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(54) **SYSTEMS AND METHODS FOR PERFORMANCE OF DEPTH SENSOR AND AUXILIARY SENSOR-BASED OPERATIONS ASSOCIATED WITH A COMPUTER-ASSISTED SURGICAL SYSTEM**

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G06T 7/55	(2017.01)
G16H 20/40	(2018.01)
G16H 30/40	(2018.01)
G16H 40/63	(2018.01)

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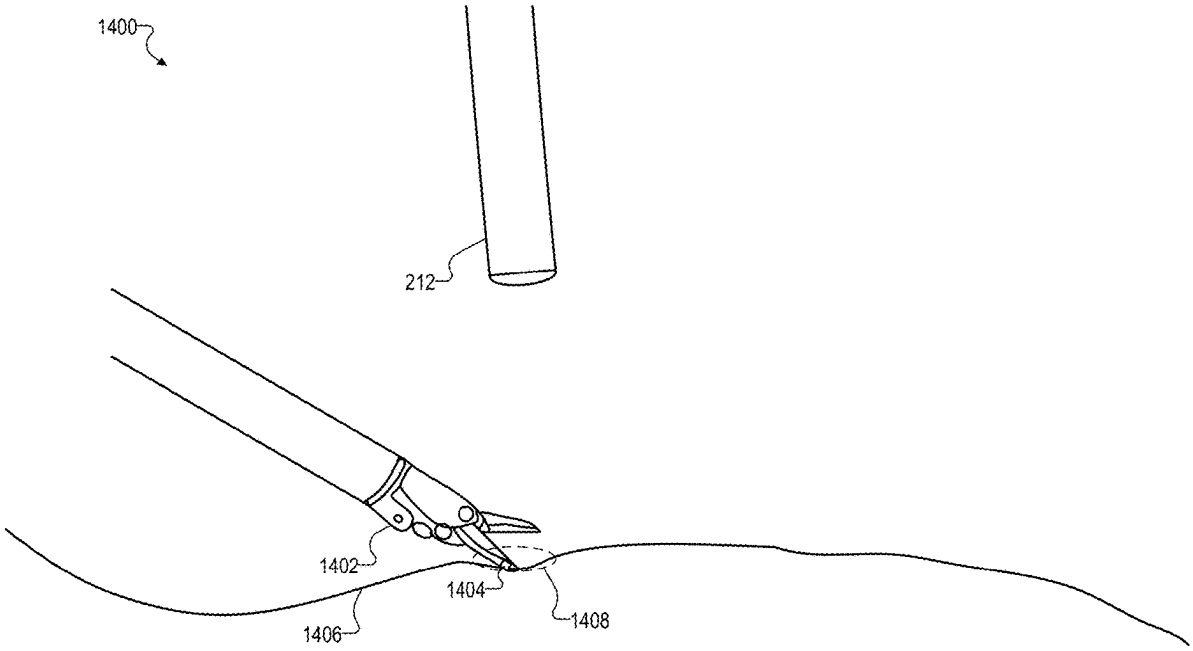
(57) **ABSTRACT**

An illustrative operation management system is configured to obtain, from a depth sensor included in an imaging device, depth data representative of a depth map for an internal space of a patient, obtain auxiliary sensor data from an auxiliary sensor not included in the imaging device, and perform, based on the depth data and the auxiliary sensor data, an operation associated with a computer-assisted surgical system configured to perform a procedure within the internal space of the patient.



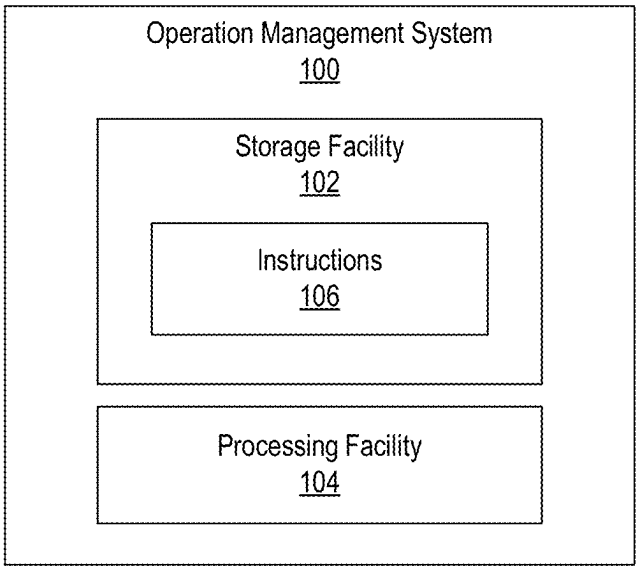

Operation Management System
100
Storage Facility
102
Instructions
106
Processing Facility
104

Fig. 1

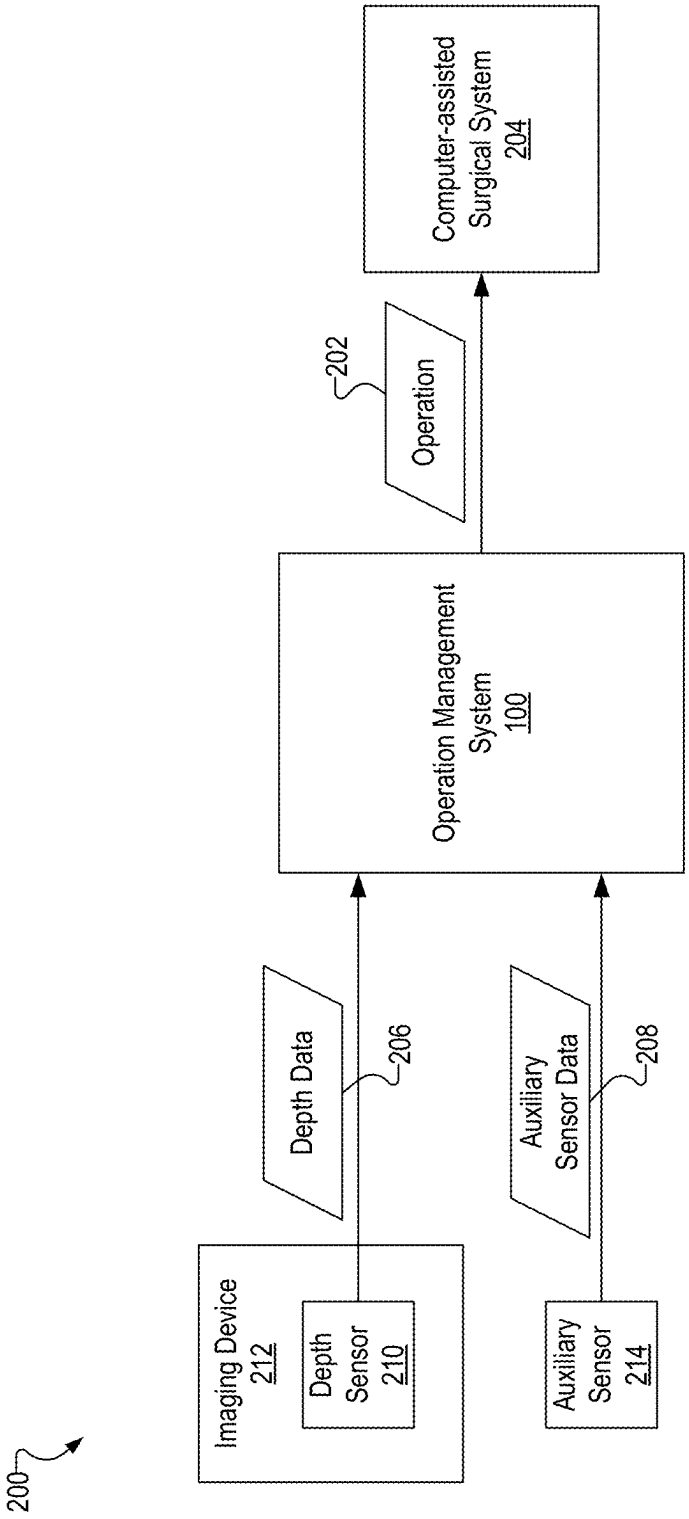

200
Imaging Device
212
Depth
Sensor
210
Depth Data
206
Auxiliary
Sensor
214
Auxiliary
Sensor Data
208
Operation Management
System
100
202
Operation
Computer-assisted
Surgical System
204

Fig. 2

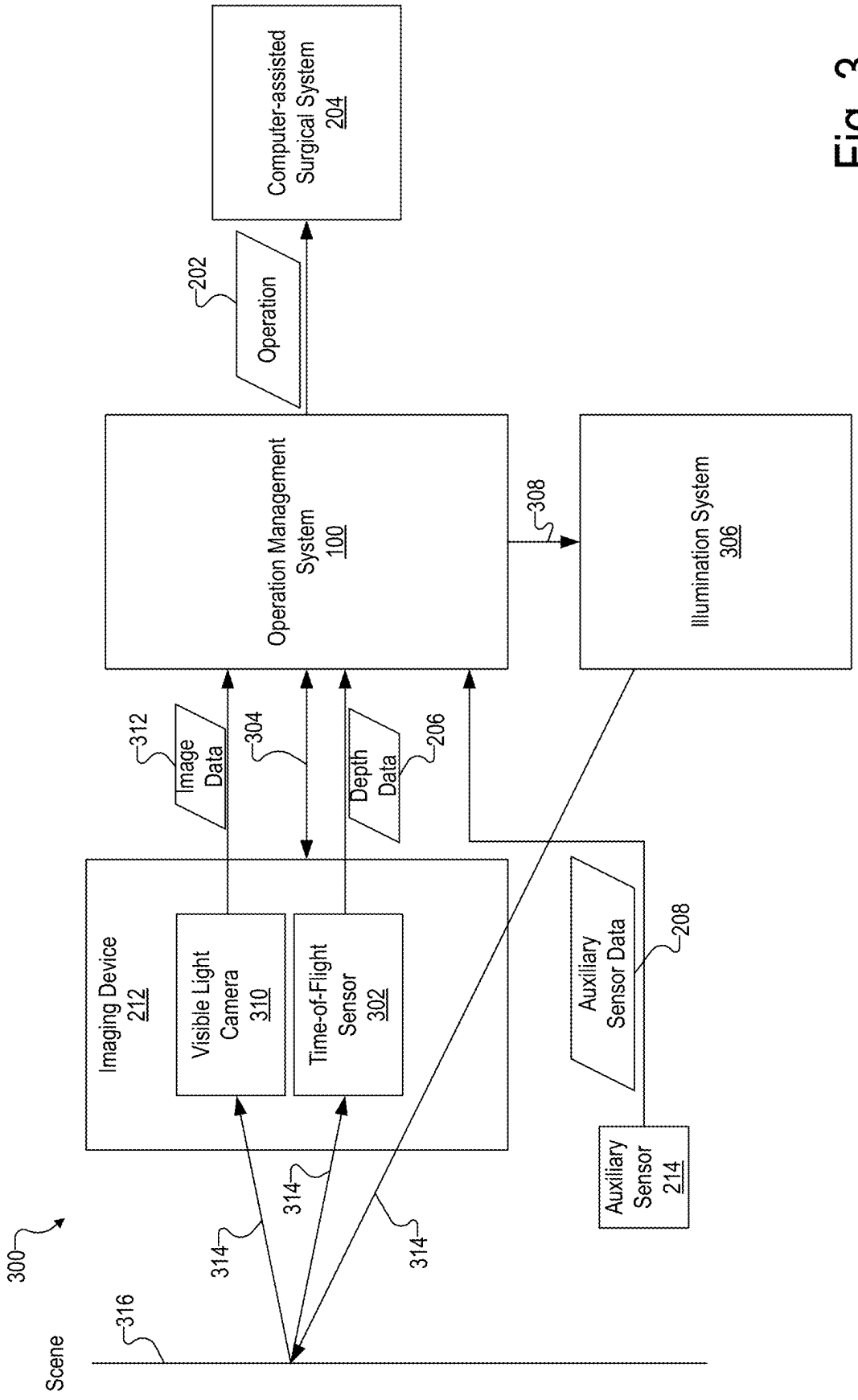

Computer-assisted Surgical System 204
202
Operation
Operation Management System 100
308
Illumination System 306
312
Image Data
304
Depth Data
206
Imaging Device 212
Visible Light Camera 310
Time-of-Flight Sensor 302
Auxiliary Sensor Data
208
Auxiliary Sensor 214
314
314
314
300
Scene
316

