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(54) **ROBOTIC LIGHT PROJECTION TOOLS**

(71) Applicant: **Ethicon LLC**, Guaynabo, PR (US)

(72) Inventors: **Charles J. Scheib**, Loveland, OH (US); **Paul G. Ritchie**, Loveland, OH (US); **Victor C. Moreno**, Cincinnati, OH (US)

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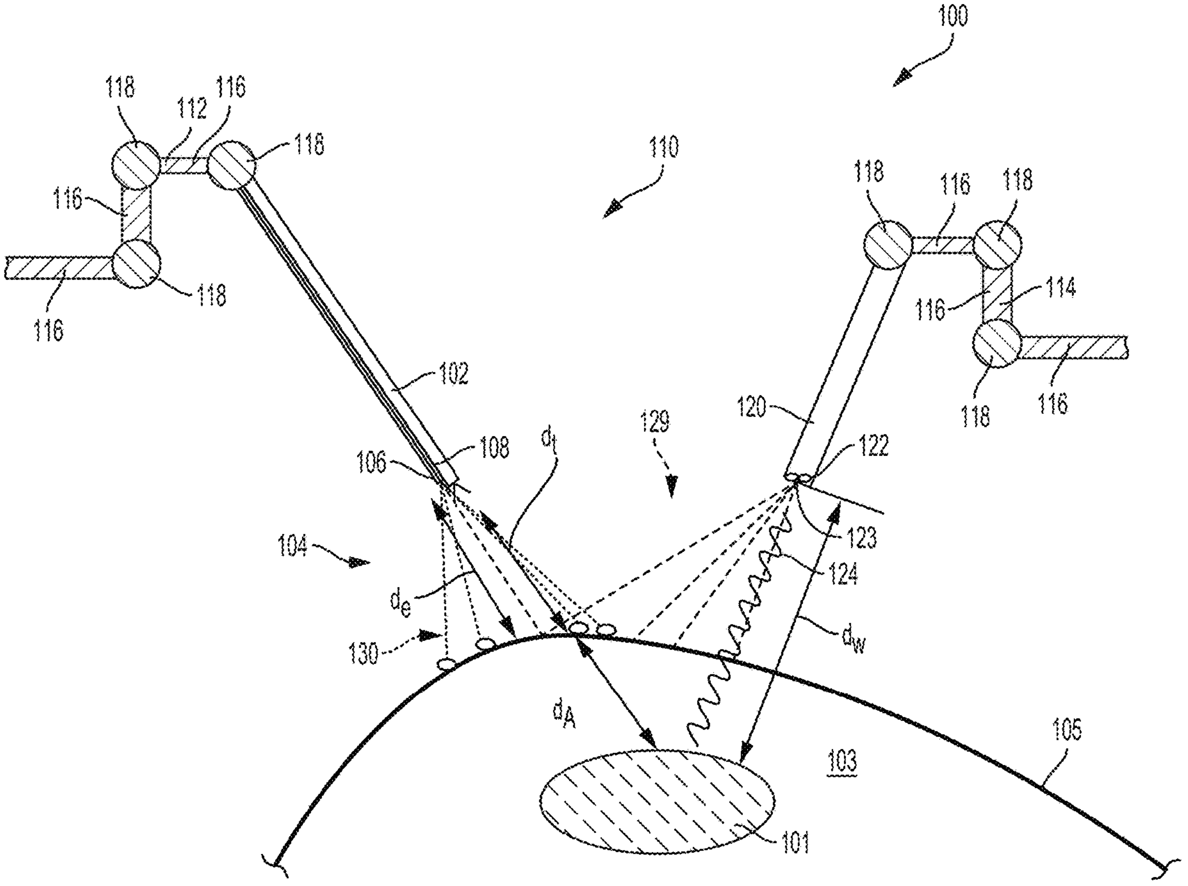
A61B 5/00	(2006.01)

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

CPC ***A61B 90/35*** (2016.02); ***A61B 5/0095*** (2013.01); ***A61B 34/73*** (2016.02); ***A61B 90/361*** (2016.02)

(57) **ABSTRACT**

A surgical visualization system is disclosed. The surgical visualization system is configured to identify one or more structure(s) and/or determine one or more distances with respect to obscuring tissue and/or the identified structure(s). The surgical visualization system can facilitate avoidance of the identified structure(s) by a surgical device. The surgical visualization system can comprise a first emitter configured to emit a plurality of tissue-penetrating light waves and a second emitter configured to emit structured light onto the surface of tissue. The surgical visualization system can also include an image sensor configured to detect reflected visible light, tissue-penetrating light, and/or structured light. The surgical visualization system can convey information to one or more clinicians regarding the position of one or more hidden identified structures and/or provide one or more proximity indicators. In various instances, a shaft-less light projection tool can be manipulated around the surgical site by a robotic tool.



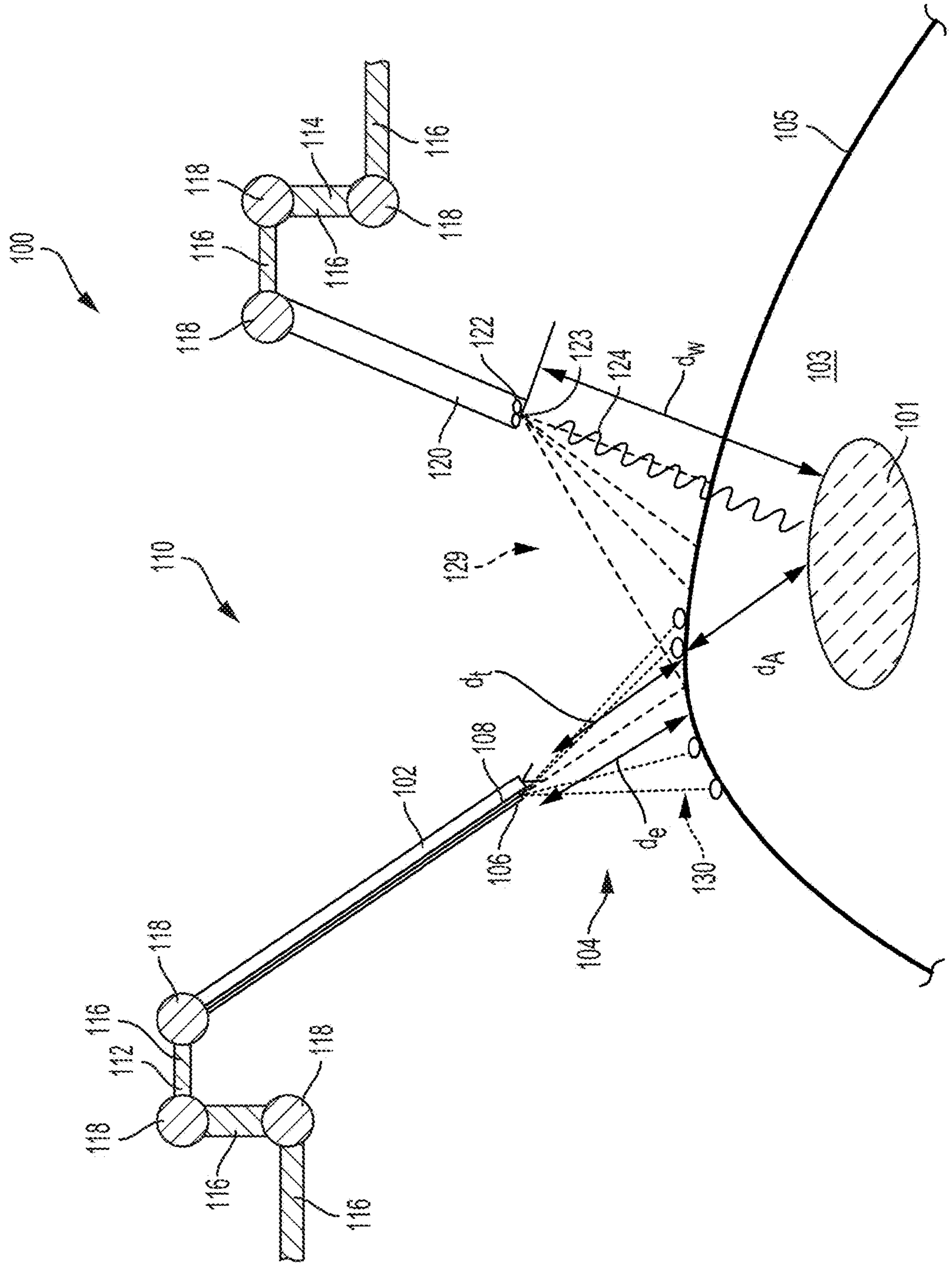

100
110
118
114
116
118
116
116
118
116
122
123
124
d_W
105
103
101
120
129
d_A
d_t
108
102
106
d_e
130
104
118
116
112
118
118
116
116

