that surgical system **2100** may similarly be used to perform open surgical procedures or other types of surgical procedures that may similarly benefit from the accuracy and convenience of surgical system **2100**. Additionally, it will be understood that the surgical session throughout which surgical system **2100** may be employed may not only include an operative phase of a surgical procedure, as is illustrated in FIG. **21**, but may also include preoperative, postoperative, and/or other suitable phases of the surgical procedure. A surgical procedure may include any procedure in which manual and/or instrumental techniques are used on a patient to investigate or treat a physical condition of the patient.

[0130] As shown in FIG. **21**, manipulating system **2102** may include a plurality of manipulator arms **2112** (e.g., manipulator arms **2112-1** through **2112-4**) to which a plurality of surgical instruments may be coupled. Each surgical instrument may be implemented by any suitable surgical tool (e.g., a tool having tissue-interaction functions), medical tool, imaging device (e.g., an endoscope), sensing instrument (e.g., a force-sensing surgical instrument), diagnostic instrument, or the like that may be used for a computer-assisted surgical procedure on patient **2108** (e.g., by being at least partially inserted into patient **2108** and manipulated to perform a computer-assisted surgical procedure on patient **2108**). While manipulating system **2102** is depicted and described herein as including four manipulator arms **2112**, it will be recognized that manipulating system **2102** may include only a single manipulator arm **2112** or any other number of manipulator arms as may serve a particular implementation.

[0131] Manipulator arms **2112** and/or surgical instruments attached to manipulator arms **2112** may include one or more displacement transducers, orientational sensors, and/or positional sensors used to generate raw (i.e., uncorrected) kinematics information. One or more components of surgical system **2100** may be configured to use the kinematics information to track (e.g., determine positions of) and/or control the surgical instruments.

[0132] User control system **2104** may be configured to facilitate control by surgeon **2110-1** of manipulator arms

2112 and surgical instruments attached to manipulator arms **2112**. For example, surgeon **2110-1** may interact with user control system **2104** to remotely move or manipulate manipulator arms **2112** and the surgical instruments. To this end, user control system **2104** may provide surgeon **2110-1** with imagery (e.g., high-definition 3D imagery) of a surgical area associated with patient **2108** as captured by an imaging system (e.g., any of the medical imaging systems described herein). In certain examples, user control system **2104** may include a stereo viewer having two displays where stereoscopic images of a surgical area associated with patient **2108** and generated by a stereoscopic imaging system may be viewed by surgeon **2110-1**. Surgeon **2110-1** may utilize the imagery to perform one or more procedures with one or more surgical instruments attached to manipulator arms **2112**.

[0133] To facilitate control of surgical instruments, user control system **2104** may include a set of master controls. These master controls may be manipulated by surgeon **2110-1** to control movement of surgical instruments (e.g., by utilizing robotic and/or teleoperation technology). The master controls may be configured to detect a wide variety of hand, wrist, and finger movements by surgeon **2110-1**. In this manner, surgeon **2110-1** may intuitively perform a procedure using one or more surgical instruments. In some examples, user control system **2104** implements user control system **806**.

[0134] Auxiliary system **2106** may include one or more computing devices configured to perform primary processing operations of surgical system **2100**. In such configurations, the one or more computing devices included in auxiliary system **2106** may control and/or coordinate operations performed by various other components (e.g., manipulating system **2102** and user control system **2104**) of surgical system **2100**. For example, a computing device included in user control system **2104** may transmit instructions to manipulating system **2102** by way of the one or more computing devices included in auxiliary system **2106**. As another example, auxiliary system **2106** may receive, from manipulating system **2102**, and process image data representative of imagery captured by an imaging device attached to one of manipulator arms **2112**.