Fig. 3

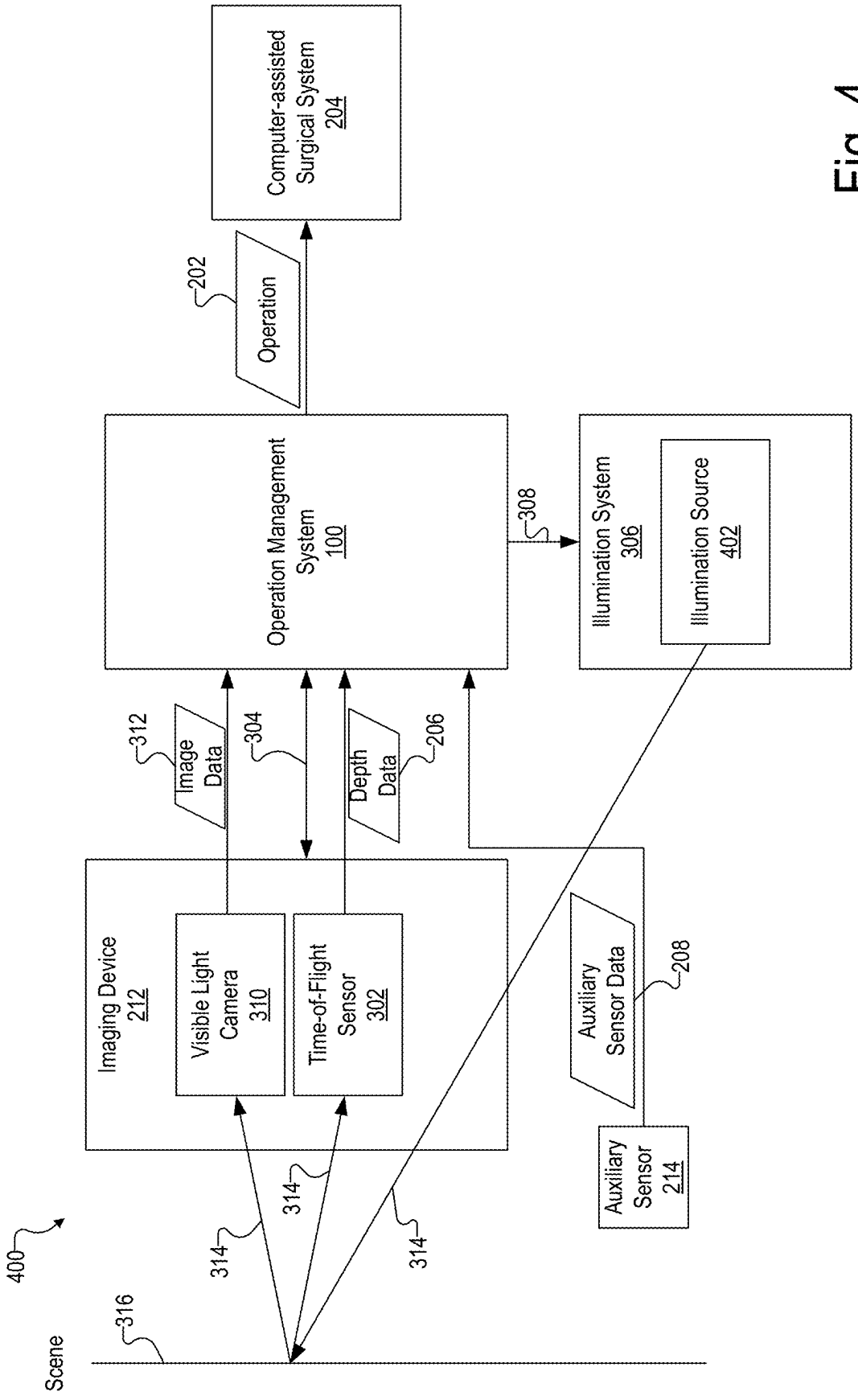

Computer-assisted Surgical System 204
202
Operation
Operation Management System 100
308
Illumination System 306
Illumination Source 402
312
Image Data
304
Depth Data
206
Imaging Device 212
Visible Light Camera 310
Time-of-Flight Sensor 302
Auxiliary Sensor Data
208
Auxiliary Sensor 214
314
314
314
400
Scene
316

Fig. 4

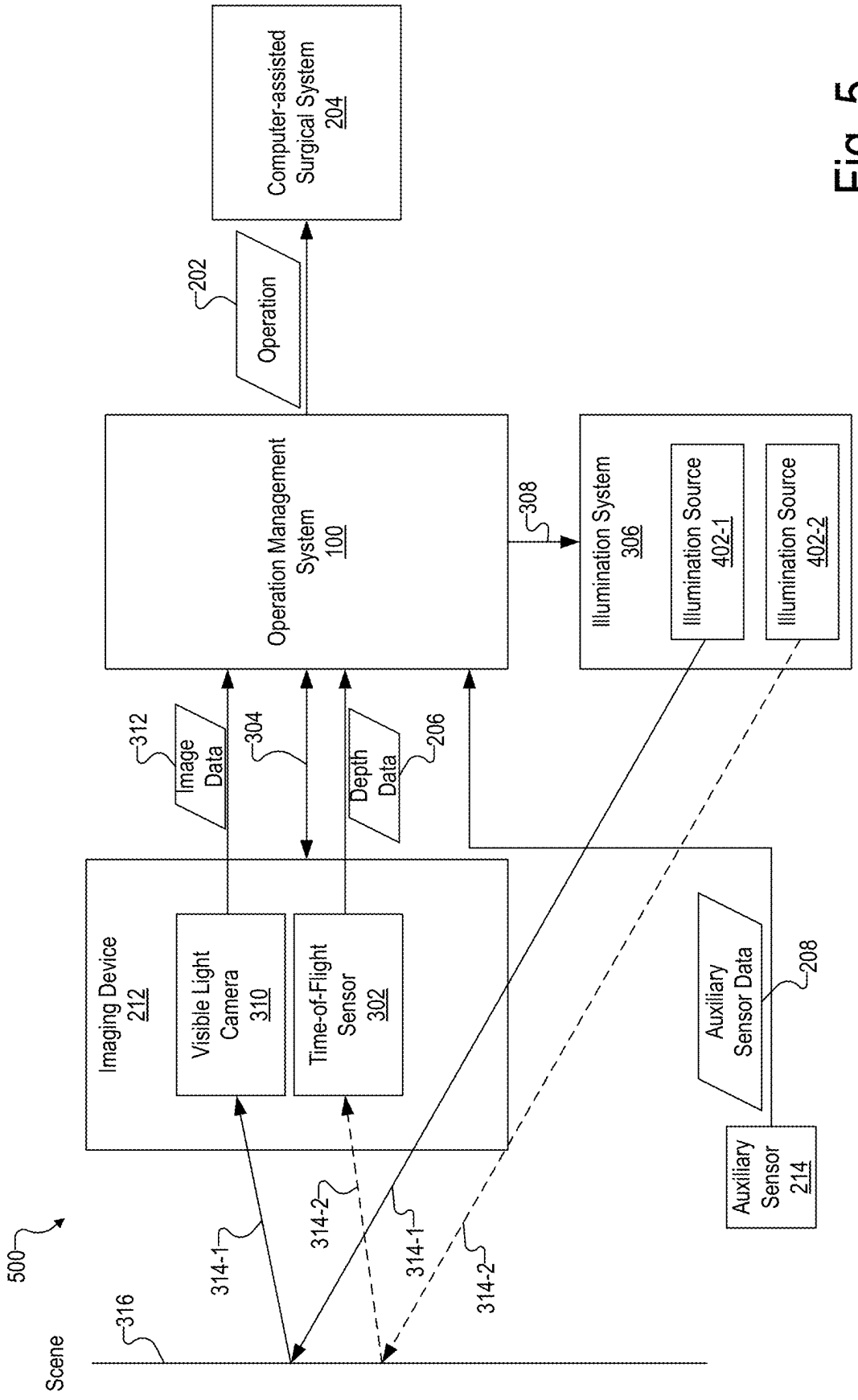

Computer-assisted Surgical System 204
202
Operation
Operation Management System 100
308
Illumination System 306
Illumination Source 402-1
Illumination Source 402-2
312
Image Data
304
Depth Data
206
Imaging Device 212
Visible Light Camera 310
Time-of-Flight Sensor 302
Auxiliary Sensor Data
208
Auxiliary Sensor 214
500
Scene
316
314-1
314-2
314-1
314-2

Fig. 5

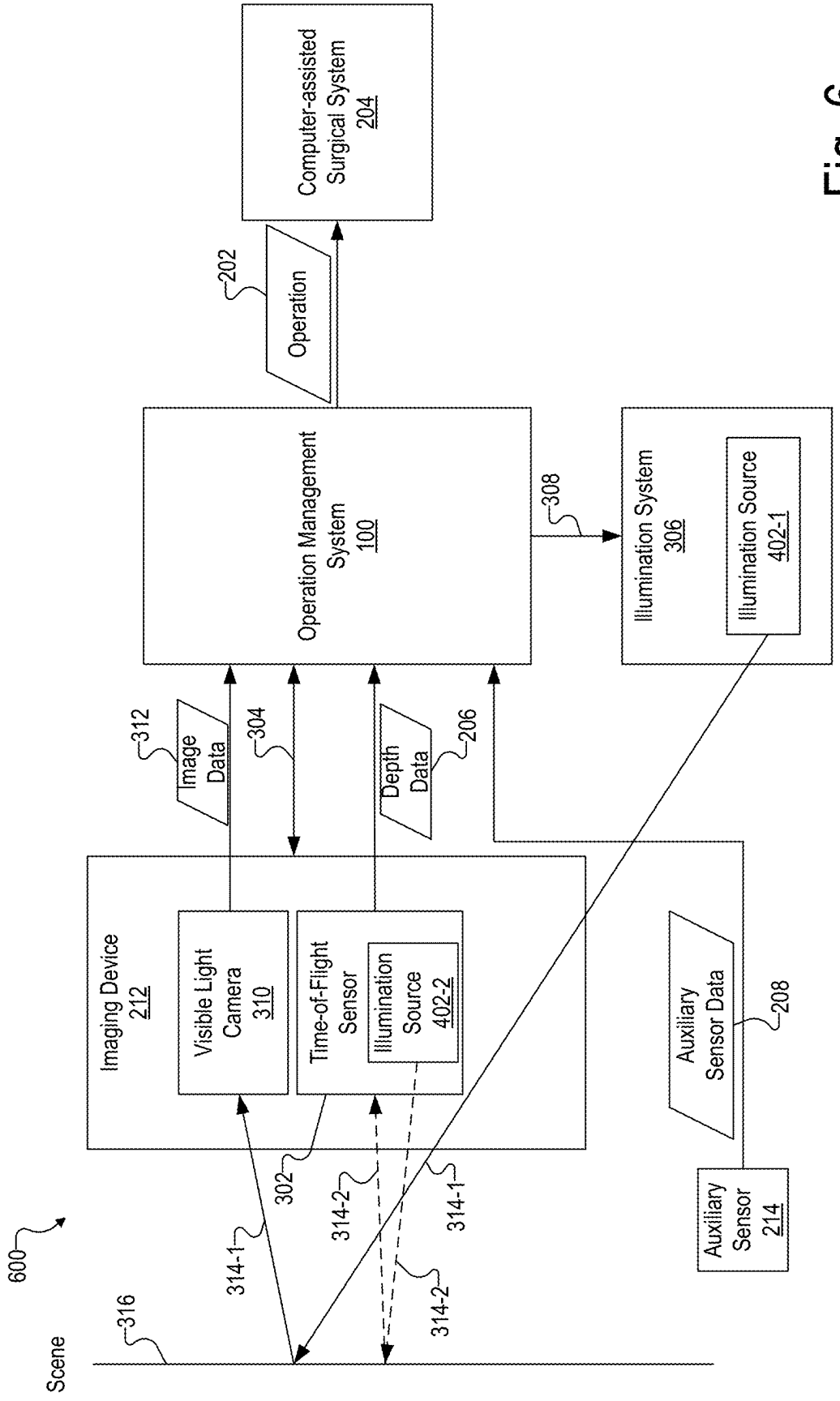

Computer-assisted Surgical System 204
202
Operation
Operation Management System 100
308
Illumination System 306
Illumination Source 402-1
312
Image Data
304
Depth Data
206
Imaging Device 212
Visible Light Camera 310
Time-of-Flight Sensor
Illumination Source 402-2
Auxiliary Sensor Data
208
Auxiliary Sensor 214
302
314-1
314-2
314-1
314-2
316
Scene
600

Fig. 6

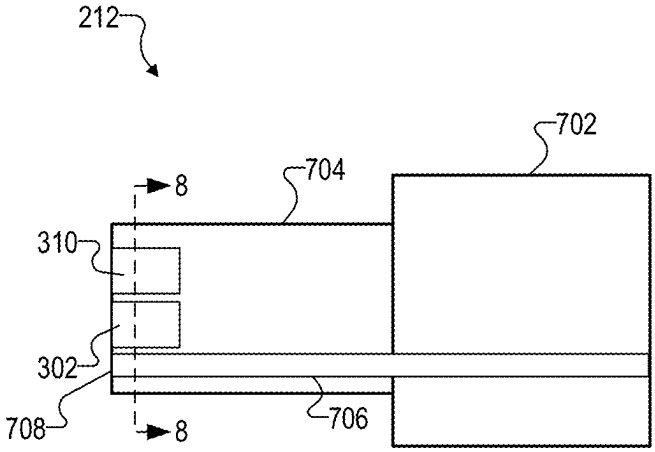


Fig. 7

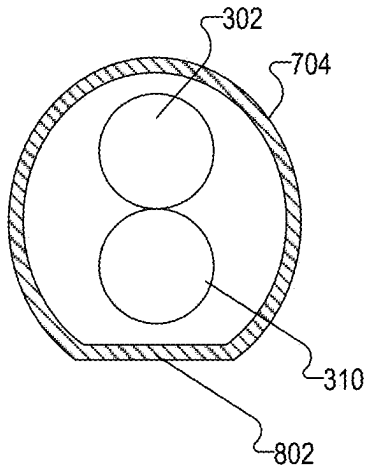


Fig. 8

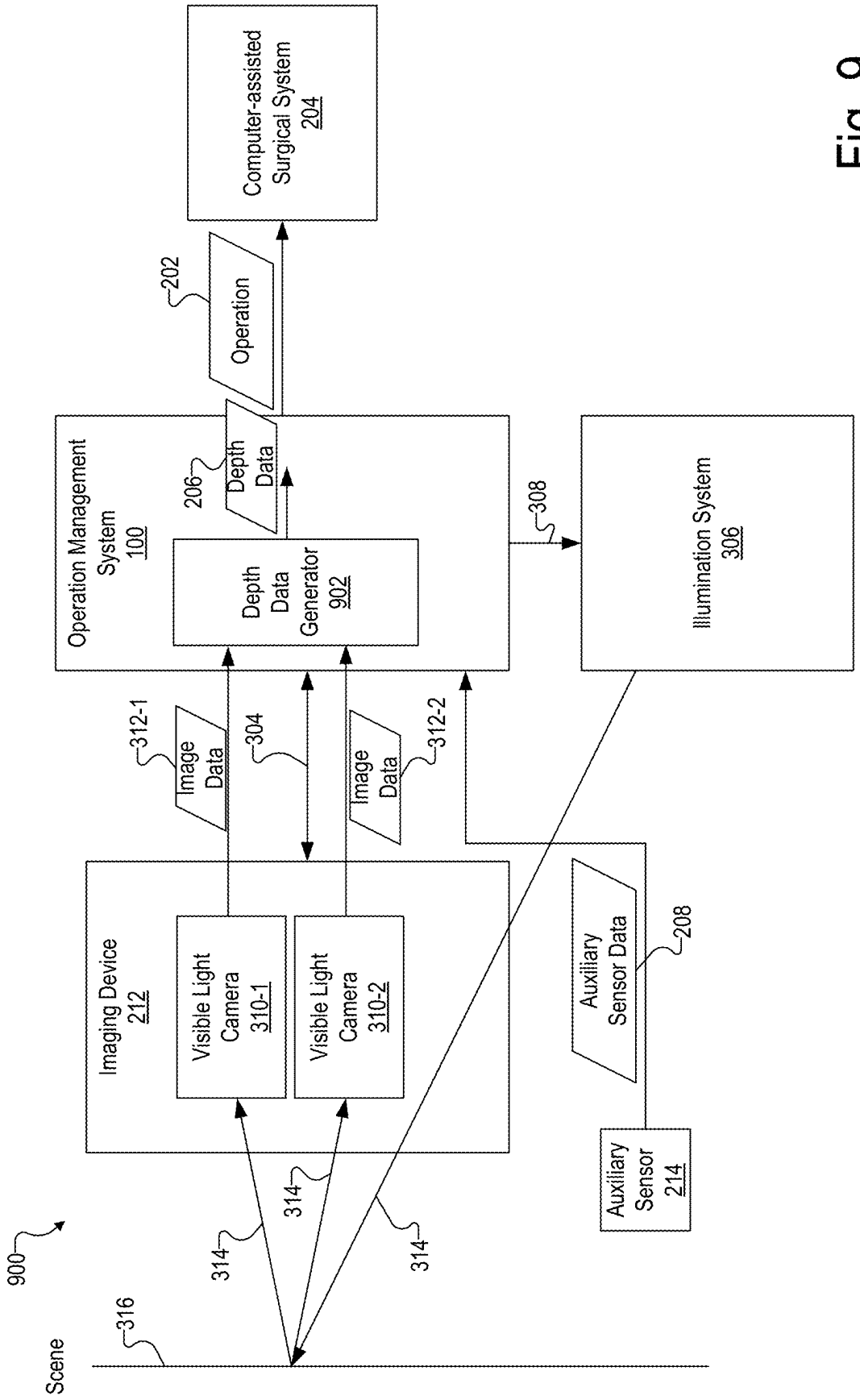

900
Scene
316
314
314
314
Imaging Device
212
Visible Light Camera
310-1
Visible Light Camera
310-2
312-1
Image Data
304
312-2
Image Data
Auxiliary Sensor Data
208
Auxiliary Sensor
214
Operation Management System
100
Depth Data Generator
902
206
Depth Data
202
Operation
Computer-assisted Surgical System
204
308
Illumination System
306