FIG. 1

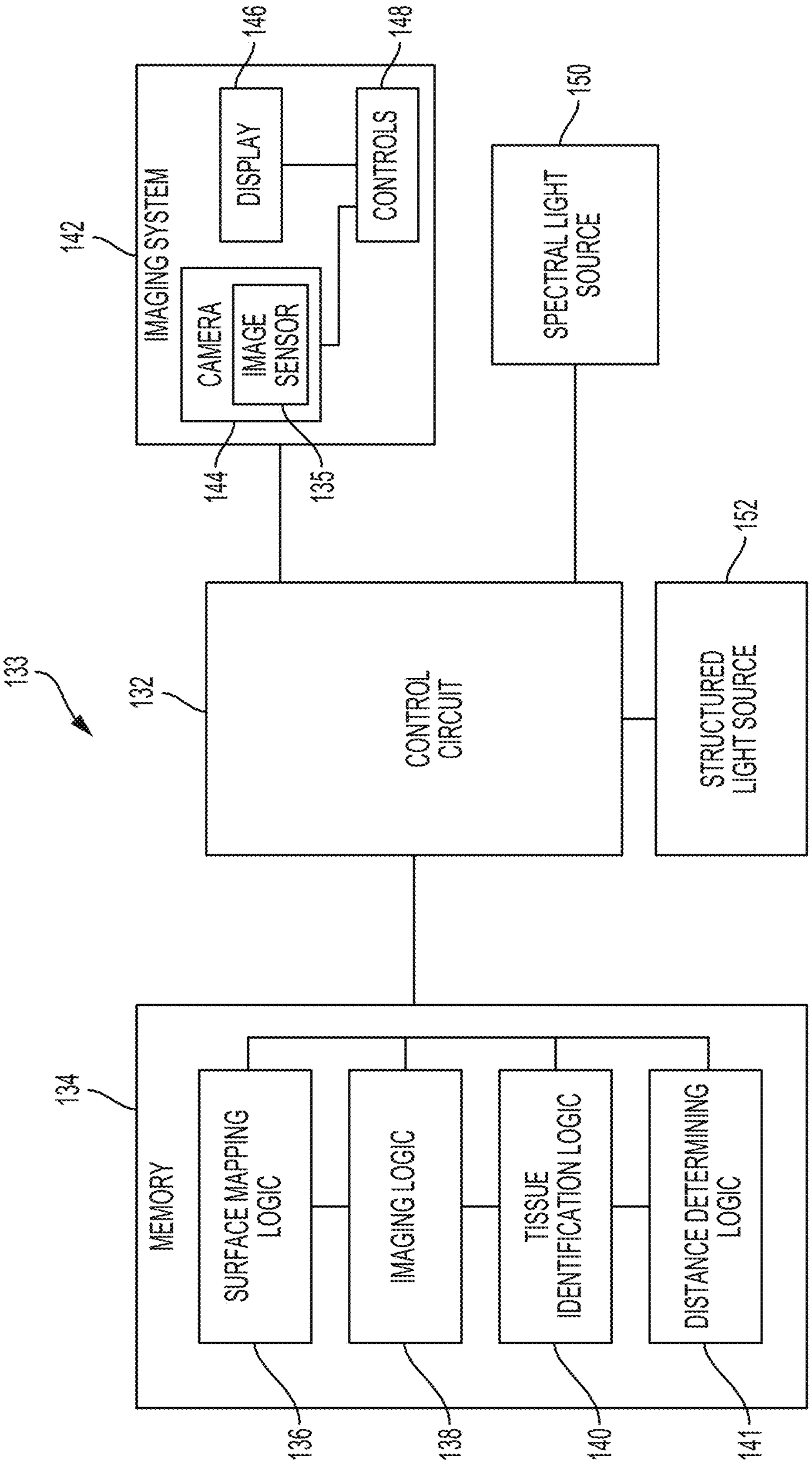

133
142
IMAGING SYSTEM
CAMERA
IMAGE SENSOR
DISPLAY
CONTROLS
146
148
144
135
SPECTRAL LIGHT SOURCE
150
132
CONTROL CIRCUIT
STRUCTURED LIGHT SOURCE
152
134
MEMORY
SURFACE MAPPING LOGIC
IMAGING LOGIC
TISSUE IDENTIFICATION LOGIC
DISTANCE DETERMINING LOGIC
136
138
140
141