[0135] In some examples, auxiliary system **2106** may be configured to present visual content to surgical team members **2110** who may not have access to the images provided to surgeon **2110-1** at user control system **2104**. To this end, auxiliary system **2106** may include a display monitor **2114** configured to display one or more user interfaces, such as images (e.g., 2D images, 3D images) of the surgical area, information associated with patient **2108** and/or the surgical procedure, and/or any other visual content as may serve a particular implementation. For example, display monitor **2114** may display images of the surgical area together with additional content (e.g., graphical content, contextual information, etc.) concurrently displayed with the images. In some embodiments, display monitor **2114** is implemented by a touchscreen display with which surgical team members **2110** may interact (e.g., by way of touch gestures) to provide user input to surgical system **2100**.

[0136] Manipulating system **2102**, user control system **2104**, and auxiliary system **2106** may be communicatively coupled one to another in any suitable manner. For example, as shown in FIG. **21**, manipulating system **2102**, user control system **2104**, and auxiliary system **2106** may be communicatively coupled by way of control lines **2116**, which may represent any wired or wireless communication link as may serve a particular implementation. To this end, manipulating system **2102**, user control system **2104**, and auxiliary system **2106** may each include one or more wired or wireless communication interfaces, such as one or more local area network interfaces, Wi-Fi network interfaces, cellular interfaces, etc.

[0137] In some examples, a non-transitory computer-readable medium storing computer-readable instructions may be provided in accordance with the principles described herein. The instructions, when executed by a processor of a computing device, may direct the processor and/or computing device to perform one or more operations, including one or more of the operations described herein. Such instructions may be stored and/or transmitted using any of a variety of known computer-readable media.

[0138] A non-transitory computer-readable medium as referred to herein may include any non-transitory storage medium that participates in providing data (e.g., instructions) that may be read and/or executed by a computing device (e.g., by a processor of a computing device). For example, a non-transitory computer-readable medium may include, but is not limited to, any combination of non-volatile storage media and/or volatile storage media. Exemplary non-volatile storage media include, but are not limited to, read-only memory, flash memory, a solid-state drive, a magnetic storage device (e.g. a hard disk, a floppy disk, magnetic tape, etc.), ferroelectric random-access memory ("RAM"), and an optical disc (e.g., a compact disc, a digital video disc, a Blu-ray disc, etc.). Exemplary volatile storage media include, but are not limited to, RAM (e.g., dynamic RAM).

[0139] FIG. **22** illustrates an exemplary computing device **2200** that may be specifically configured to perform one or more of the processes described herein. Any of the systems, computing devices, and/or other components described herein may be implemented by computing device **2200**.

[0140] As shown in FIG. **22**, computing device **2200** may include a communication interface **2202**, a processor **2204**, a storage device **2206**, and an input/output ("I/O") module **2208** communicatively connected one to another via a communication infrastructure **2210**. While an exemplary computing device **2200** is shown in FIG. **22**, the components illustrated in FIG. **22** are not intended to be limiting. Additional or alternative components may be used in other embodiments. Components of computing device **2200** shown in FIG. **22** will now be described in additional detail.

[0141] Communication interface **2202** may be configured to communicate with one or more computing devices. Examples of communication interface **2202** include, without limitation, a wired network interface (such as a network interface card), a wireless network interface (such as a wireless network interface card), a modem, an audio/video connection, and any other suitable interface.

[0142] Processor **2204** generally represents any type or form of processing unit capable of processing data and/or interpreting, executing, and/or directing execution of one or more of the instructions, processes, and/or operations described herein. Processor **2204** may perform operations by executing computer-executable instructions **2212** (e.g., an application, software, code, and/or other executable data instance) stored in storage device **2206**.

[0143] Storage device **2206** may include one or more data storage media, devices, or configurations and may employ any type, form, and combination of data storage media and/or device. For example, storage device **2206** may include, but is not limited to, any combination of the non-volatile media and/or volatile media described herein. Electronic data, including data described herein, may be temporarily and/or permanently stored in storage device **2206**. For example, data representative of computer-executable instructions **2212** configured to direct processor **2204** to perform any of the operations described herein may be stored within storage device **2206**. In some examples, data may be arranged in one or more databases residing within storage device **2206**.