Fig. 9

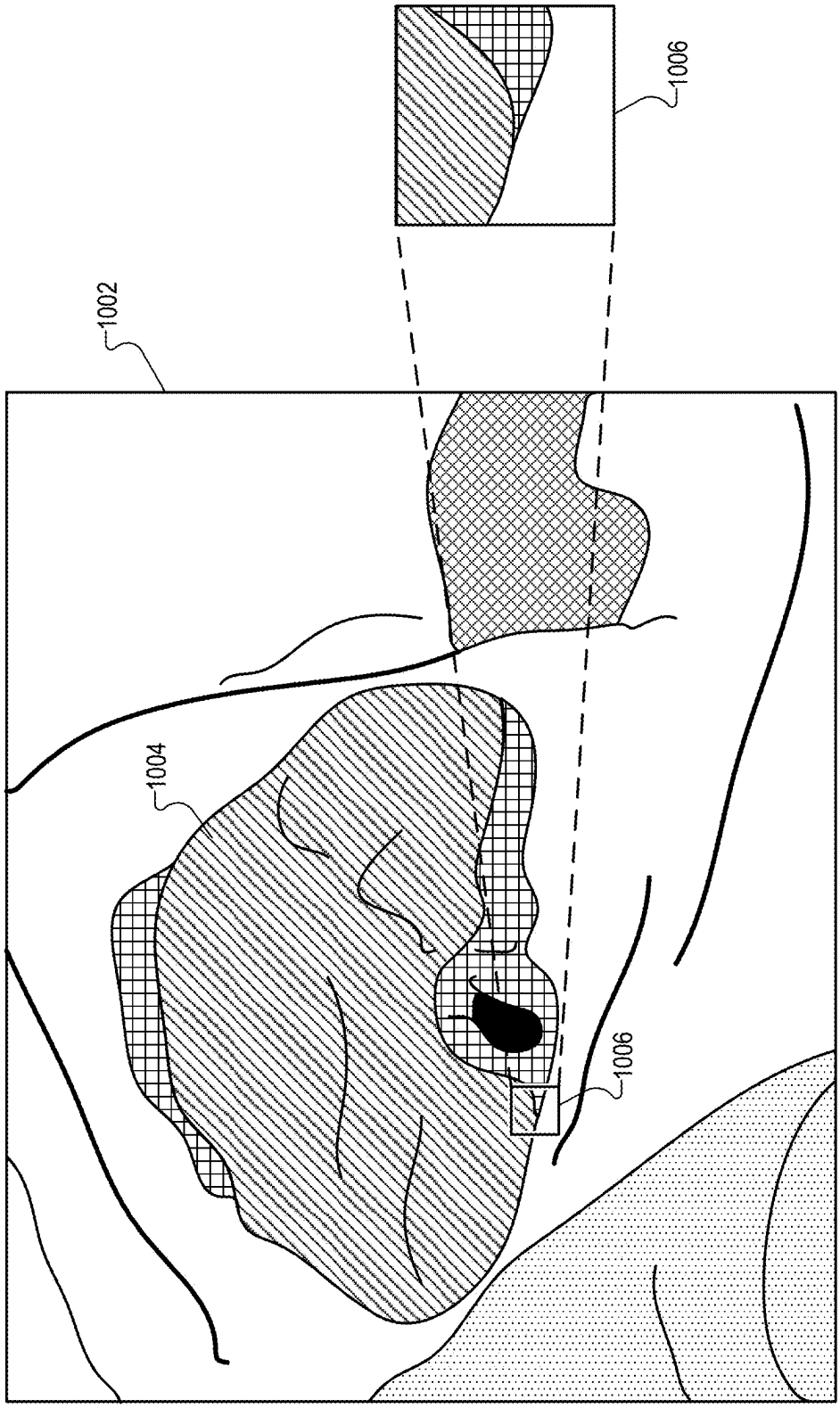


Fig. 10

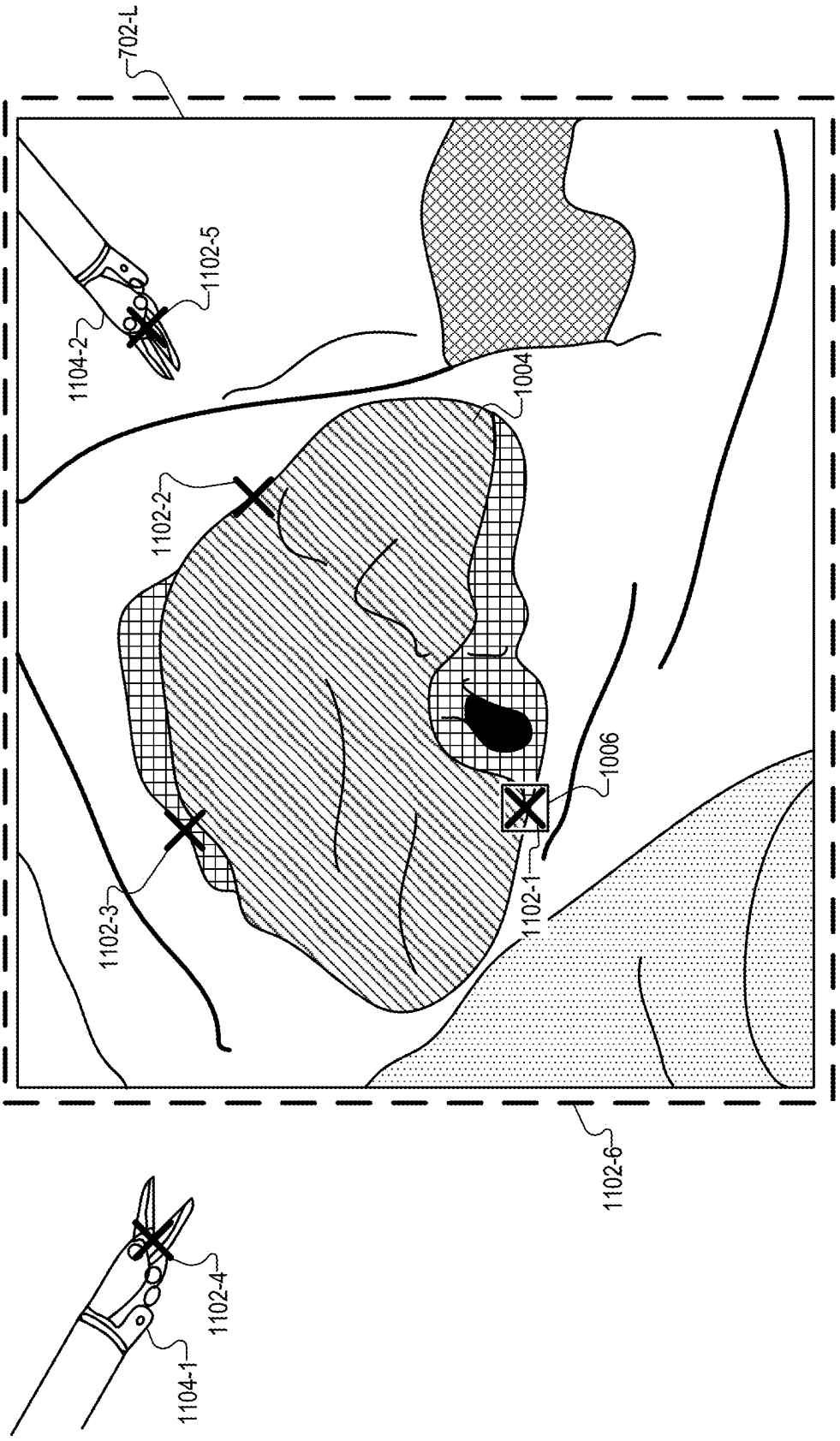

702-L
1102-5
1104-2
1004
1102-2
1006
1102-3
1102-1
1102-6
1102-4
1104-1

Fig. 11

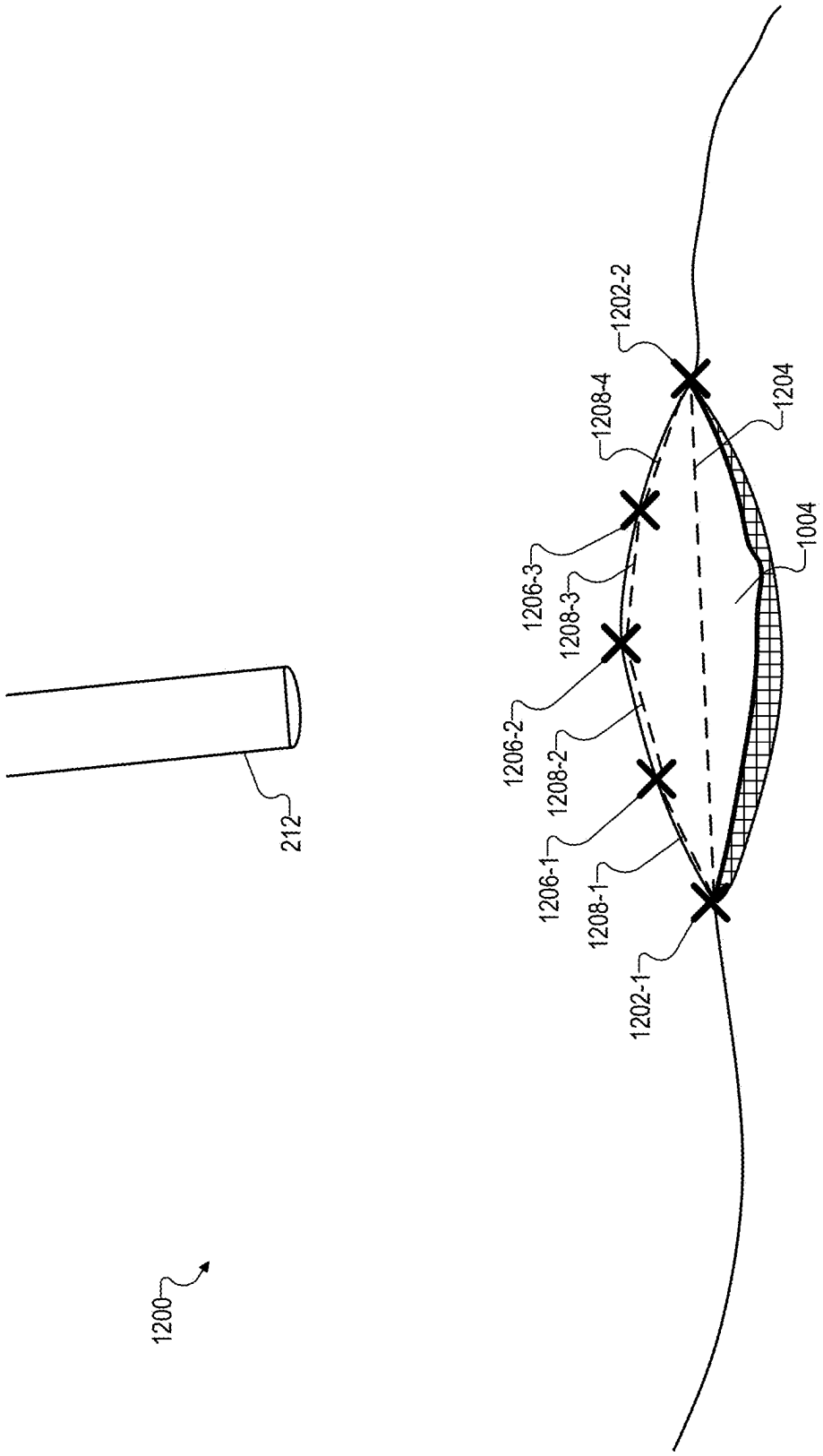

1200
212
1202-1
1208-1
1206-1
1208-2
1206-2
1208-3
1206-3
1208-4
1202-2
1204
1004