FIG. 2

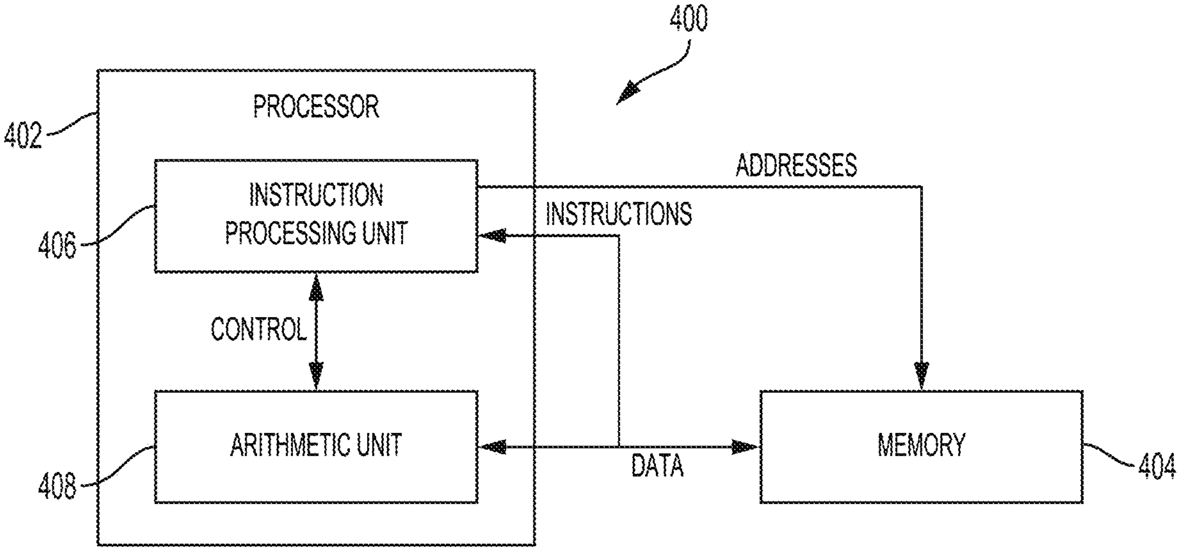


FIG. 2A

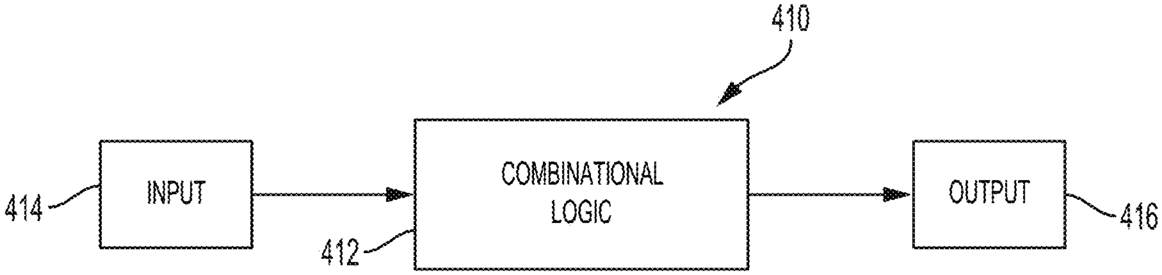


FIG. 2B

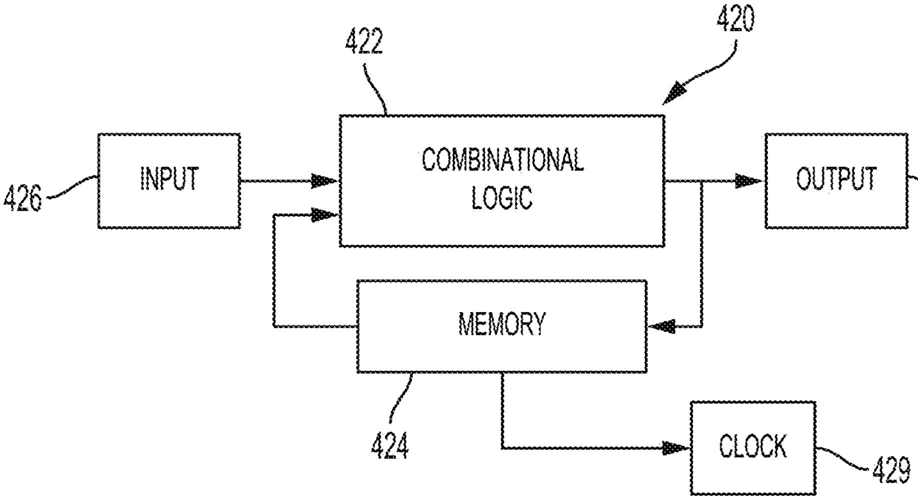


FIG. 2C

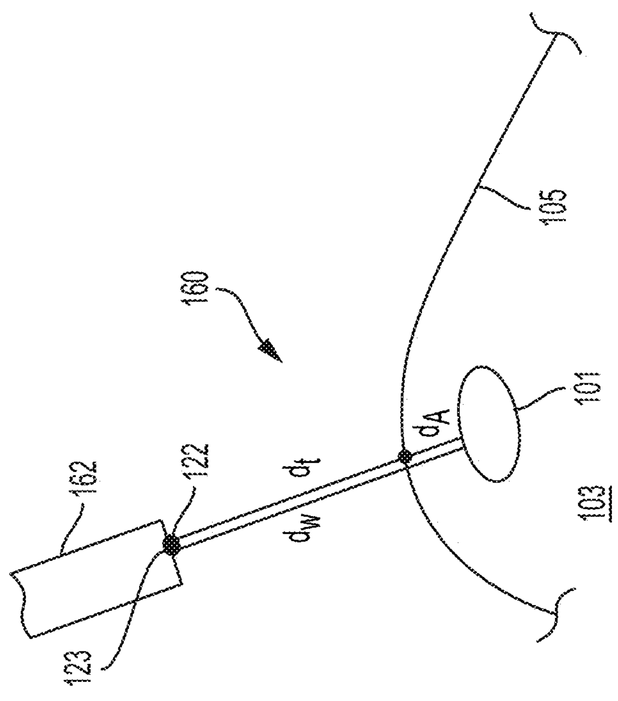

160
162
122
123
d_t
d_W
d_A
101
103
105

FIG. 4

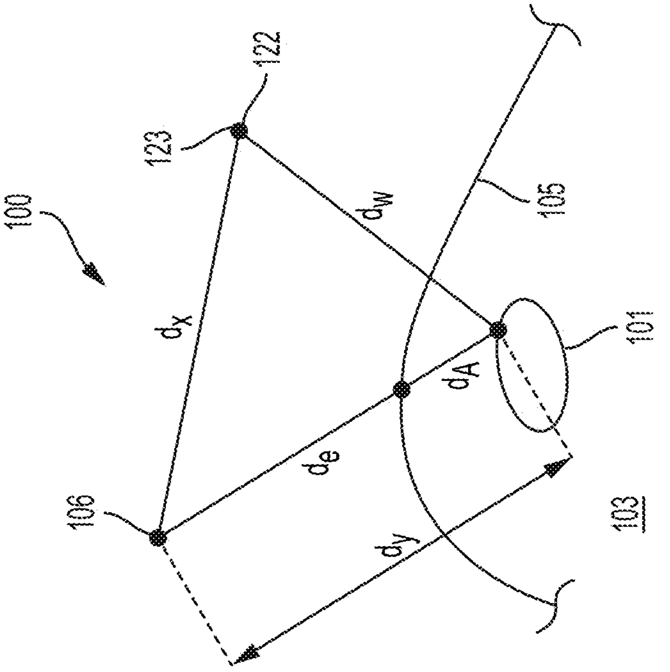

100
123
122
d_W
d_x
105
101
d_A
d_e
106
d_y
103

FIG. 3

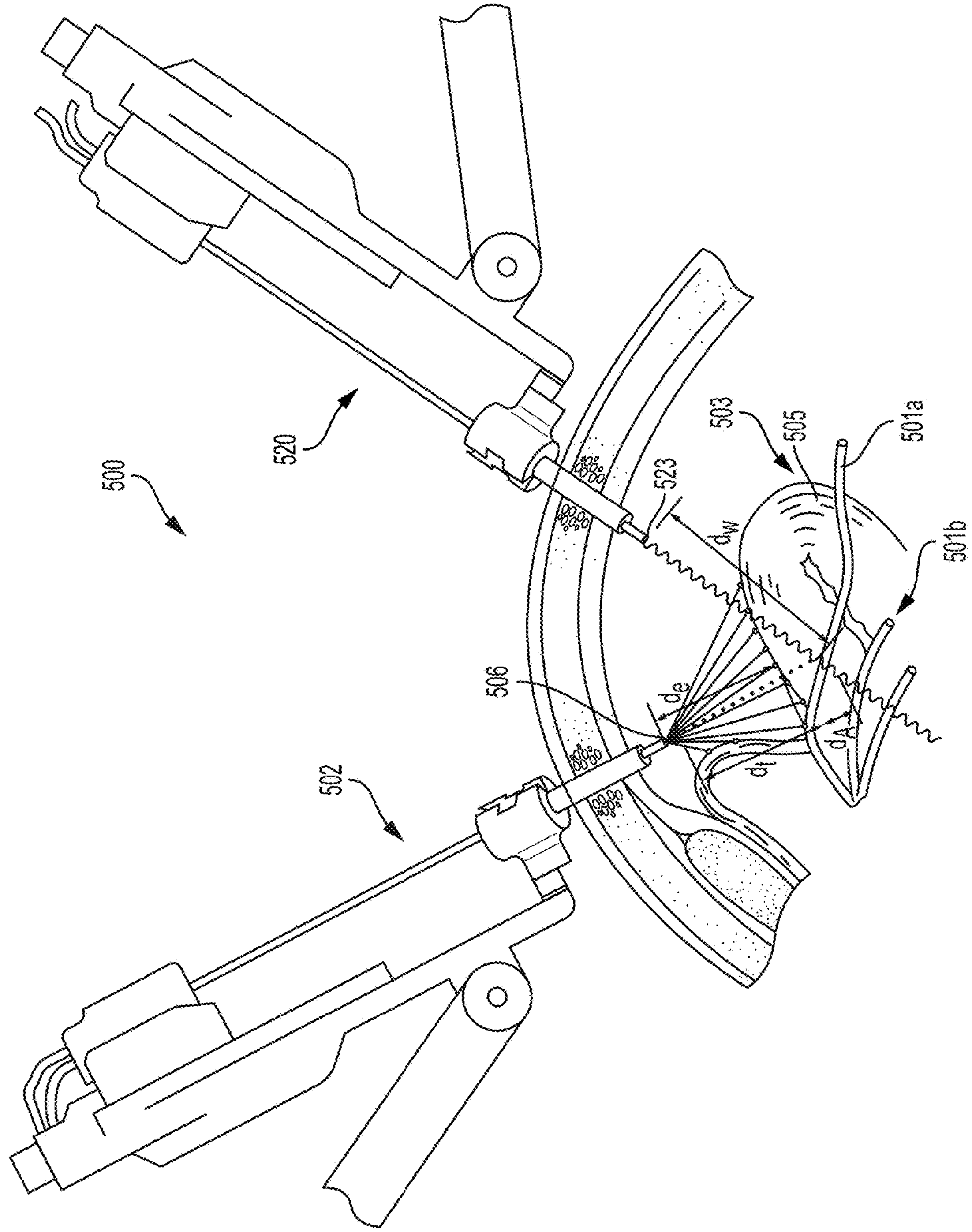


FIG. 5

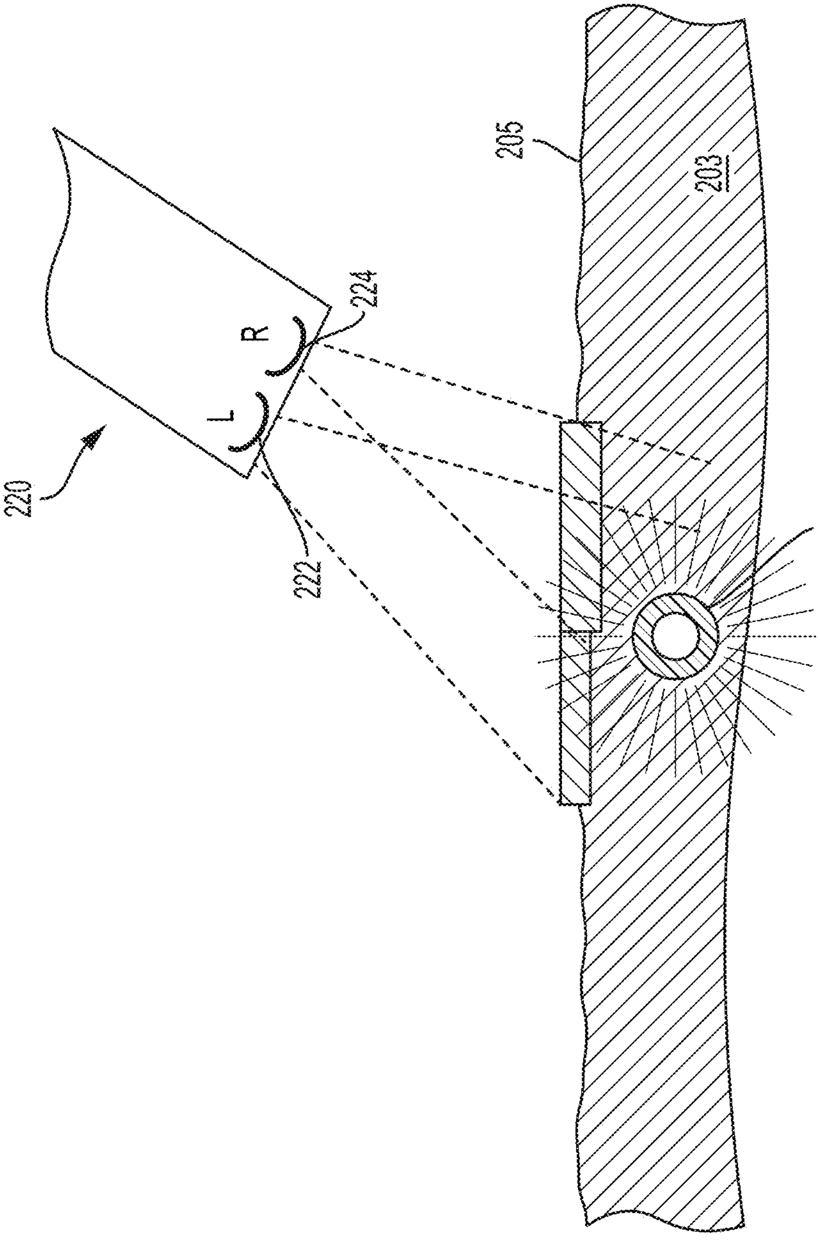


FIG. 6

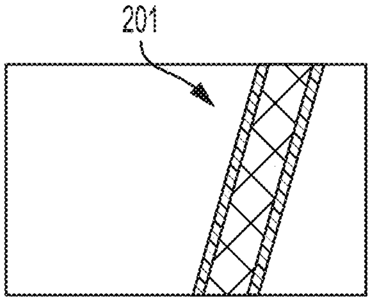


FIG. 7A

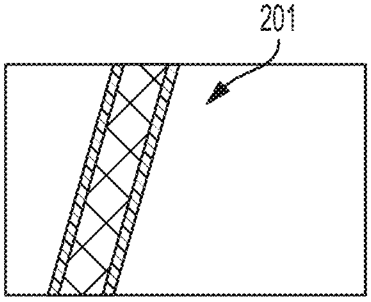


FIG. 7B

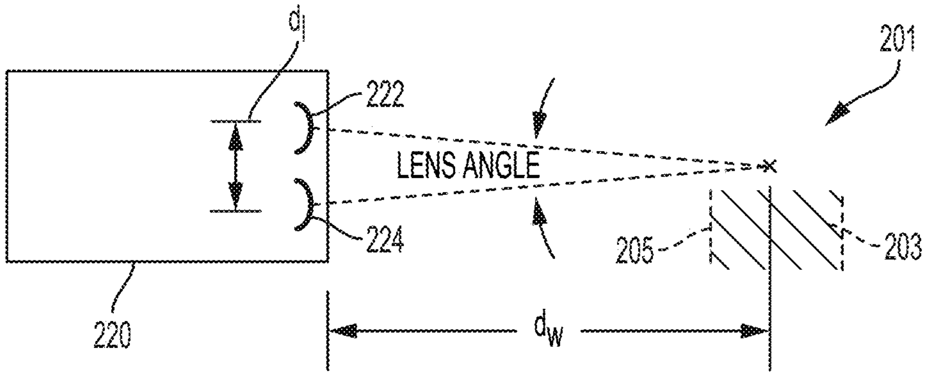


FIG. 8