[0144] I/O module **2208** may include one or more I/O modules configured to receive user input and provide user output. I/O module **2208** may include any hardware, firmware, software, or combination thereof supportive of input and output capabilities. For example, I/O module **2208** may include hardware and/or software for capturing user input, including, but not limited to, a keyboard or keypad, a touchscreen component (e.g., touchscreen display), a receiver (e.g., an RF or infrared receiver), motion sensors, and/or one or more input buttons.

[0145] I/O module **2208** may include one or more devices for presenting output to a user, including, but not limited to, a graphics engine, a display (e.g., a display screen), one or more output drivers (e.g., display drivers), one or more audio speakers, and one or more audio drivers. In certain embodiments, I/O module **2208** is configured to provide graphical data to a display for presentation to a user. The graphical data may be representative of one or more graphical user interfaces and/or any other graphical content as may serve a particular implementation.

[0146] In the preceding description, various exemplary embodiments have been described with reference to the accompanying drawings. It will, however, be evident that various modifications and changes may be made thereto, and additional embodiments may be implemented, without departing from the scope of the invention as set forth in the claims that follow. For example, certain features of one embodiment described herein may be combined with or substituted for features of another embodiment described herein. The description and drawings are accordingly to be regarded in an illustrative rather than a restrictive sense.

What is claimed is:

1. A system comprising:

a non-transitory memory storing instructions; and

a processor communicatively coupled to the memory and configured to execute the instructions to:

instruct a display device to render a virtual medical element representative of a physical medical element over a target region within an image of an internal space of a patient, the target region depicting an anatomical surface to be covered by the physical medical element;

receive, while the virtual medical element is rendered over the target region, user input that sets at least one of a pose of the virtual medical element within the image or a size of the virtual medical element; and

determine, based on the user input and on depth data, physical dimensions for sizing the physical medical element that is to be introduced into the patient, the determining the physical dimensions for the physical medical element comprising:

identifying, based on the pose and the size of the virtual medical element, a plurality of pixels within the image that are covered by the virtual medical element;

determining a two-dimensional pixel area of the plurality of pixels;

determining, based on the depth data, depth values for each of the plurality of pixels;

determining, based on the two-dimensional pixel area and the depth values, a surface area of the anatomical surface to be covered by the physical medical element; and

basing the physical dimensions on the surface area of the anatomical surface.

2. The system of claim **1**, wherein:

the processor is further configured to execute the instructions to access deformation data representative of a deformation model of the physical medical element; and

the determining of the physical dimensions for the physical medical element is further based on the deformation data.

3. The system of claim **1**, wherein a surface area for the physical medical element as defined by the physical dimensions is greater than a physical area represented by the two-dimensional pixel area.

4. The system of claim **1**, wherein the processor is further configured to execute the instructions to output data representative of the physical dimensions.

5. The system of claim **1**, wherein the processor is further configured to execute the instructions to project the virtual medical element onto a physical material from which the physical medical element is to be cut.

6. The system of claim **1**, wherein the receiving of the user input comprises receiving user input that adjusts at least one of the pose of the virtual medical element within the image or the size of the virtual medical element.

7. The system of claim **6**, wherein the processor is further configured to execute the instructions to dynamically adjust, in response to receiving the user input that adjusts at least one of the pose of the virtual medical element within the image or the size of the virtual medical element, the rendering of the virtual medical element in substantially real time to depict at least one of the pose or the size of the virtual medical element as adjusted by the user input.

8. The system of claim **1**, wherein:

the physical medical element comprises one or more of a mesh patch, gauze, a bandage, a plate, a prosthesis, a specimen containment bag, a fastener, or bone putty.