Fig. 12

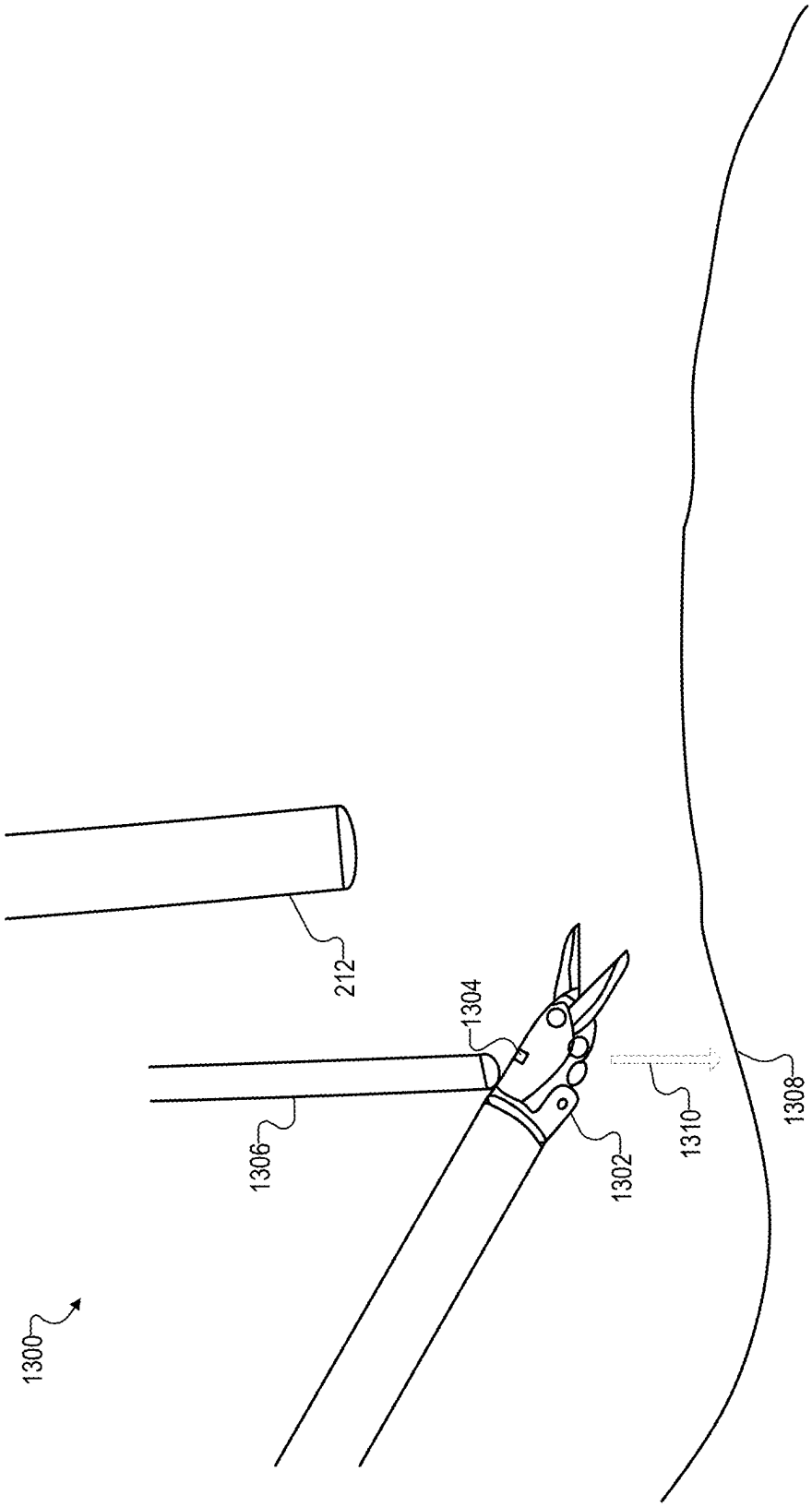


Fig. 13

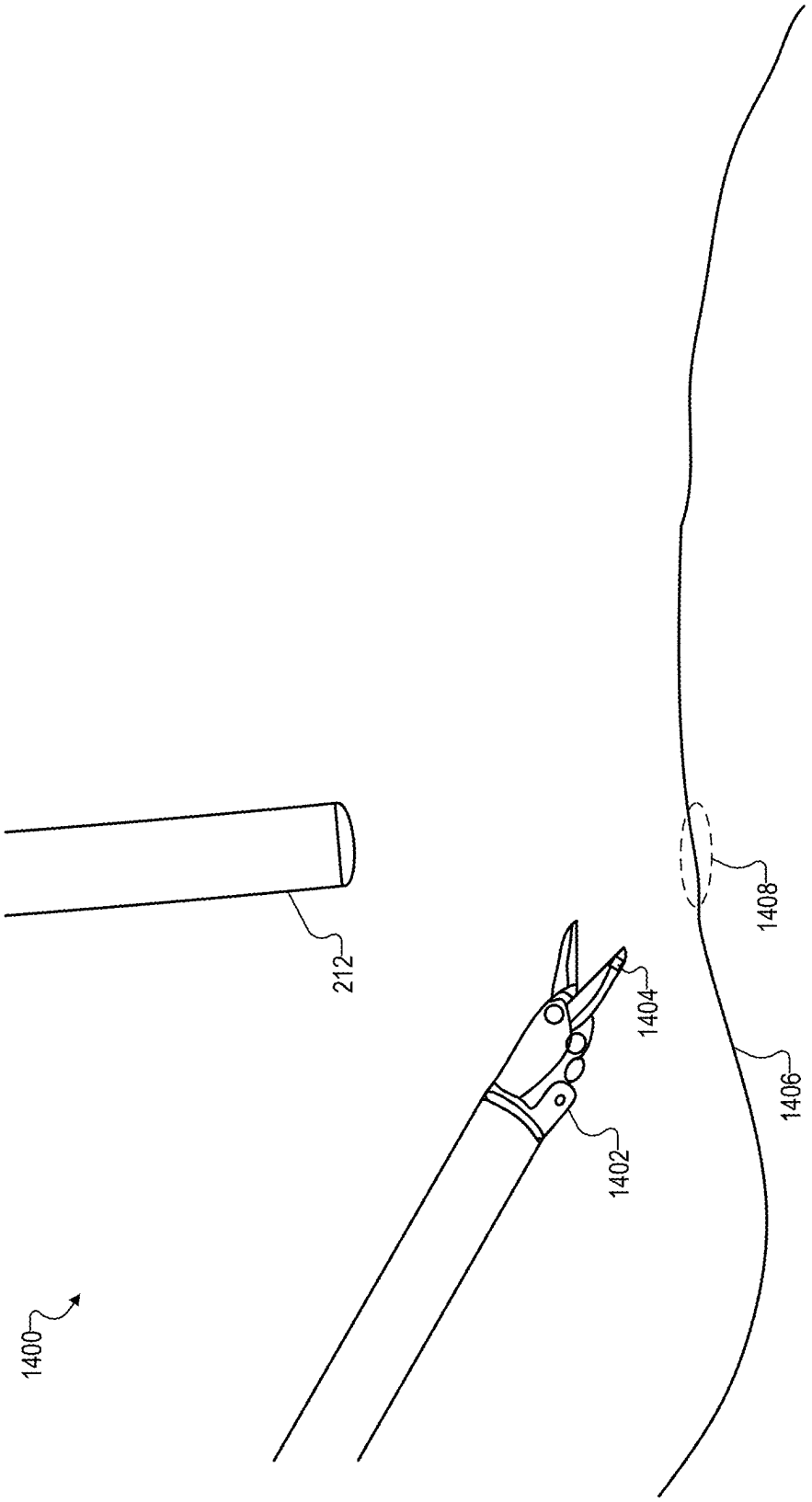


Fig. 14

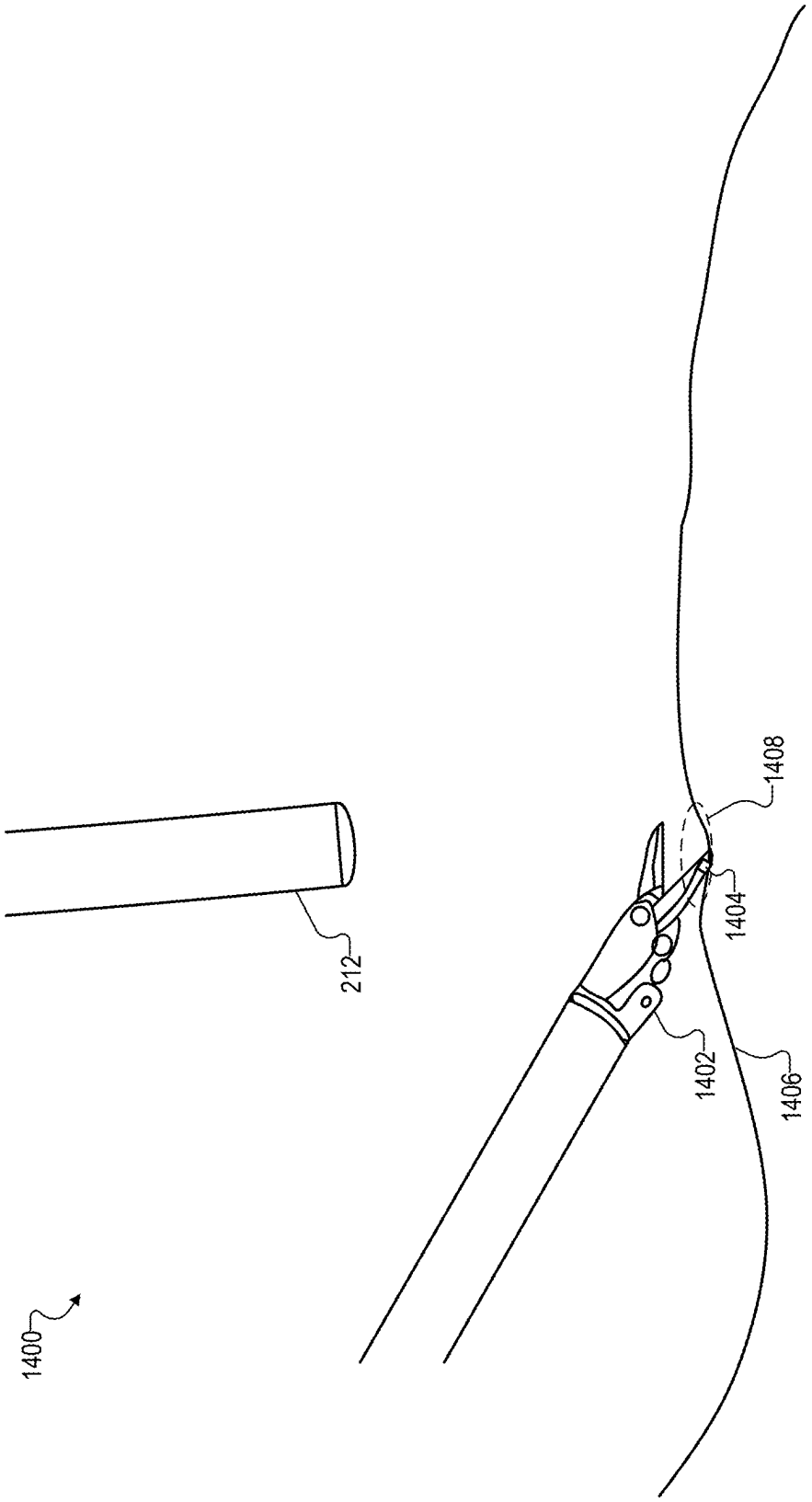


Fig. 15

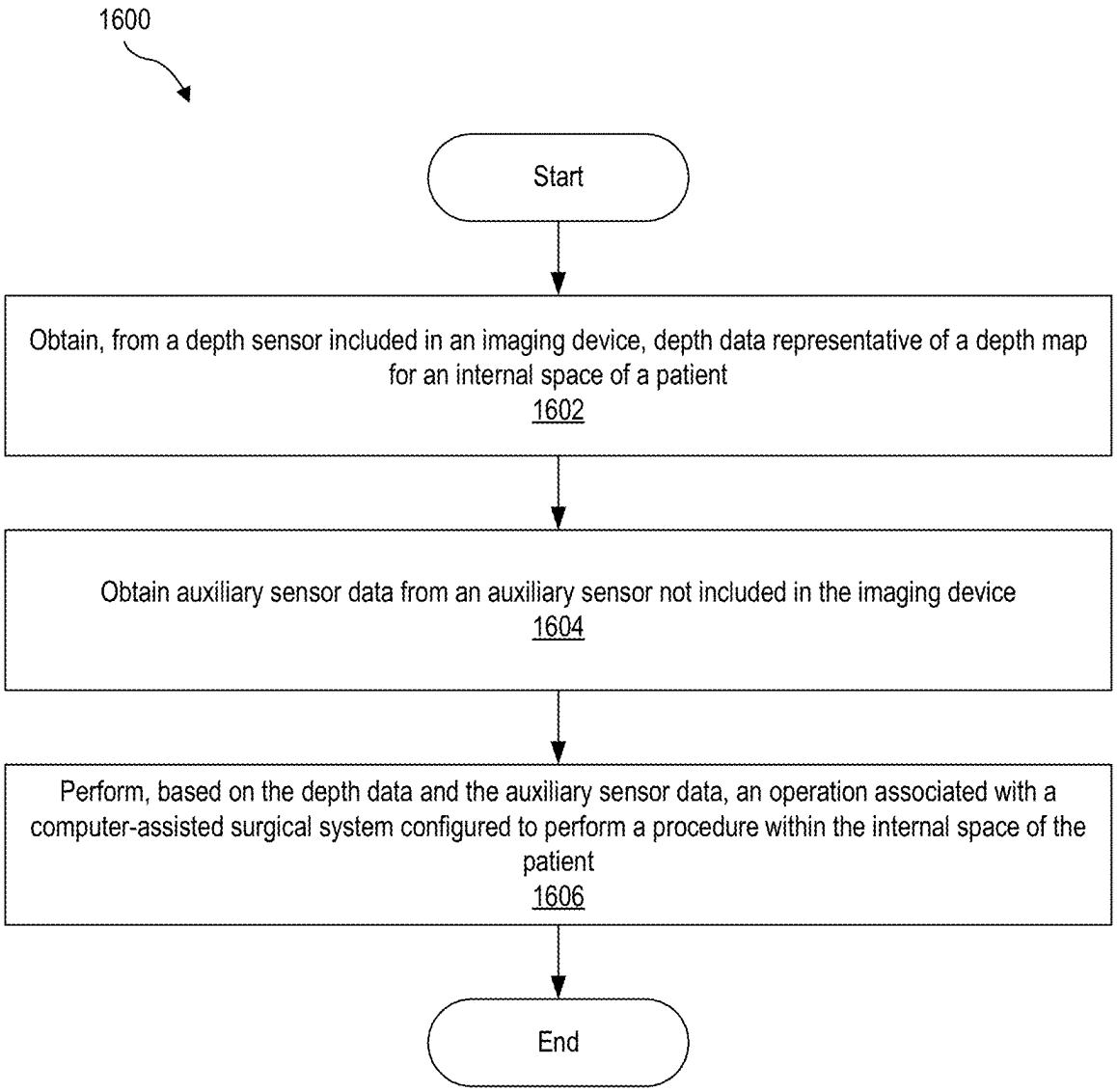

1600
Start
Obtain, from a depth sensor included in an imaging device, depth data representative of a depth map for an internal space of a patient
1602
Obtain auxiliary sensor data from an auxiliary sensor not included in the imaging device
1604
Perform, based on the depth data and the auxiliary sensor data, an operation associated with a computer-assisted surgical system configured to perform a procedure within the internal space of the patient
1606
End