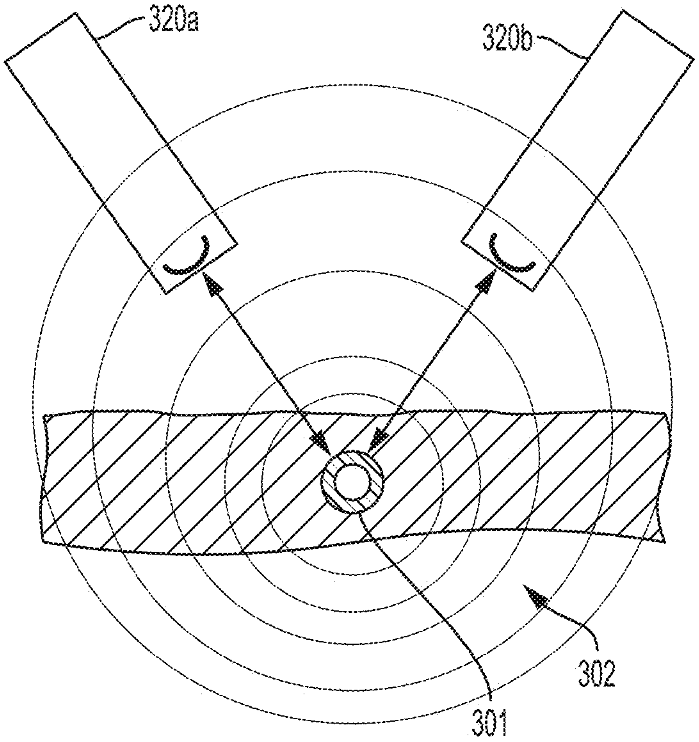


FIG. 9

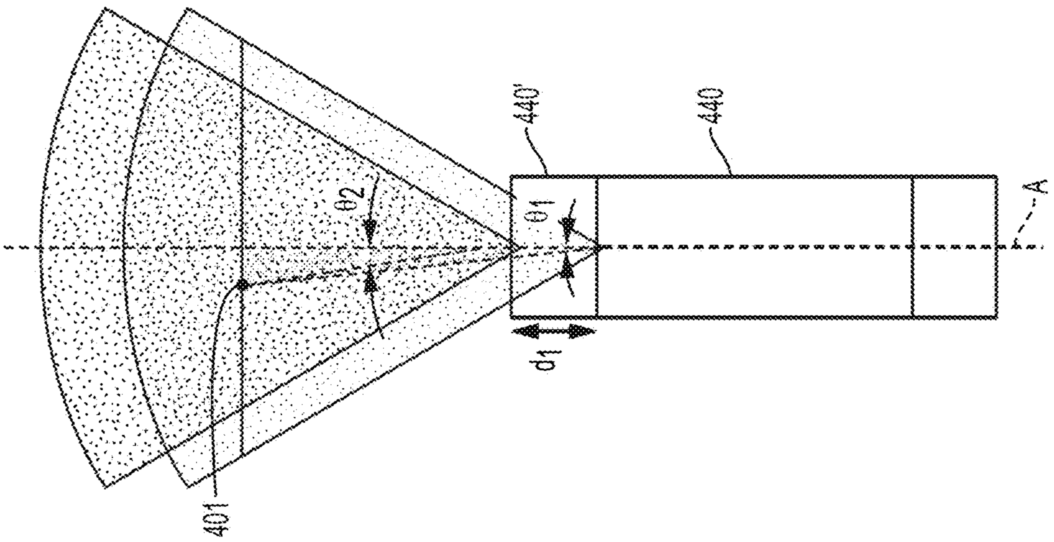


FIG. 10A

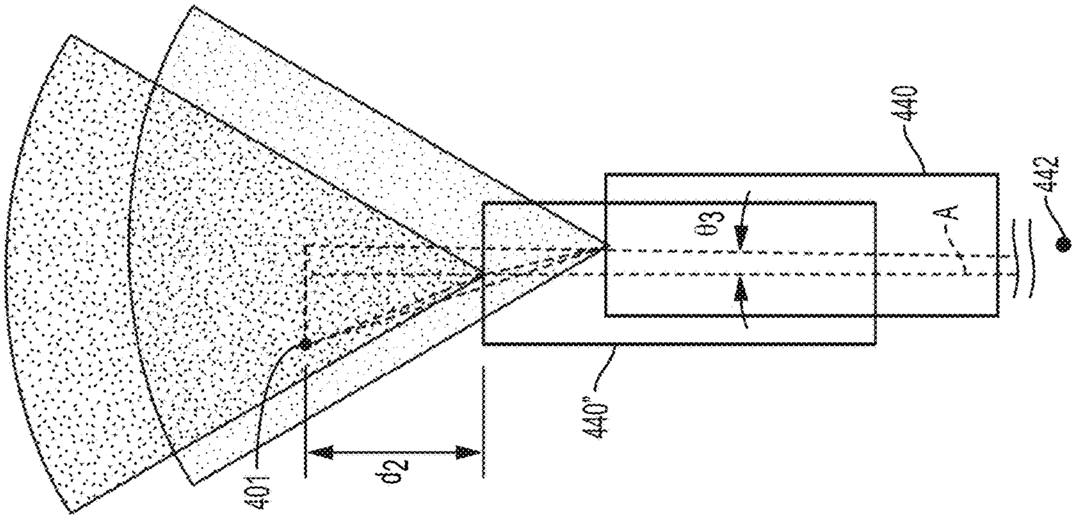


FIG. 10B

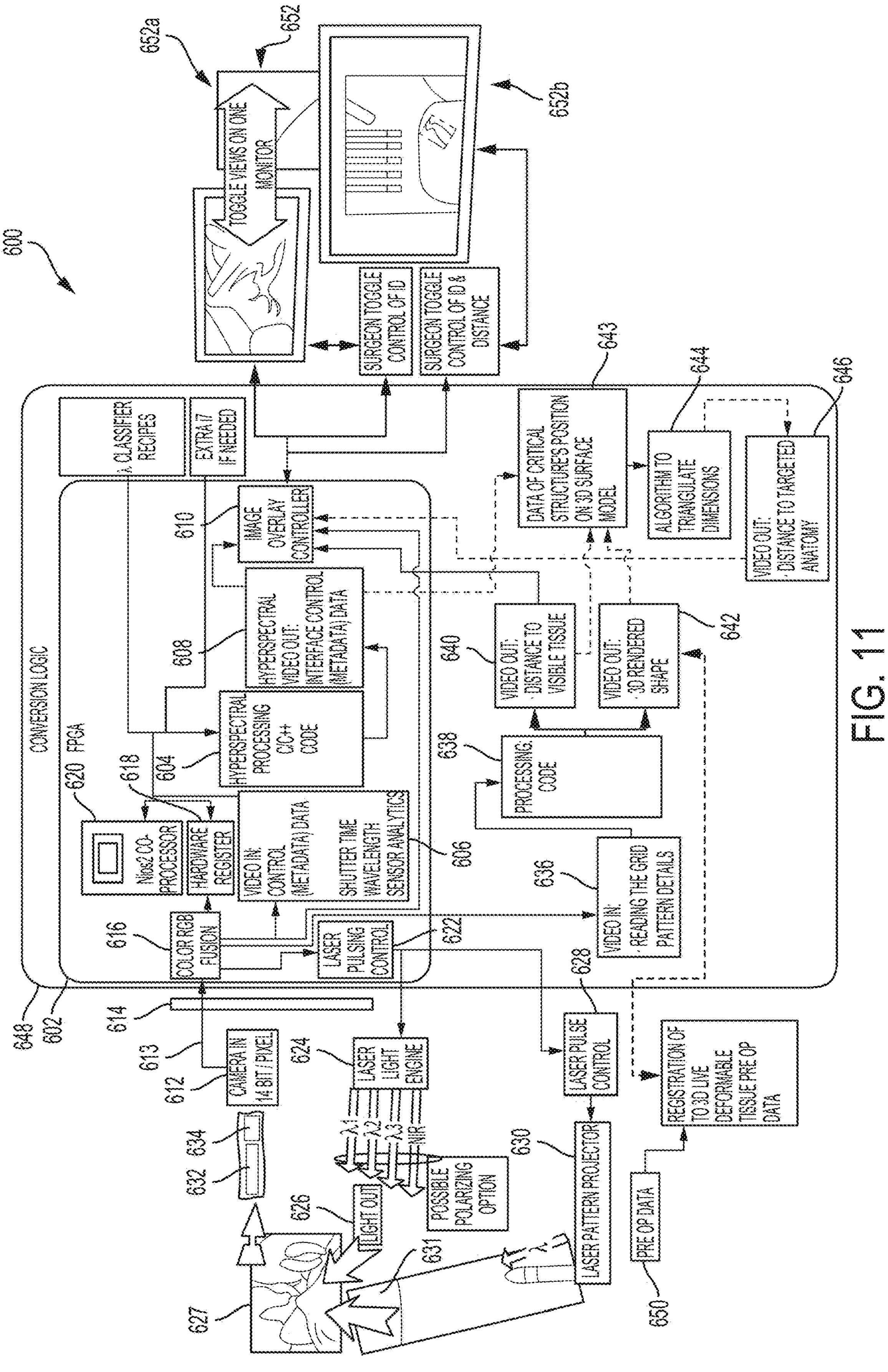

600
652a
652
652b
TOGGLE VIEWS ON ONE MONITOR
SURGEON TOGGLE CONTROL OF ID
SURGEON TOGGLE CONTROL OF ID & DISTANCE
643
644
646
CONVERSION LOGIC
λ CLASSIFIER RECIPES
EXTRA I7 IF NEEDED
610
IMAGE OVERLAY CONTROLLER
DATA OF CRITICAL STRUCTURES POSITION ON 3D SURFACE MODEL
ALGORITHM TO TRIANGULATE DIMENSIONS
VIDEO OUT: DISTANCE TO TARGETED ANATOMY
608
HYPERSPECTRAL VIDEO OUT: INTERFACE CONTROL (METADATA) DATA
640
VIDEO OUT: DISTANCE TO VISIBLE TISSUE
VIDEO OUT: 3D RENDERED SHAPE
642
620 FPGA
618
604
HYPERSPECTRAL PROCESSING C/C++ CODE
638
PROCESSING CODE
Nios2 CO-PROCESSOR
HARDWARE REGISTER
VIDEO IN: CONTROL (METADATA) DATA
SHUTTER TIME WAVELENGTH SENSOR ANALYTICS
606
636
VIDEO IN: READING THE GRID PATTERN DETAILS
616
COLOR RGB FUSION
LASER PULSING CONTROL
622
648
602
614
613
612
CAMERA IN 14 BIT / PIXEL
624
LASER LIGHT ENGINE
628
LASER PULSE CONTROL
REGISTRATION OF TO 3D LIVE DEFORMABLE TISSUE PRE OP DATA
632
634
λ1
λ2
λ3
NIR
630
LASER PATTERN PROJECTOR
626
LIGHT OUT
POSSIBLE POLARIZING OPTION
631
627
PRE OP DATA
650