9. The system of claim **1**, wherein the image is acquired by an imaging device aimed at the internal space of the patient, and wherein the processor is further configured to execute the instructions to:

access image data representative of the image acquired by the imaging device;

identify, based on the image data and the depth data, a region within the image that depicts tissue in need of being covered by the physical medical element; and

designate the region as the target region.

10. The system of claim **9**, wherein the imaging device comprises a visible light camera and the image acquired by the imaging device comprises a two-dimensional visible light image acquired by the visible light camera.

11. The system of claim **10**, wherein the processor is further configured to execute the instructions to direct a depth sensor in the imaging device and separate from the visible light camera to acquire the depth data while the imaging device is aimed at the internal space of the patient.

12. The system of claim **11**, wherein the depth sensor comprises a time-of-flight sensor.

13. The system of claim **9**, the processor is further configured to execute the instructions to:

direct a first visible light camera included in the imaging device to acquire a first visible light image of the internal space;

direct a second visible light camera included in the imaging device to acquire a second visible light image of the internal space; and

generate, based on the first and second visible light images, the depth data.

14. The system of claim **9**, wherein the identifying of the region within the image that depicts tissue in need of being covered by the physical medical element comprises inputting the image data and the depth data into a machine learning model configured to identify a tissue anomaly.

15. The system of claim **9**, wherein the identifying of the region within the image that depicts tissue in need of being covered by the physical medical element comprises:

segmenting, based on the image data and the depth data, the image; and

identifying the region based on the segmenting.

16. The system of claim **1**, wherein the processor is further configured to execute the instructions to obtain the depth data based on a preoperative image registered to the image.

17. The system of claim **16**, wherein the preoperative image comprises an image generated by at least one of a computer-aided tomography (CT) scanner, a magnetic resonance imaging (MRI) device, an ultrasound device, or a three-dimensional scanning (LIDAR) device.

18. A method comprising:

instructing a display device to render a virtual medical element representative of a physical medical element over a target region within an image of an internal space of a patient, the target region depicting an anatomical surface to be covered by the physical medical element;

receiving, while the virtual medical element is rendered over the target region, user input that sets at least one of a pose of the virtual medical element within the image or a size of the virtual medical element; and

determining, based on the user input and on depth data, physical dimensions for sizing the physical medical element that is to be introduced into the patient, the determining the physical dimensions for the physical medical element comprising:

identifying, based on the pose and the size of the virtual medical element, a plurality of pixels within the image that are covered by the virtual medical element;

determining a two-dimensional pixel area of the plurality of pixels;

determining, based on the depth data, depth values for each of the plurality of pixels;

determining, based on the two-dimensional pixel area and the depth values, a surface area of the anatomical surface to be covered by the physical medical element; and

basing the physical dimensions on the surface area of the anatomical surface.

19. The method of claim **18**, wherein:

the method further comprises accessing deformation data representative of a deformation model of the physical medical element; and

the determining of the physical dimensions for the physical medical element is further based on the deformation data.

20. A non-transitory computer-readable medium storing instructions that, when executed, direct a processor of a computing device to:

instruct a display device to render a virtual medical element representative of a physical medical element over a target region within an image of an internal space of a patient, the target region depicting an anatomical surface to be covered by the physical medical element;

receive, while the virtual medical element is rendered over the target region, user input that sets at least one of a pose of the virtual medical element within the image or a size of the virtual medical element; and

determine, based on the user input and on depth data, physical dimensions for sizing the physical medical element that is to be introduced into the patient, the determining the physical dimensions for the physical medical element comprising:

identifying, based on the pose and the size of the virtual medical element, a plurality of pixels within the image that are covered by the virtual medical element;

determining a two-dimensional pixel area of the plurality of pixels;

determining, based on the depth data, depth values for each of the plurality of pixels;

determining, based on the two-dimensional pixel area and the depth values, a surface area of the anatomical surface to be covered by the physical medical element; and

basing the physical dimensions on the surface area of the anatomical surface.

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