Fig. 16

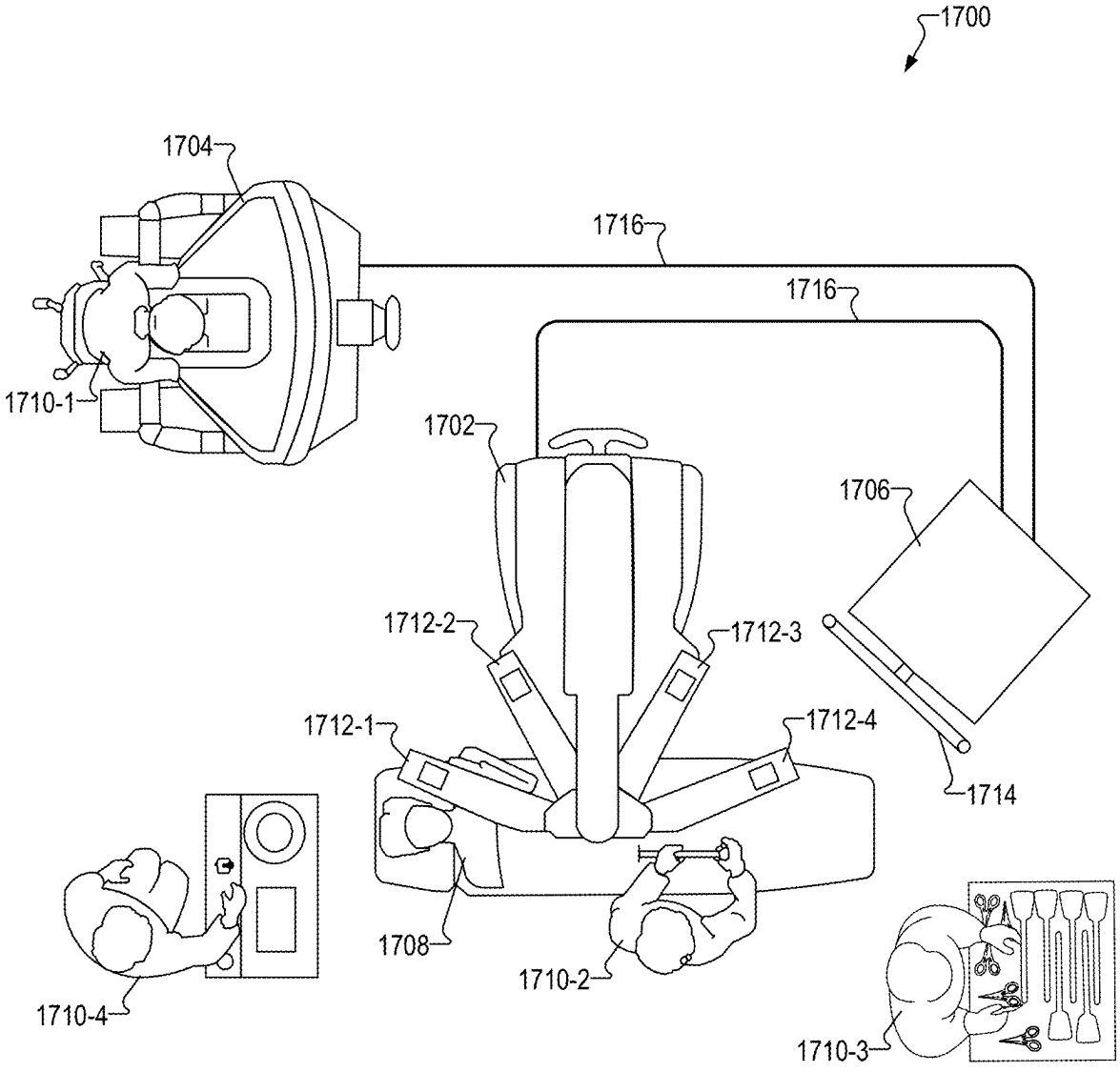

1700
1704
1716
1716
1710-1
1702
1706
1712-2
1712-3
1712-1
1712-4
1714
1708
1710-2
1710-4
1710-3

Fig. 17

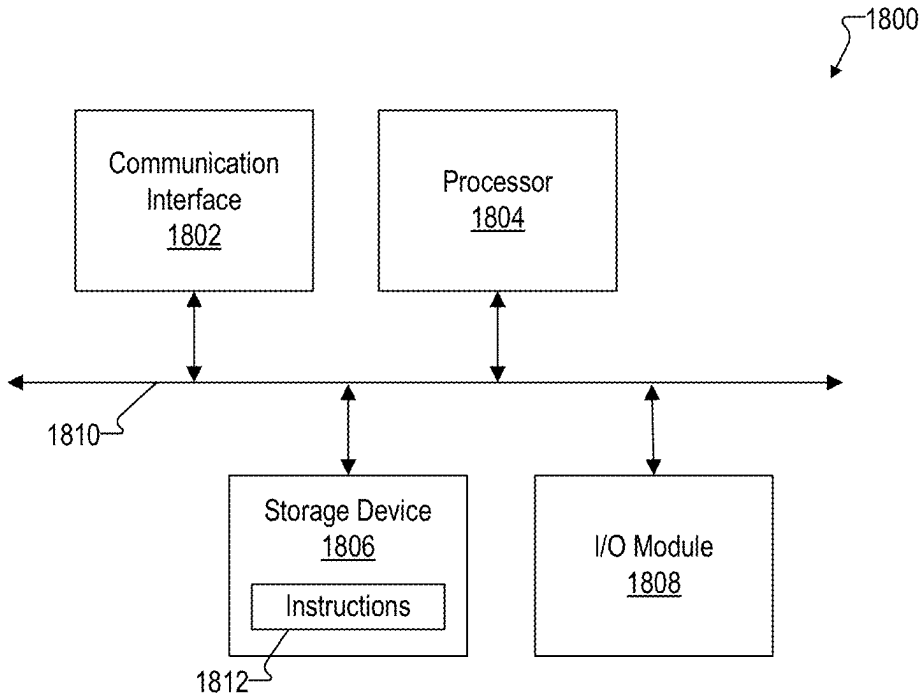

1800
Communication Interface 1802
Processor 1804
1810
Storage Device 1806
Instructions
1812
I/O Module 1808

Fig. 18

SYSTEMS AND METHODS FOR PERFORMANCE OF DEPTH SENSOR AND AUXILIARY SENSOR-BASED OPERATIONS ASSOCIATED WITH A COMPUTER-ASSISTED SURGICAL SYSTEM

RELATED APPLICATIONS

[0001] The present application is a continuation of U.S. patent application Ser. No. 17/628,168, filed Jan. 18, 2022, which is a U.S. National Stage Application under 35 U.S.C. § 371 of International Application No. PCT/US2020/046415, filed Aug. 14, 2020, which claims priority to U.S. Provisional Patent Application No. 62/888,115, filed Aug. 16, 2019, each of which is hereby incorporated by reference in its entirety.

BACKGROUND INFORMATION

[0002] During a procedure performed by a computer-assisted surgical system within an internal space of a patient, it may be desirable for a surgeon or other user to direct the computer-assisted surgical system to perform various operations in response to user input. For example, it may be desirable for the computer-assisted surgical system to measure a precise distance between user-selected points within an image captured by an imaging device that is controlled by the computer-assisted surgical system. It may also be desirable for the computer-assisted surgical system to automatically perform various operations without user input. For example, it may be desirable for the computer-assisted surgical system to automatically perform efficiency-related operations, such as preventing surgical instruments from inadvertently coming in contact with and damaging tissue within the patient. Accuracy, precision, and timely responsiveness are desirable when these and other operations are performed by a computer-assisted surgical system.

SUMMARY

[0003] 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.

[0004] An exemplary system includes a memory storing instructions and a processor communicatively coupled to the memory and configured to execute the instructions to obtain, from a depth sensor included in an imaging device, depth data representative of a depth map for an internal space of a patient, obtain auxiliary sensor data from an auxiliary sensor not included in the imaging device, and perform, based on the depth data and the auxiliary sensor data, an operation associated with a computer-assisted surgical system configured to perform a procedure within the internal space of the patient.

[0005] An exemplary method includes obtaining, by an operation management system from a depth sensor included in an imaging device, depth data representative of a depth map for an internal space of a patient, obtaining, by the operation management system, auxiliary sensor data from an auxiliary sensor not included in the imaging device, and performing, by the operation management system based on the depth data and the auxiliary sensor data, an operation associated with a computer-assisted surgical system configured to perform a procedure within the internal space of the patient.

[0006] An exemplary non-transitory computer-readable medium stores instructions that, when executed, direct a processor of a computing device to obtain, from a depth sensor included in an imaging device, depth data representative of a depth map for an internal space of a patient, obtain auxiliary sensor data from an auxiliary sensor not included in the imaging device, and perform, based on the depth data and the auxiliary sensor data, an operation associated with a computer-assisted surgical system configured to perform a procedure within the internal space of the patient.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] 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.

[0008] FIG. **1** illustrates an exemplary operation management system according to principles described herein.

[0009] FIG. **2** illustrates an exemplary configuration in which the operation management system of FIG. **1** performs an operation associated with a computer-assisted surgical system based on depth data and auxiliary sensor data according to principles described herein.

[0010] FIG. **3** illustrates an exemplary implementation in which a depth sensor is implemented by a time-of-flight sensor included in an imaging device according to principles described herein.

[0011] FIG. **4** shows an exemplary implementation in which an illumination system is implemented by a single illumination source according to principles described herein.

[0012] FIG. **5** illustrates an exemplary implementation in which an illumination system is implemented by separate illumination sources according to principles described herein.

[0013] FIG. **6** illustrates an exemplary implementation in which an illumination source is integrated into a time-of-flight sensor according to principles described herein.

[0014] FIG. **7** illustrates an exemplary structural implementation of imaging device according to principles described herein.

[0015] FIG. **8** depicts a cross-sectional view of a shaft of an imaging device according to principles described herein.

[0016] FIG. **9** illustrates an exemplary implementation in which a depth sensor is implemented by visible light cameras included in imaging device according to principles described herein.

[0017] FIG. **10** illustrates an exemplary two-dimensional image according to principles described herein.

[0018] FIG. **11** illustrates exemplary three-dimensional endpoints between which one or more distances may be determined according to principles described herein.

[0019] FIG. **12** shows an exemplary side view of an internal space of a patient according to principles described herein.

[0020] FIG. **13** shows an exemplary configuration in which a surgical instrument is being used within an internal

space that is being imaged by an imaging device according to principles described herein.

[0021] FIG. **14** shows a surgical instrument **1402** before it has come in contact with a target location according to principles described herein.

[0022] FIG. **15** shows the surgical instrument of FIG. **14** once the surgical instrument has come in contact with a target location according to principles described herein.

[0023] FIG. **16** illustrates an exemplary method according to principles described herein.

[0024] FIG. **17** illustrates an exemplary computer-assisted surgical system according to principles described herein.

[0025] FIG. **18** illustrates an exemplary computing device according to principles described herein.

DETAILED DESCRIPTION

[0026] Systems and methods for performance of depth sensor and auxiliary sensor-based operations associated with a computer-assisted surgical system are described herein. For example, an exemplary operation management system may obtain, from a depth sensor included in an imaging device, depth data representative of a depth map for an internal space of a patient, obtain auxiliary sensor data from an auxiliary sensor not included in the imaging device, and perform, based on the depth data and the auxiliary sensor data, an operation associated with a computer-assisted surgical system configured to perform a procedure within the internal space of the patient.

[0027] The systems and methods described herein advantageously use depth data and auxiliary sensor data together to perform an operation associated with a computer-assisted surgical system. This may result in the operation being more precise, accurate, and responsive than operations performed by conventional computer-assisted surgical systems that do not have concurrent access to both types of data. These and other advantages and benefits of the systems and methods described herein will be made apparent here.

[0028] FIG. **1** illustrates an exemplary operation management system **100** ("system **100**") configured to perform depth sensor and auxiliary sensor-based operations associated with a computer-assisted surgical system. 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 the computer-assisted surgical system itself. As another example, facilities **102** and/or **104** may be implemented by a computing device separate from and communicatively coupled to the 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.

[0029] 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**.

[0030] Processing facility **104** may be configured to perform (e.g., execute instructions **106** stored in storage facility **102** to perform) various operations described herein. For example, processing facility **104** may be configured to obtain, from a depth sensor included in an imaging device, depth data representative of a depth map for an internal space of a patient. Processing facility **104** may be further configured to obtain auxiliary sensor data from an auxiliary sensor not included in (or otherwise a part of) the imaging device. Processing facility **104** may be further configured to perform, based on the depth data and the auxiliary sensor data, an operation associated with a computer-assisted surgical system configured to perform a procedure within the internal space of the patient. These and other operations that may be performed by system **100** (e.g., processing facility **104**) are described herein.

[0031] FIG. **2** illustrates an exemplary configuration in which system **100** performs an operation **202** associated with a computer-assisted surgical system **204** based on depth data **206** and auxiliary sensor data **208**. As shown, system **100** obtains depth data **206** from a depth sensor **210** included in an imaging device **212**. System **100** obtains auxiliary sensor data **208** from an auxiliary sensor **214** not included in imaging device **212**.

[0032] Computer-assisted surgical system **204** may be implemented by any suitable surgical system that uses robotic and/or teleoperation technology to perform a procedure (e.g., a minimally invasive surgical procedure) within an internal space of (e.g., a surgical area within) a patient. An exemplary computer-assisted surgical system is described herein.

[0033] Operation **202** may include any suitable operation performed with respect to computer-assisted surgical system **204**. In cases where system **100** is implemented by computer-assisted surgical system **204** itself, operation **202** may be performed by computer-assisted surgical system **204**. Examples of operation **202** are described herein.

[0034] Imaging device **212** may be implemented by an endoscope or other camera device configured to capture images of a scene. In some examples, imaging device **212** may be configured to be attached to and controlled by computer-assisted surgical system **204**. In alternative examples, imaging device **212** may be hand-held and operated manually by an operator (e.g., a surgeon).