FIG. 11

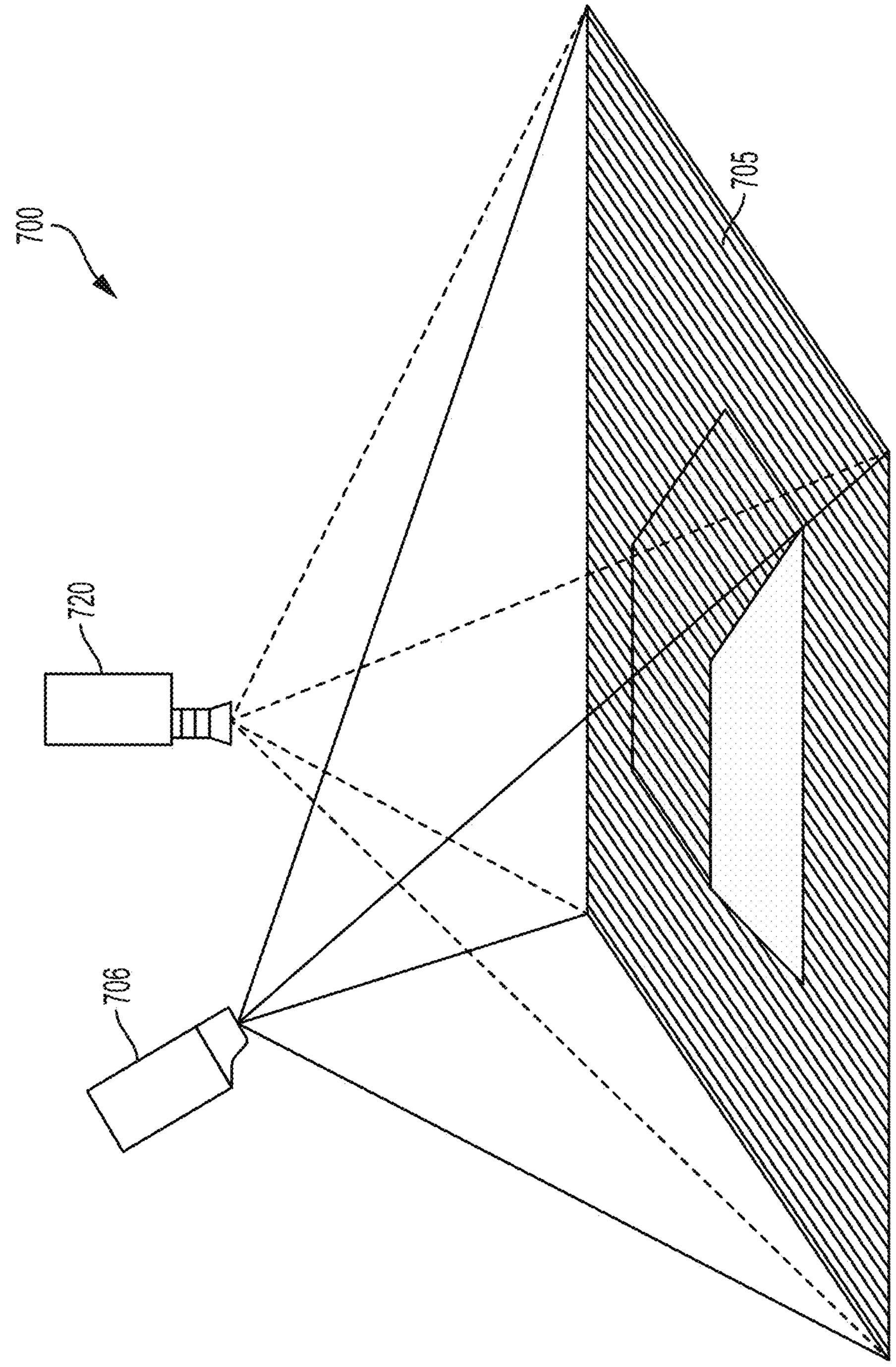


FIG. 12

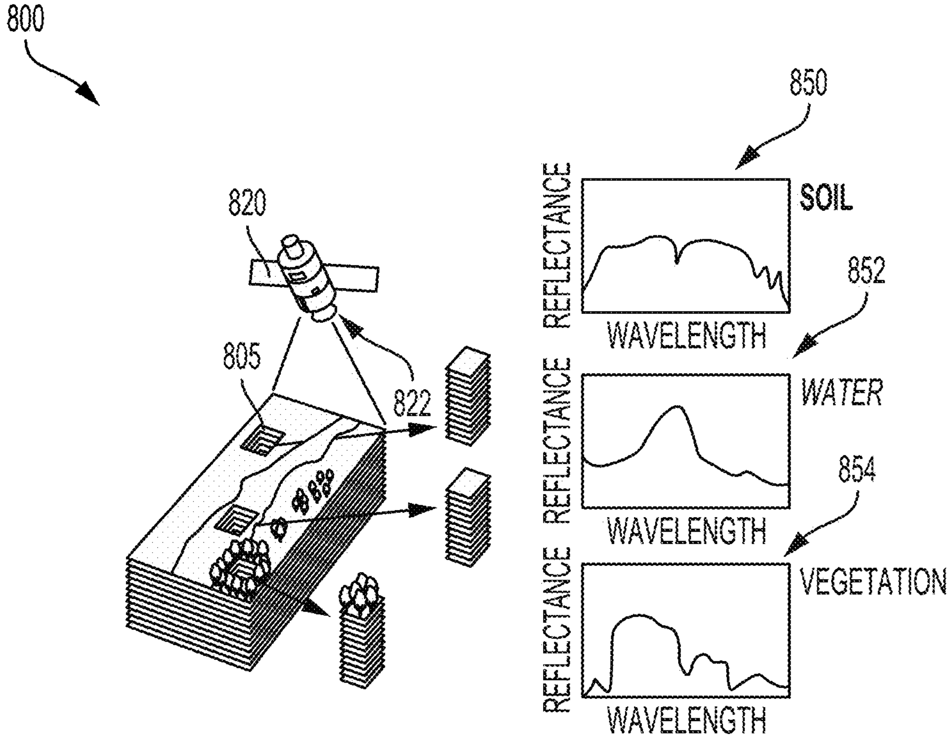

800
820
805
822
850
REFLECTANCE
WAVELENGTH
SOIL
852
REFLECTANCE
WAVELENGTH
WATER
854
REFLECTANCE
WAVELENGTH
VEGETATION

FIG. 13

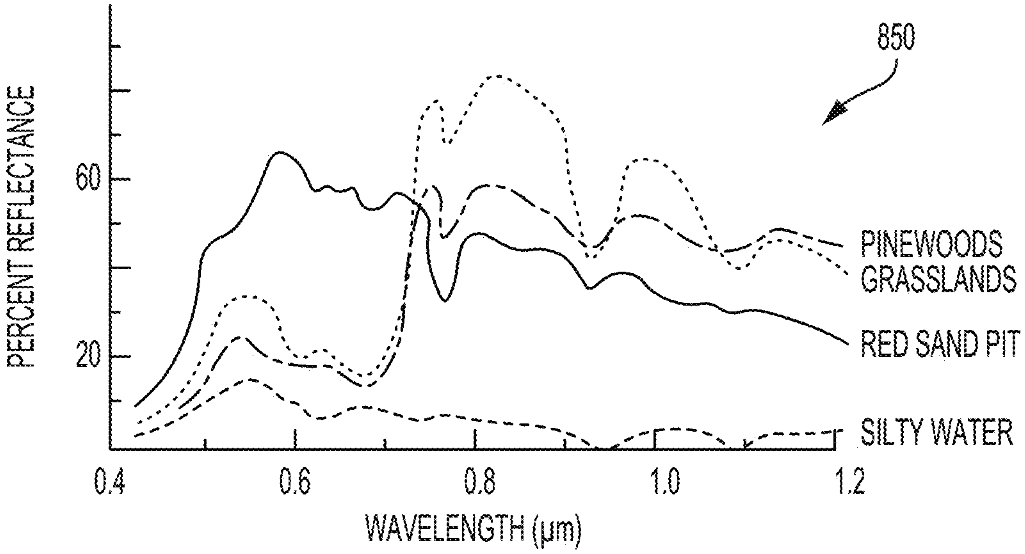

850
PERCENT REFLECTANCE
60
20
0.4
0.6
0.8
1.0
1.2
WAVELENGTH (μm)
PINEWOODS
GRASSLANDS
RED SAND PIT
SILTY WATER

FIG. 14

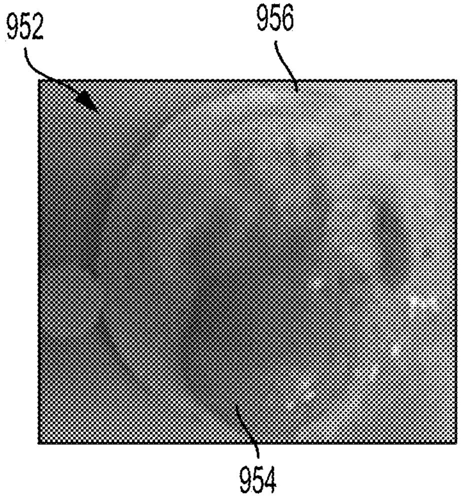


FIG. 15A

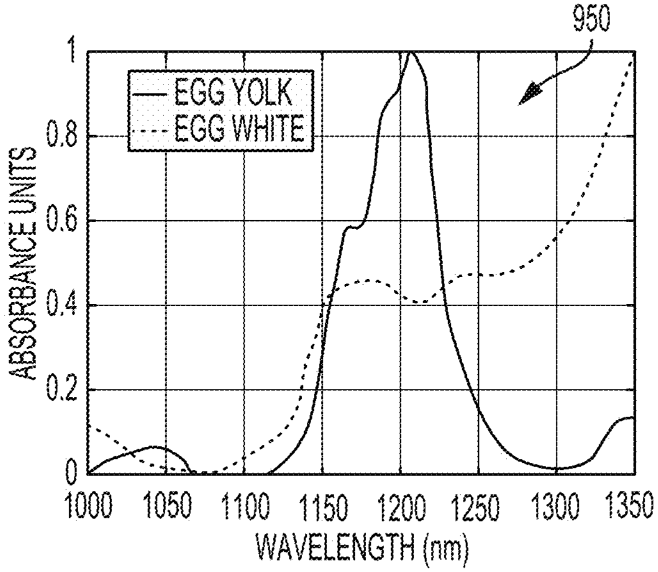


FIG. 15B

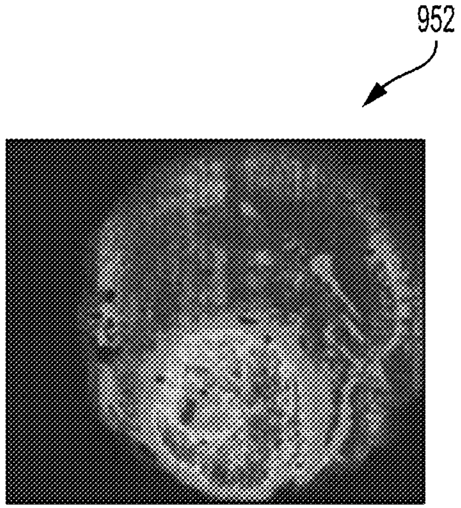


FIG. 15C

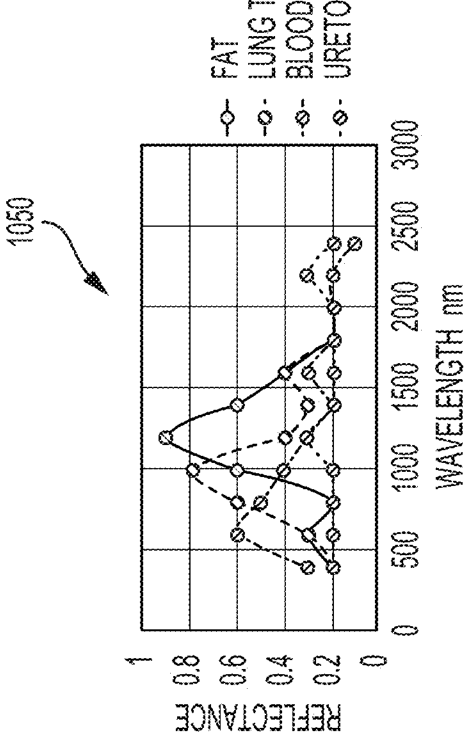