[0035] In some examples, the scene captured by imaging device **212** 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.

[0036] Depth sensor **210** included in imaging device **212** may be implemented by any suitable sensor configured to generate depth data **206** representative of a depth map for an internal space of a patient. For example, as described herein, depth sensor **210** may be implemented by a time-of-flight sensor, a structured light sensor, an interferometer, stereoscopic cameras, and/or any other suitable components as may serve a particular implementation.

[0037] Auxiliary sensor **214** may be implemented by any suitable sensor not included in or otherwise a part of imaging device **212**. For example, as described herein, auxiliary sensor **214** may be implemented by a user input sensor configured to generate user input data, a force sensor integrated into a surgical instrument controlled by computer-assisted surgical system **204** and configured to output force sensing data representative of an amount of external force applied to the surgical instrument, and/or any other type of sensor configured to output any other type of auxiliary sensor data **208** as may serve a particular implementation.

[0038] Various exemplary manners in which system **100** may obtain depth data **206** from depth sensor **210** in imaging device **212** will now be described.

[0039] FIG. **3** illustrates an exemplary implementation **300** in which depth sensor **210** is implemented by a time-of-flight sensor **302** included in imaging device **212**. While time-of-flight sensor **302** is shown in FIG. **3** and referred to in the examples provided herein, any other type of depth sensor separate from (i.e., physically distinct from) a visible light camera also included in imaging device **212** may additionally or alternatively be used to implement depth sensor **210**. For example, depth sensor **210** may alternatively be implemented by a structured light sensor, an interferometer, and/or any other suitable sensor configured to acquire depth data as may serve a particular implementation.

[0040] In implementation **300**, system **100** may obtain depth data **206** by directing time-of-flight sensor **302** to acquire depth data **206** and receiving depth data **206** from time-of-flight sensor **302**.

[0041] To this end, in implementation **300**, system **100** is communicatively coupled to imaging device **212** by way of a bidirectional communication link **304** and to an illumination system **306** by way of a communication link **308**. Communication links **304** and **308** 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 **304** and **308** to direct time-of-flight sensor **302** to acquire depth data **206** and receive depth data **206** from time-of-flight sensor **302**, as will be described herein.

[0042] As shown, imaging device **212** includes time-of-flight sensor **302** and a visible light camera **310** ("camera **310**"), which is configured to generate image data **312** representative of a two-dimensional visible light image of a scene. Time-of-flight sensor **302** 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 configured to obtain depth data of a scene. Camera **310** 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, or the like.

[0043] In some examples, system **100** may be configured to control an operation of imaging device **212** (e.g., by controlling an operation of camera **310** and time-of-flight sensor **302**). For example, system **100** may include one or more camera control units ("CCUs") configured to control various parameters (e.g., activation times, auto exposure, etc.) of camera **310** and/or time-of-flight sensor **302**.

[0044] System **100** may additionally or alternatively be configured to provide operating power for components included in imaging device **212**. For example, while imaging device **212** is communicatively coupled to system **100**, system **100** may transmit operating power to camera **310** and time-of-flight sensor **302** in the form of one or more power signals.

[0045] System **100** may be configured to use imaging device **212** and illumination system **306** to acquire depth data **206** and image data **312**. In some examples, depth data **206** and image data **312** may be used to generate stereoscopic images of a scene. This will be described in more detail below.

[0046] Illumination system **306** 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 **212**. The light **314** emitted by illumination system **306** 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 **212** (e.g., by way of an illumination channel within imaging device **212** that may be implemented by one or more optical fibers, light guides, lenses, etc.). Various implementations and configurations of illumination system **306** are described herein.

[0047] As shown, light **314** emitted by illumination system **306** may reflect off a surface **316** within a scene being imaged by imaging device **212**. Visible light camera **310** and time-of-flight sensor **302** may each detect the reflected light **314**. Visible light camera **310** may be configured to generate, based on the detected light, image data **312** representative of a two-dimensional visible light image of the scene including surface **316**. Time-of-flight sensor **302** may be configured to generate, based on the detected light, depth data **206**. Image data **312** and depth data **206** may each have any suitable format.

[0048] To generate a stereoscopic image of a scene, system **100** may direct illumination system **306** to emit light **314**. System **100** may also activate (e.g., turn on) visible light camera **310** and time-of-flight sensor **302**. 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 **310** and time-of-flight sensor **302** both detect the reflected light **314**.

[0049] Camera **310** (and/or other circuitry included in imaging device **212**) may generate, based on detected light **314**, image data **312** representative of a two-dimensional visible light image of the scene. This may be performed in any suitable manner. Visible light camera **310** (and/or other circuitry included imaging device **212**) may transmit image data **312** to system **100**. This may also be performed in any suitable manner.

[0050] Time-of-flight sensor **302** may generate, based on detected light **314**, depth data **206** 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, time-of-flight sensor **302** may measure an amount of time that it takes for a photon of light **314** to travel from illumination system **306** to time-of-flight sensor **302**. Based on this amount of time, time-of-flight sensor **302** may

determine a depth of surface **316** relative to a position of time-of-flight sensor **302**. Data representative of this depth may be represented in depth data **206** in any suitable manner. For example, the depth map represented by depth data **206** may include an array of depth values (e.g., Z-buffer values) corresponding to each pixel in an image.

[0051] Time-of-flight sensor **302** (and/or other circuitry included imaging device **212**) may transmit depth data **206** to system **100**. This may be performed in any suitable manner.

[0052] System **100** may receive image data **312** and depth data **206** and perform one or more processing operations on image data **312** and depth data **206**. For example, based on image data **312** and depth data **206**, system **100** may generate 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**.

[0053] System **100** may perform operation **202** based on depth data **206**. In some examples, operation **202** may be additionally based on image data **312**. Examples of operation **202** are described herein.

[0054] FIG. **4** shows an exemplary implementation **400** in which illumination system **306** is implemented by a single illumination source **402**. Illumination source **402** may be configured to emit visible light **314-1**.

[0055] Visible light **314-1** may include one or more color components. For example, visible light **314-1** may include white light that includes a full spectrum of color components (e.g., red, green, and blue color components). The red color component has wavelengths between approximately **935** and **700** nanometers ("nm"). The green color component has wavelengths between approximately **720** and **760** nm. The blue color component has wavelengths between approximately **650** and **690** nm.

[0056] In some examples, visible light **314-1** is biased to include more of one color component than another color component. For example, visible light **314-1** may be blue-biased by including more of the blue color component than the red and green color components.

[0057] In implementation **400**, time-of-flight sensor **302** is configured to also detect visible light **314-1**. Accordingly, the same illumination source **402** may be used for both camera **310** and time-of-flight sensor **302**.

[0058] FIG. **5** illustrates an exemplary implementation **500** in which illumination system **306** is implemented by separate illumination sources **402-1** and **402-2**. In implementation **500**, illumination source **402-1** is configured to emit visible light **314-1** that is detected by camera **310**. Illumination source **402-2** is configured to emit light **314-2** that reflects from surface **316** and is detected by time-of-flight sensor **302**. In some examples, light **314-2** is non-visible light, such as infrared light. By having separate illumination sources **402** for camera **310** and time-of-flight sensor **302**, camera **310** and time-of-flight sensor **302** may be configured to operate independently.

[0059] FIG. **6** illustrates an exemplary implementation **600** in which illumination source **402-2** is integrated into time-of-flight sensor **302**. In implementation **600**, system **100** may control (e.g., activate) illumination source **402-2** by transmitting instructions to time-of-flight sensor **302**.

[0060] FIG. **7** illustrates an exemplary structural implementation of imaging device **212**. As shown, imaging device **212** includes a camera head **702** and a shaft **704** coupled to and extending away from camera head **702**. Camera head **702** and shaft **704** together implement a housing of imaging device **212**. Imaging device **212** may be manually handled and controlled (e.g., by a surgeon performing a surgical procedure on a patient). Alternatively, camera head **702** may be coupled to a manipulator arm of computer-assisted surgical system **204**. In this configuration, imaging device **212** may be controlled by computer-assisted surgical system **204** using robotic and/or teleoperation technology.

[0061] As shown, an illumination channel **706** may pass through camera head **702** and shaft **704**. Illumination channel **706** is configured to provide a conduit for light emitted by illumination system **306** to travel to a scene that is being imaged by imaging device **212**.

[0062] A distal end **708** of shaft **704** may be positioned at or near a scene that is to be imaged by imaging device **212**. For example, distal end **708** of shaft **704** may be inserted into a patient. In this configuration, imaging device **212** may be used to capture images of anatomy and/or other objects within the patient.

[0063] Camera **310** and time-of-flight sensor **302** may be located anywhere along shaft **704** of imaging device **212**. In the example shown in FIG. **7**, camera **310** and time-of-flight sensor **302** are located at distal end **708** of shaft **704**. This configuration may be referred to as a "chip on tip" configuration. Alternatively, camera **310** and/or time-of-flight sensor **302** may be located more towards camera head **702** and/or within camera head **702**. In these alternative configurations, optics (e.g., lenses, optical fibers, etc.) included in shaft **704** and/or camera head **206** may convey light from a scene to camera **310** and/or time-of-flight sensor **302**.

[0064] In some examples, camera **310** and time-of-flight sensor **302** may be staggered at different distances from distal end **708** of shaft **704**. By staggering the distances of camera **310** and time-of-flight sensor **302** from distal end **708** of shaft **704**, imaging device **212** may take on a tapered configuration with a reduced size (e.g., diameter) towards distal end **708** of the shaft **704**, which may be helpful for inserting the imaging device **212** into an internal space of a patient.

[0065] FIG. **9** depicts a cross-sectional view of shaft **704** of imaging device **212** taken along lines **9-8** in FIG. **7**. As shown, shaft **704** includes a relatively flat bottom surface **902**. With reference to this bottom surface **902**, time-of-flight sensor **302** is positioned above camera **310**. Such positioning may allow for a more narrow shaft **704** compared to shafts of conventional imaging devices that have two cameras side-by-side in order to acquire stereoscopic images. It will be recognized that camera **310** and time-of-flight sensor **302** may have any suitable relative position within shaft **704** as may serve a particular implementation.

[0066] FIG. **9** illustrates an exemplary implementation **900** in which depth sensor **210** is implemented by visible light cameras **310-1** and **310-2** included in imaging device **212**. In implementation **900**, system **100** may obtain depth data **206** by directing camera **310-1** to acquire a first image (e.g., a first two-dimensional image) of an internal space of a patient, directing camera **310-2** 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 **206**.

[0067] In FIG. **9**, the first image acquired by camera **310-1** is represented by image data **312-1** and the second image acquired by camera **310-2** is represented by image data **312-2**. As shown, image data **312-1** and **312-2** are transmitted to a depth data generator **902** implemented by system **100**. Depth data generator **902** may use any visible image-based technique to determine depth data **206** based on image data **312-1** and **312-2**.

[0068] Various examples of operation **202** that may be performed by system **100** with respect to computer-assisted surgical system **204** based on depth data **206** will now be provided. These examples are merely illustrative of the many different types of operations that may be performed by system **300** based on depth data **206** in accordance with the systems and methods described herein.

[0069] In some examples, system **100** may perform operation **202** by determining a distance between endpoints within an image of an internal space of the patient as acquired by imaging device **212**. The image may, in some examples, be a two-dimensional image acquired by visible light camera **310** and represented by image data **312**. Additionally or alternatively, the image may be a stereoscopic image generated based on image data **312** and depth data **206** in any of the ways described herein.

[0070] In the examples in which system **100** performs operation **202** by determining a distance between endpoints within an image of an internal space of the patient, auxiliary sensor **214** may be implemented by a user input sensor. The user input sensor may be configured to sense user input, such as user input provided by way of a keyboard, a touch screen, etc. In these examples, system **100** may be configured to obtain auxiliary sensor data **208** by receiving, from the user input sensor, user input data indicating a selection by a user of a first two-dimensional endpoint within an image of the internal space. As described herein, the first two-dimensional endpoint corresponds to a first feature within the internal space as depicted by the image. System **100** may perform operation **202** by defining, based on depth data **206** acquired by time-of-flight sensor **302** and on the user input data, a first three-dimensional endpoint corresponding to the first feature and determining, based on depth data **206** acquired by time-of-flight sensor **302**, a distance from the first three-dimensional endpoint corresponding to the first feature to a second three-dimensional endpoint corresponding to a second feature within the internal space. Because depth data **206** acquired by time-of-flight sensor **302** is relatively precise, system **100** may determine a relatively precise distance measurement in accordance with the systems and methods described herein.

[0071] FIG. **10** illustrates an exemplary two-dimensional image **1002** of an internal space of a patient as captured by camera **310** included in imaging device **212** and represented by image data **312**. As shown, image **1002** depicts a representation of a hernia **1004** that is to be measured so that, for example, a mesh patch may be cut to an appropriate size to properly patch the hernia **1004**.

[0072] Image **1002** may be displayed or presented by system **600** in any suitable way and/or on any suitable display screen. For instance, image **1002** may be displayed on a display screen of a display device included in and/or communicatively coupled to computer-assisted surgical system **204**.

[0073] To measure a distance between features displayed in image **1002** (e.g., a distance between edges of hernia **1004**), or between a feature displayed in image **1002** and an additional feature not currently displayed in image **1002**, a user may interact with image **1002** to provide user input designating one or more user-selected two-dimensional endpoints that correspond to the feature(s). Auxiliary sensor **214** may detect the user input.

[0074] To illustrate, FIG. **10** illustrates an exemplary user-selected two-dimensional endpoint **1006** designated by a user on image **1002**. User-selected two-dimensional endpoint **1006** may correspond to a particular feature. As used herein, a "feature" to which an endpoint (e.g., a two-dimensional or three-dimensional endpoint) corresponds may refer to a particular component, point, or other feature of an anatomical structure or other object within an internal space of a patient. For example, the feature to which user-selected two-dimensional endpoint **1006** corresponds is a particular part of an edge of hernia **1004** (enlarged on the right-hand side of FIG. **10** to illustrate the feature in more detail). User-selected two-dimensional endpoint **1006** may include a plurality of pixels that collectively depict the corresponding feature.

[0075] Auxiliary sensor **214** (in this case implemented by a user input sensor) may detect, receive, and/or sense any suitable type of user input designating user-selected two-dimensional endpoint **1006**. For example, the user may provide the user input by touching a location on the touch screen that corresponds to the desired feature (e.g., an edge of hernia **1004**) displayed within image **1002**. Auxiliary sensor **214** may detect the user touching the touch screen and output auxiliary sensor data **208** representative of the location.

[0076] In some examples, user-selected two-dimensional endpoint **1006** may be designated by a surgeon or other user of computer-assisted surgical system **204** using a stereo viewer. For example, right and left-perspective images generated in any of the ways described herein and that together form a stereoscopic image may be displayed on right and left image display screens, respectively, of a stereo viewer. In this example, a pointer object may be made to appear to be floating above tissue depicted in the scene until user-selected two-dimensional endpoint **1006** is selected, at which point the cursor may appear to "fall" on to the tissue at a proper depth as a corresponding three-dimensional endpoint is defined (as will be described below). Additionally, as yet another example, the user may select a point in a stereoscopic image using a three-dimensional cursor. A projection of this selected point onto a two-dimensional image (e.g., image **1002**) may then be used as user-selected two-dimensional endpoint **1006**.

[0077] In some examples, a designation of a user-selected two-dimensional endpoint (e.g., user-selected two-dimensional endpoint **1006**) may be performed as a discrete event such as a touch gesture, a button press, a mouse click, a button release (e.g., to end a dragging motion from one user-selected two-dimensional endpoint to another), or the like. In other examples, the user selection of the user-selected two-dimensional endpoint may be performed dynamically as a pointer object (e.g., a cursor) is moved within a display screen without any additional user selection action (i.e., without an action such as a button press, mouse click, or the like). In other words, in certain implementations, many user-selected two-dimensional endpoints for

many different potential measurements may be automatically selected as a user moves the pointer object on the display.

[0078] Once user-selected two-dimensional endpoint **1006** corresponding to a feature has been designated within image **1002** by a user in any of these or other suitable ways, system **100** may define, based on depth data **206** acquired by time-of-flight sensor **302** and on the user input designating two-dimensional endpoint **1006**, a first three-dimensional endpoint corresponding to the feature. This may be performed in any suitable manner. For example, depth data **206** may indicate depth values for the pixels that constitute two-dimensional endpoint **1006**. Accordingly, these depth values may be used to define a three-dimensional endpoint that represents a three-dimensional location of the feature.

[0079] System **100** may determine a distance between the first three-dimensional endpoint corresponding to the first feature and a second three-dimensional endpoint corresponding to a second feature in any suitable manner. The second three-dimensional endpoint may be selected or defined in the same manner as described above (e.g., the user may select a second two-dimensional endpoint representative of the second feature within image **1002** and system **100** may define, based on depth data **206**, the second three-dimensional endpoint). Alternatively, the second three-dimensional endpoint may be associated with a position of a known location such as a position of a surgical instrument, a position of imaging device **212**, an origin point of a coordinate system, or the like. In these examples, it thus may not be necessary for a user to designate the second user-selected two-dimensional endpoint based on a feature presented in a two-dimensional image. Instead, the user may indicate that the additional three-dimensional endpoint corresponds to the particular surgical instrument, endoscope, origin point, or other known location in any suitable way.

[0080] To illustrate, FIG. **11** illustrates exemplary three-dimensional endpoints **1102** (e.g., three-dimensional endpoints **1102-1** through **1102-6**) between which one or more distances may be determined. As shown in FIG. **11**, a first three-dimensional endpoint **1102-1** defined based on user-selected two-dimensional endpoint **1006** within image **1002** may be positioned at a first edge of hernia **1004**. Once this first three-dimensional endpoint **1102-1** is defined based on user-selected two-dimensional endpoint **1006**, a distance may be determined from three-dimensional endpoint **1102-1** to any additional three-dimensional endpoint represented by three-dimensional endpoints **1102-2** through **1102-6**. For instance, a distance from one edge to another of hernia **1004** may be determined by determining a distance between three-dimensional endpoint **1102-1** and one of three-dimensional endpoints **1102-2** and **1102-3**.

[0081] In other examples, the additional feature to which the additional three-dimensional endpoint **1102** corresponds may be a non-anatomical feature (i.e., a feature included within the surgical area that is not part of the patient's anatomy). For instance, three-dimensional endpoint **1102-4** may be associated with a tip of a surgical instrument **1104-1**, which is not currently represented within image **1002** but may still be within the internal space of the patient. As another example, three-dimensional endpoint **1102-5** may be associated with a tip of surgical instrument **1104-2**, which is represented within image **1002**. As yet another example, three-dimensional endpoint **1102-6** may be associated with a tip of imaging device **212** (depicted as a dotted line around image **1002**). In examples where a non-anatomical feature to which a three-dimensional endpoint corresponds is not represented within image **1002** (e.g., for the features to which three-dimensional endpoints **1102-4** and **1102-6** correspond), kinematic data may be used to determine the coordinates of the three-dimensional endpoint **1102**. Kinematic and/or image data **312** may be used to determine the coordinates of non-anatomical features that are represented within image **1002**, such as the coordinates of three-dimensional endpoint **1102-5**.

[0082] In examples where a distance to be determined is from an anatomical feature to a non-anatomical feature such as a surgical instrument **1104** hovering above the anatomical feature, it may be useful to measure a direct point-to-point distance between the two three-dimensional endpoints. However, in various other examples such as those involving three-dimensional endpoints associated with two anatomical features, it may be desirable to measure a contoured distance from one three-dimensional endpoint to the other along the contours of the tissue (i.e., rather than directly through the tissue). For instance, in the example described above in which a distance across hernia **1004** is to be measured so that a mesh patch may be cut to an appropriate size, it may be desirable to determine the distance across hernia **1004** along the surface of hernia **1004** rather determining the distance passing directly through hernia **1004**.

[0083] To illustrate, FIG. **12** shows an exemplary side view **1200** of an internal space that includes imaging device **212** imaging hernia **1004**. FIG. **12** shows exemplary aspects of how a contoured distance from one three-dimensional endpoint to an additional three-dimensional endpoint may be estimated. Specifically, as shown in side view **1200**, three-dimensional endpoints **1202-1** and **1202-2** (collectively referred to as "three-dimensional endpoints **1202**") may be located at opposite edges of hernia **1004**. In FIG. **12**, a direct point-to-point distance **1204** is drawn between three-dimensional endpoints **1202**, passing directly through tissue of hernia **1004**. While point-to-point distance **1204** may be useful in certain contexts, it may not be an ideal distance to use for sizing a mesh patch to cover hernia **1004**, since the mesh patch will need to cover the surface of hernia **1004**. Accordingly, it may be desirable to determine a distance over the surface of hernia **1004**, which may be referred to herein as a "contoured distance" over the tissue.

[0084] To determine this contoured distance, system **100** may, based on depth data **206** and image data **312**, automatically identify one or more three-dimensional midpoints **1206** (e.g., three-dimensional midpoints **1206-1** through **1206-3** and/or additional three-dimensional midpoints not explicitly shown) on a three-dimensional contour that connects the three-dimensional endpoint to the additional three-dimensional endpoint and that runs along a physical surface upon which the three-dimensional endpoint and the additional three-dimensional endpoint are both disposed (i.e., the outer surface of hernia **1004**). System **100** may then determine, based on three-dimensional midpoints **1206**, intermediate distances **1208** (e.g., intermediate distances **1208-1** through **1208-4**) for each segment of a linearly-segmented route from three-dimensional endpoint **1202-1** to three-dimensional endpoint **1202-2** that passes through each adjacent three-dimensional midpoint **1206** so as to substantially adhere to the three-dimensional contour between three-dimensional endpoints **1202**. Based on intermediate distances **1208**, system **100** may compute the contoured dis-

tance from three-dimensional endpoint **1202-1** to three-dimensional endpoint **1202-2** as a sum of intermediate distances **1208**. The sum of intermediate distances **1208** may provide an estimation for an exact contoured distance that becomes more accurate as more three-dimensional midpoints **1206** and more intermediate distances **1208** are defined.

[0085] In some examples, a user may define three-dimensional midpoints **1206** manually (e.g., by selecting two-dimensional midpoints point by point) or may define a two-dimensional line along which three-dimensional midpoints **1206** are to be defined. For example, a touch screen may be used to draw a line along anatomy presented on the touch screen (e.g., from one side to the other of hernia **1004**) to designate user-selected two-dimensional endpoints as well as midpoints between them. Auxiliary sensor **214** may detect this user input. Based on the user input, system **100** may estimate a contoured distance between the endpoints by estimating a distance along the contours of tissue connecting the endpoints by way of the midpoints. In other examples, other types of user interfaces such as pointer-based interfaces may be employed to achieve a similar result.

[0086] Additionally or alternatively, system **100** may perform operation **202** by performing an efficiency-related operation associated with computer-assisted surgical system **204**. For example, system **100** may perform operation **202** by controlling a movement of a surgical instrument connected to computer-assisted surgical system **204** in a manner that prevents harm from being afflicted on the patient.

[0087] To illustrate, auxiliary sensor **214** may be implemented by a force sensor integrated into a surgical instrument controlled by computer-assisted surgical system **204**. The force sensor may be configured to generate force sensing data representative of an amount of external force applied to the surgical instrument. Based on the force sensing data and depth data **206**, system **100** may determine that the surgical instrument begins moving towards a structure (e.g., an organ or other tissue) located in the internal space of a patient in response to external force applied to the surgical instrument. In response, system **100** may instruct computer-assisted surgical system **204** to stop the movement of the surgical instrument towards the structure before the surgical instrument damages the structure (e.g., by plunging into the structure).

[0088] To illustrate, FIG. **13** shows an exemplary configuration **1300** in which a surgical instrument **1302** is being used within an internal space that is being imaged by imaging device **212**. As shown, surgical instrument **1302** includes a force sensor **1304**. Force sensor **1304** may be integrated into surgical instrument **1302** in any suitable manner. For example, as shown, force sensor **1304** may be disposed on an outer surface of surgical instrument **1302**. Additionally or alternatively, force sensor **1304** may be housed within surgical instrument **1302**. While FIG. **13** shows force sensor **1304** located towards a distal end of surgical instrument **1302**, it will be recognized that force sensor **1304** may be located at any position on or within surgical instrument **1302** as may serve a particular implementation. Moreover, in some examples, surgical instrument **1302** may include a plurality of force sensors at different locations on and/or within surgical instrument **1302**.

[0089] In some examples, a user (e.g., a surgeon) may remotely control movement of surgical instrument **1302** by using his or her hands to interact with a set of master controls configured to detect a wide variety of hand, wrist, and/or finger movements by the user. In response to the user manipulating the master controls, computer-assisted surgical system **204** may move and/or otherwise manipulate surgical instrument **1302** in a corresponding manner.

[0090] However, in some cases, an unexpected force may be applied to surgical instrument **1302** that causes the user's hands to become disengaged from the master controls. In these cases, surgical instrument **1302** may inadvertently move in an uncontrolled manner and/or at an uncontrolled speed. This may cause surgical instrument **1302** to undesirably come in contact with and/or plunge into a structure (e.g., an organ or other tissue) within the patient. This contact may cause damage to the structure.

[0091] To illustrate, while a surgeon is remotely controlling movement of surgical instrument **1302**, an assistant located in the operating room may be using a laparoscopic tool **1306** to perform a laparoscopic operation within the patient. While so doing, the assistant made inadvertently cause laparoscopic tool **1306** to collide with surgical instrument **1302**. This collision may cause the surgeon's hands to become disengaged from the master controls being used to control surgical instrument **1302**. This, in turn, may cause surgical instrument **1302** to move towards structure **1308** in a direction illustrated by arrow **1310**.

[0092] Hence, in accordance with the systems and methods described herein, depth data **206** generated by depth sensor **210** within imaging device **212** in combination with force sensing data generated by force sensor **1304** may be used to determine that surgical instrument **1302** begins moving towards structure **1308** in response to external force applied by laparoscopic tool **1306**. The force sensing data indicate a strength and a direction of the force. Based on this data, system **100** may determine an approximate direction and speed at which surgical instrument **1302** is moving. In some examples, kinematic data associated with surgical instrument **1302** and maintained by computer-assisted surgical system **204** may also be used to determine the approximate direction and speed at which surgical instrument **1302** is moving. Depth data **206** may indicate a depth of both surgical instrument **1302** and structure **1308**, which information may be used to determine how close surgical instrument **1302** is getting to structure **1308**. System **100** may accordingly be configured to instruct computer-assisted surgical system **204** to stop the movement of surgical instrument **1302** towards structure **1308** before surgical instrument **1302** comes in contact with structure **1308**.

[0093] Additionally or alternatively, system **100** may perform operation **202** by determining an amount of tissue deformation that occurs when a surgical instrument is in contact with the tissue. In this example, auxiliary sensor **214** may be implemented by a force sensor integrated into a surgical instrument controlled by computer-assisted surgical system **204**. As described above, the force sensor may be configured to generate force sensing data representative of an amount of external force applied to the surgical instrument. Based on the force sensing data, system **100** may determine that the surgical instrument is in contact with tissue. In response to this determination, system **100** may use depth data **206** to determine an amount of deformation of the tissue that is caused by the surgical instrument being in contact with the tissue.

[0094] To illustrate, FIGS. **14-15** show an exemplary configuration **1400** in which a surgical instrument **1402** is

used to perform a tissue deformation analysis operation within an internal space of a patient that is being imaged by imaging device **212**. Surgical instrument **1402** may be similar to surgical instrument **1302** in that surgical instrument **1402** includes a force sensor **1404**. As shown, force sensor **1404** is disposed towards a distal end of surgical instrument **1402**.

[0095] In the example of FIGS. **14-15**, a user may use surgical instrument **1402** to interact with tissue **1406**. In particular, the user may guide surgical instrument **1402** towards a target location **1408** of tissue **1406** in order to perform the tissue deformation analysis operation with respect to target location **1408**. FIG. **14** shows surgical instrument **1402** before it has come in contact with target location **1408**, and FIG. **15** shows surgical instrument **1402** once it has come in contact with target location **1408**.

[0096] In some examples, system **100** may obtain a first depth dataset (e.g., a first dataset included in depth data **206**) while surgical instrument **1402** is not in contact with tissue **1406** (e.g., in the position shown in FIG. **14**). System **100** may also obtain a second depth dataset (e.g., a second dataset included in depth data **206**) while surgical instrument **1402** is in contact with target location **1408** of tissue **1406** (e.g., in the position shown in FIG. **15**). Based on the first and second datasets, system **100** may determine an amount of deformation of tissue **1406** at target location **1408** that is caused by surgical instrument **1402** being in contact with target location **1408** of tissue **1406**. For example, system **100** may determine a difference between the first and second depth datasets and thereby ascertain an amount of deformation of tissue **1406**.