FIG. 16

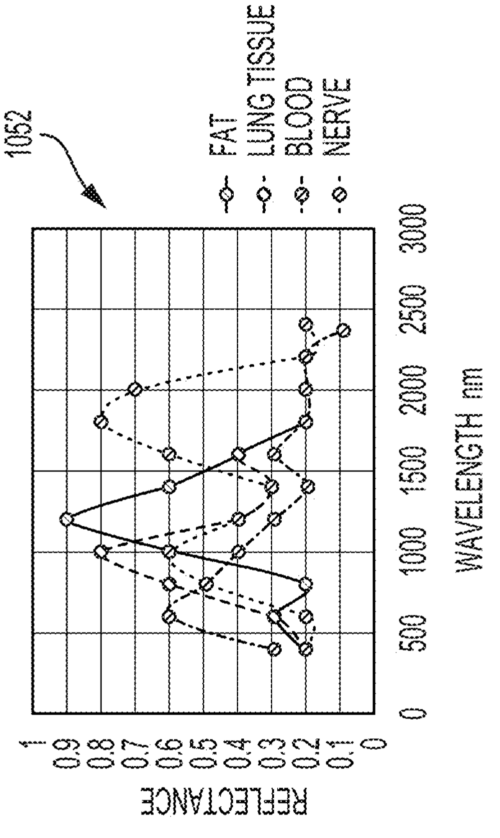


FIG. 17

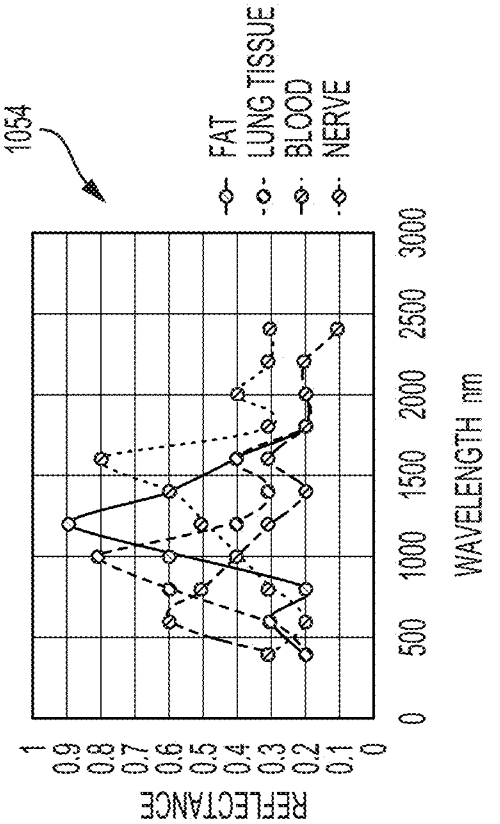


FIG. 18

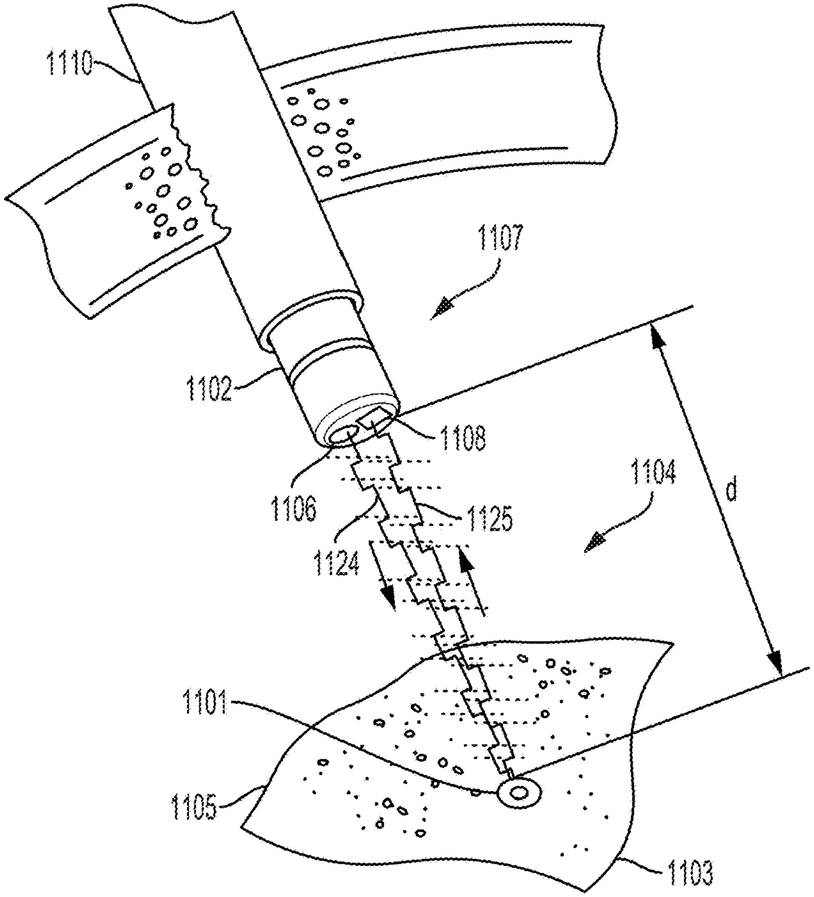

1110
1107
1102
1108
1106
1104
d
1125
1124
1101
1105
1103

FIG. 19

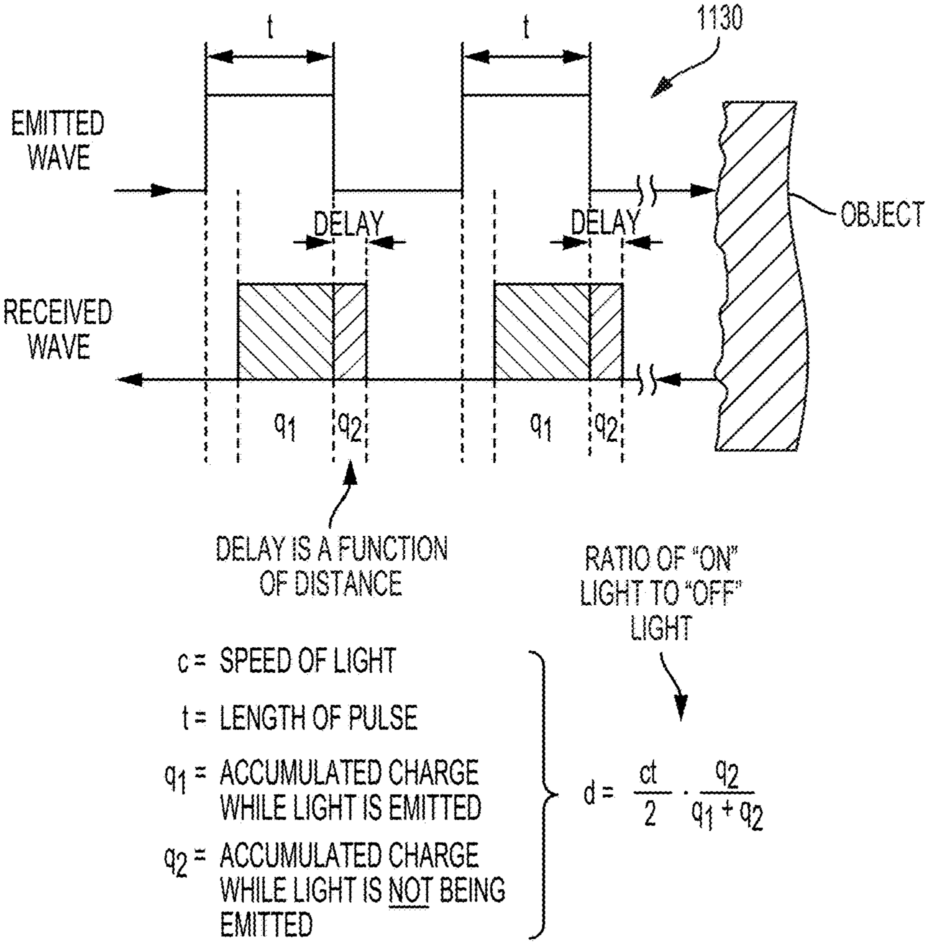

t
t
1130
EMITTED WAVE
DELAY
DELAY
OBJECT
RECEIVED WAVE
q_1
q_2
q_1
q_2
DELAY IS A FUNCTION OF DISTANCE
RATIO OF "ON" LIGHT TO "OFF" LIGHT
c = SPEED OF LIGHT
t = LENGTH OF PULSE
q_1 = ACCUMULATED CHARGE WHILE LIGHT IS EMITTED
q_2 = ACCUMULATED CHARGE WHILE LIGHT IS NOT BEING EMITTED
$d = \frac{ct}{2} \cdot \frac{q_2}{q_1 + q_2}$