[0097] Based on the determined amount of tissue deformation, system **100** may perform one or more operations. For example, system **100** may determine a characteristic of tissue **1406** based on the amount of tissue deformation.

[0098] For example, based on the determined amount of tissue deformation, system **100** may determine a presence of a structure underneath tissue **1406**. To illustrate, by measuring an amount of force applied to target location **1408** of tissue **1406** and determining a resulting amount of tissue deformation, system **100** may determine that a particular type of mass (e.g., a tumor) is underneath tissue **1406**. This determination may be made in any suitable manner.

[0099] As another example, based on the determined amount of tissue deformation, system **100** may determine a difference between tissue **1408** and other tissue within the internal space of the patient. For example, if target location **1406** deforms more than a different location within tissue **1406** in response to the same amount of force, system **100** may determine that the tissue **1406** at target location **1406** is diseased, damaged, or otherwise different than the tissue **1406** at the different location.

[0100] FIG. **16** illustrates an exemplary method **1600** that may be performed by an operation management system (e.g., system **100** and/or any implementation thereof). While FIG. **16** illustrates exemplary operations according to one embodiment, other embodiments may omit, add to, reorder, and/or modify any of the operations shown in FIG. **16**.

[0101] In operation **1602**, an operation management system obtains, from a depth sensor included in an imaging device, depth data representative of a depth map for an internal space of a patient. Operation **1602** may be performed in any of the ways described herein.

[0102] In operation **1604**, the operation management system obtains auxiliary sensor data from an auxiliary sensor not included in the imaging device. Operation **1604** may be performed in any of the ways described herein.

[0103] In operation **1606**, the operation management system performs, based on the depth data and the auxiliary sensor data, an operation associated with a computer-assisted surgical system configured to perform a procedure within the internal space of the patient. Operation **1606** may be performed in any of the ways described herein.

[0104] FIG. **17** illustrates an exemplary computer-assisted surgical system **1700** ("surgical system **1700**"). Surgical system **1700** may be an implementation of computer-assisted surgical system **204**. As shown, surgical system **1700** may include a manipulating system **1702**, a user control system **1704**, and an auxiliary system **1706** communicatively coupled one to another. Surgical system **1700** may be utilized by a surgical team to perform a computer-assisted surgical procedure on a patient **1708**. As shown, the surgical team may include a surgeon **1710-1**, an assistant **1710-2**, a nurse **1710-3**, and an anesthesiologist **1710-4**, all of whom may be collectively referred to as "surgical team members **1710**." Additional or alternative surgical team members may be present during a surgical session as may serve a particular implementation.

[0105] While FIG. **17** illustrates an ongoing minimally invasive surgical procedure, it will be understood that surgical system **1700** 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 **1700**. Additionally, it will be understood that the surgical session throughout which surgical system **1700** may be employed may not only include an operative phase of a surgical procedure, as is illustrated in FIG. **17**, 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.

[0106] As shown in FIG. **17**, manipulating system **1702** may include a plurality of manipulator arms **1712** (e.g., manipulator arms **1712-1** through **1712-4**) 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 **1708** (e.g., by being at least partially inserted into patient **1708** and manipulated to perform a computer-assisted surgical procedure on patient **1708**). While manipulating system **1702** is depicted and described herein as including four manipulator arms **1712**, it will be recognized that manipulating system **1702** may include only a single manipulator arm **1712** or any other number of manipulator arms as may serve a particular implementation.

[0107] Manipulator arms **1712** and/or surgical instruments attached to manipulator arms **1712** 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 **1700** may be configured to use the kinematics

information to track (e.g., determine positions of) and/or control the surgical instruments.

[0108] User control system **1704** may be configured to facilitate control by surgeon **1710-1** of manipulator arms **1712** and surgical instruments attached to manipulator arms **1712**. For example, surgeon **1710-1** may interact with user control system **1704** to remotely move or manipulate manipulator arms **1712** and the surgical instruments. To this end, user control system **1704** may provide surgeon **1710-1** with imagery (e.g., high-definition 3D imagery) of a surgical area associated with patient **1708** as captured by an imaging system (e.g., any of the medical imaging systems described herein). In certain examples, user control system **1704** may include a stereo viewer having two displays where stereoscopic images of a surgical area associated with patient **1708** and generated by a stereoscopic imaging system may be viewed by surgeon **1710-1**. Surgeon **1710-1** may utilize the imagery to perform one or more procedures with one or more surgical instruments attached to manipulator arms **1712**.

[0109] To facilitate control of surgical instruments, user control system **1704** may include a set of master controls. These master controls may be manipulated by surgeon **1710-1** 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 **1710-1**. In this manner, surgeon **1710-1** may intuitively perform a procedure using one or more surgical instruments.

[0110] Auxiliary system **1706** may include one or more computing devices configured to perform primary processing operations of surgical system **1700**. In such configurations, the one or more computing devices included in auxiliary system **1706** may control and/or coordinate operations performed by various other components (e.g., manipulating system **1702** and user control system **1704**) of surgical system **1700**. For example, a computing device included in user control system **1704** may transmit instructions to manipulating system **1702** by way of the one or more computing devices included in auxiliary system **1706**. As another example, auxiliary system **1706** may receive, from manipulating system **1702**, and process image data representative of imagery captured by an imaging device attached to one of manipulator arms **1712**.

[0111] In some examples, auxiliary system **1706** may be configured to present visual content to surgical team members **1710** who may not have access to the images provided to surgeon **1710-1** at user control system **1704**. To this end, auxiliary system **1706** may include a display monitor **1714** configured to display one or more user interfaces, such as images (e.g., 2D images) of the surgical area, information associated with patient **1708** and/or the surgical procedure, and/or any other visual content as may serve a particular implementation. For example, display monitor **1714** 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 **1714** is implemented by a touchscreen display with which surgical team members **1710** may interact (e.g., by way of touch gestures) to provide user input to surgical system **1700**.

[0112] Manipulating system **1702**, user control system **1704**, and auxiliary system **1706** may be communicatively coupled one to another in any suitable manner. For example, as shown in FIG. **17**, manipulating system **1702**, user control system **1704**, and auxiliary system **1706** may be communicatively coupled by way of control lines **1716**, which may represent any wired or wireless communication link as may serve a particular implementation. To this end, manipulating system **1702**, user control system **1704**, and auxiliary system **1706** 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.

[0113] 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.

[0114] 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).

[0115] FIG. **18** illustrates an exemplary computing device **1800** 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 **1800**.

[0116] As shown in FIG. **18**, computing device **1800** may include a communication interface **1802**, a processor **1804**, a storage device **1806**, and an input/output ("I/O") module **1808** communicatively connected one to another via a communication infrastructure **1810**. While an exemplary computing device **1800** is shown in FIG. **18**, the components illustrated in FIG. **18** are not intended to be limiting. Additional or alternative components may be used in other embodiments. Components of computing device **1800** shown in FIG. **18** will now be described in additional detail.

[0117] Communication interface **1802** may be configured to communicate with one or more computing devices. Examples of communication interface **1802** 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.

[0118] Processor **1804** 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 **1804** may perform operations by executing computer-executable instructions **1812** (e.g., an

application, software, code, and/or other executable data instance) stored in storage device **1806**.

[0119] Storage device **1806** 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 **1806** 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 **1806**. For example, data representative of computer-executable instructions **1812** configured to direct processor **1804** to perform any of the operations described herein may be stored within storage device **1806**. In some examples, data may be arranged in one or more databases residing within storage device **1806**.

[0120] I/O module **1808** may include one or more I/O modules configured to receive user input and provide user output. I/O module **1808** may include any hardware, firmware, software, or combination thereof supportive of input and output capabilities. For example, I/O module **1808** 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.

[0121] I/O module **1808** 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 **1808** 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.

[0122] 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.

1. A system, comprising:

a memory storing instructions; and

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

obtain depth data representative of a depth map for an internal space of a patient;

obtain force sensing data representative of an amount of external force applied to a component of a computer-assisted surgical system configured to perform a procedure within the internal space of the patient; and

perform, based on the depth data and the force sensing data, an operation associated with the computer-assisted surgical system.

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

the obtaining of the depth data representative of the depth map comprises:

directing a time-of-flight sensor included in an imaging device to acquire the depth data; and

receiving the depth data from the time-of-flight sensor.

3. The system of claim **2**, wherein the imaging device further comprises a visible light camera configured to acquire a two-dimensional visible light image of the internal space.

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

the processor is further configured to execute the instructions to receive user input data indicating a selection by a user of a first two-dimensional endpoint within an image of the internal space, the first two-dimensional endpoint corresponding to a first feature within the internal space as depicted by the image; and

the performing of the operation associated with the computer-assisted surgical system comprises:

defining, based on the depth data and on the user input data, a first three-dimensional endpoint corresponding to the first feature; and

determining, based on the depth data, a distance from the first three-dimensional endpoint corresponding to the first feature to a second three-dimensional endpoint corresponding to a second feature within the internal space.

5. The system of claim **4**, wherein:

the processor is further configured to execute the instructions to receive additional user input data indicating a selection of a second two-dimensional endpoint within the image, the second two-dimensional endpoint corresponding to the second feature; and

the performing of the operation associated with the computer-assisted surgical system further comprises defining, based on the depth data and the additional user input data, the second three-dimensional endpoint corresponding to the second feature.

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

the obtaining of the depth data representative of the depth map comprises:

directing a first visible light camera in an imaging device to acquire a first image of the internal space,

directing a second visible light camera in the imaging device to acquire a second image of the internal space, and

generating, based on the first and second images, the depth map.

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

the component comprises a surgical instrument controlled by the computer-assisted surgical system; and

the performing of the operation associated with the computer-assisted surgical system comprises:

determining, based on the depth data and on the force sensing data, that the surgical instrument begins moving towards a structure located in the internal space in response to the external force applied to the surgical instrument; and

instructing, in response to the determining that the surgical instrument begins moving towards the structure, the computer-assisted surgical system to stop the movement of the surgical instrument towards the structure.

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

the component comprises a surgical instrument controlled by the computer-assisted surgical system;

the obtaining of the depth data comprises obtaining a first depth dataset while a surgical instrument controlled by the computer-assisted surgical system is not in contact with tissue in the internal space of the patient and a second depth dataset while the surgical instrument is in contact with the tissue; and

the performing of the operation associated with the computer-assisted surgical system comprises:

determining, based on the force sensing data, that the surgical instrument is in contact with the tissue, and

determining, in response to the determining that the surgical instrument is in contact with the tissue and based on the first and second depth datasets, an amount of deformation of the tissue that is caused by the surgical instrument being in contact with the tissue.

9. The system of claim **8**, wherein the processor is further configured to execute the instructions to determine a characteristic of the tissue based on the amount of deformation.

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

the component comprises a surgical instrument controlled by the computer-assisted surgical system; and

the force is applied to the surgical instrument by an object not being controlled by the computer-assisted surgical system.

11. The system of claim **1**, wherein the obtaining the force sensing data comprises obtaining the force sensing data from a force sensor integrated into the component.

12. A method comprising:

obtaining depth data representative of a depth map for an internal space of a patient;

obtaining force sensing data representative of an amount of external force applied to a component of a computer-assisted surgical system configured to perform a procedure within the internal space of the patient; and

performing, based on the depth data and the force sensing data, an operation associated with the computer-assisted surgical system.

13. The method of claim **12**, wherein:

the obtaining of the depth data representative of the depth map comprises:

directing a time-of-flight sensor included in an imaging device to acquire the depth data; and

receiving the depth data from the time-of-flight sensor.

14. The method of claim **13**, wherein the imaging device further comprises a visible light camera configured to acquire a two-dimensional visible light image of the internal space.

15. The method of claim **13**, wherein:

the method further comprises receiving user input data indicating a selection by a user of a first two-dimensional endpoint within an image of the internal space, the first two-dimensional endpoint corresponding to a first feature within the internal space as depicted by the image; and

the performing of the operation associated with the computer-assisted surgical system comprises:

defining, based on the depth data and on the user input data, a first three-dimensional endpoint corresponding to the first feature; and

determining, based on the depth data, a distance from the first three-dimensional endpoint corresponding to the first feature to a second three-dimensional endpoint corresponding to a second feature within the internal space.

16. The method of claim **15**, wherein:

the method further comprises receiving additional user input data indicating a selection of a second two-dimensional endpoint within the image, the second two-dimensional endpoint corresponding to the second feature; and

the performing of the operation associated with the computer-assisted surgical system further comprises defining, based on the depth data and the additional user input data, the second three-dimensional endpoint corresponding to the second feature.

17. The method of claim **12**, wherein:

the obtaining of the depth data representative of the depth map comprises:

directing a first visible light camera in an imaging device to acquire a first image of the internal space,

directing a second visible light camera in the imaging device to acquire a second image of the internal space, and

generating, based on the first and second images, the depth map.

18. The method of claim **12**, wherein:

the component comprises a surgical instrument controlled by the computer-assisted surgical system; and

the performing of the operation associated with the computer-assisted surgical system comprises:

determining, based on the depth data and on the force sensing data, that the surgical instrument begins moving towards a structure located in the internal space in response to the external force applied to the surgical instrument; and

instructing, in response to the determining that the surgical instrument begins moving towards the structure, the computer-assisted surgical system to stop the movement of the surgical instrument towards the structure.

19. The method of claim **12**, wherein:

the component comprises a surgical instrument controlled by the computer-assisted surgical system;

the obtaining of the depth data comprises obtaining a first depth dataset while a surgical instrument controlled by the computer-assisted surgical system is not in contact with tissue in the internal space of the patient and a second depth dataset while the surgical instrument is in contact with the tissue; and

the performing of the operation associated with the computer-assisted surgical system comprises:

determining, based on the force sensing data, that the surgical instrument is in contact with the tissue, and

determining, in response to the determining that the surgical instrument is in contact with the tissue and based on the first and second depth datasets, an amount of deformation of the tissue that is caused by the surgical instrument being in contact with the tissue.

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

obtaining depth data representative of a depth map for an internal space of a patient;

obtaining force sensing data representative of an amount of external force applied to a component of a computer-assisted surgical system configured to perform a procedure within the internal space of the patient; and

performing, based on the depth data and the force sensing data, an operation associated with the computer-assisted surgical system.

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