FIG. 20

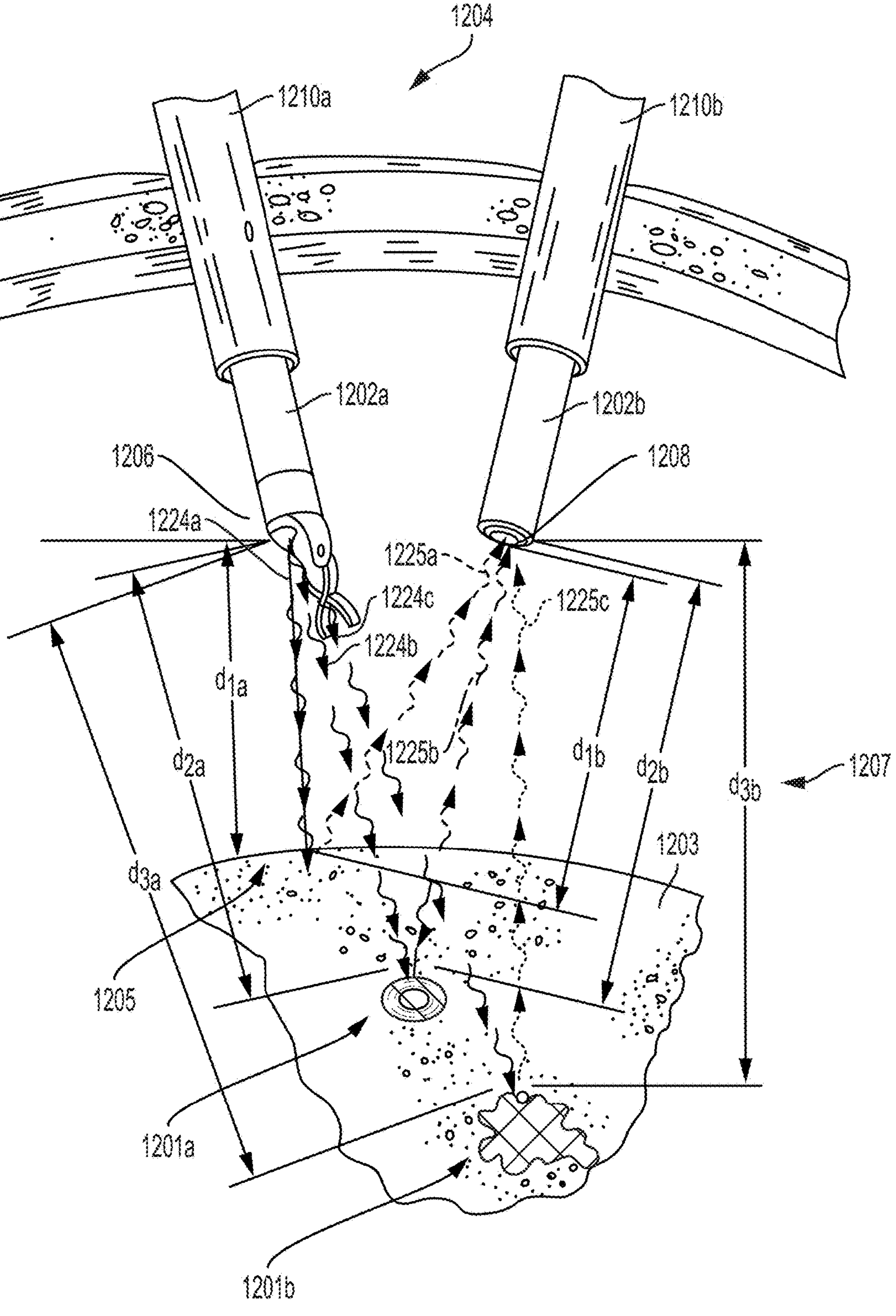

1204
1210a
1210b
1202a
1202b
1206
1208
1224a
1225a
1224c
1225c
1224b
d1a
1225b
d1b
d2a
d2b
d3b
1207
1203
d3a
1205
1201a
1201b

FIG. 21

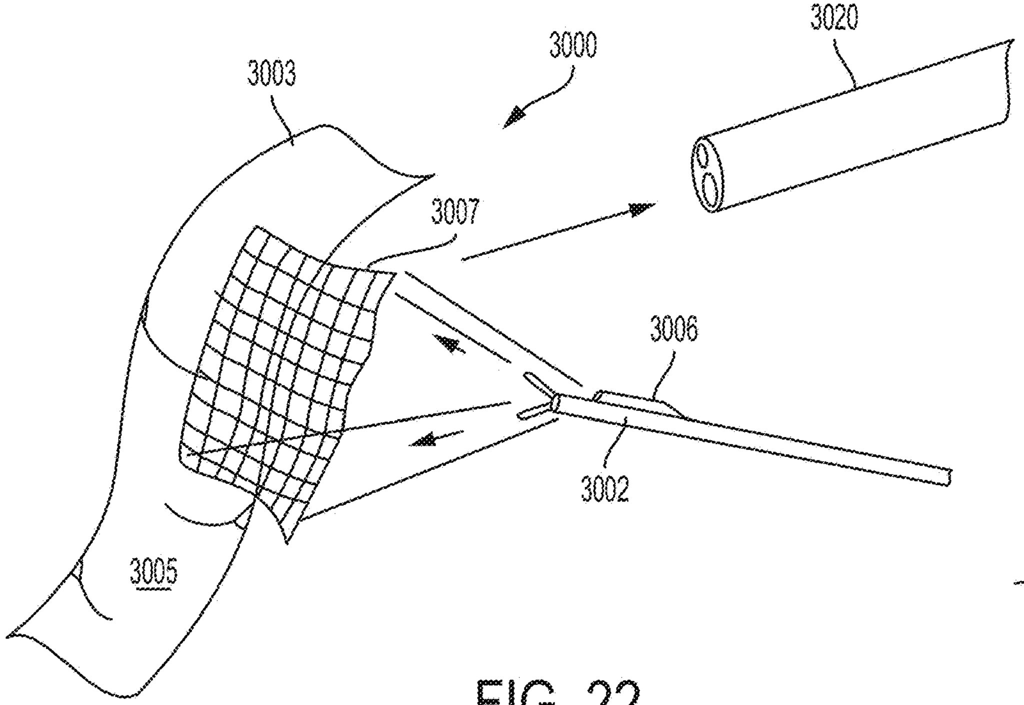

3000
3020
3003
3007
3006
3002
3005

FIG. 22

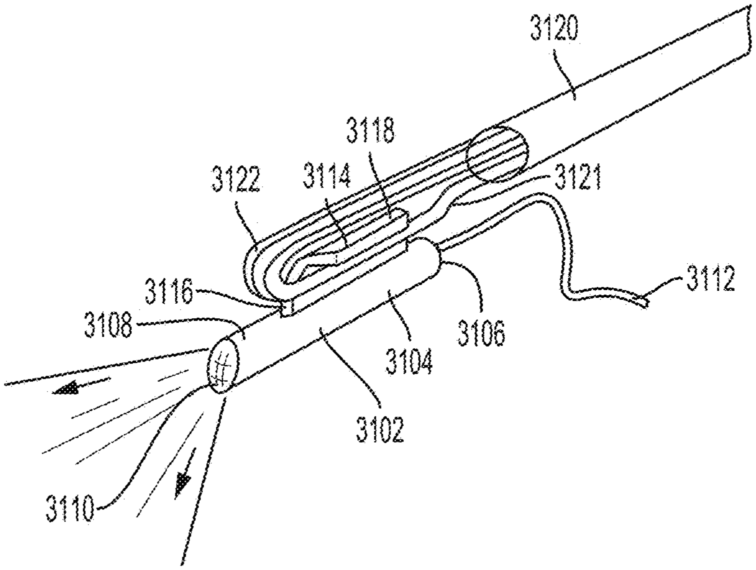

3120
3118
3122
3114
3121
3116
3112
3108
3106
3104
3102
3110

FIG. 23

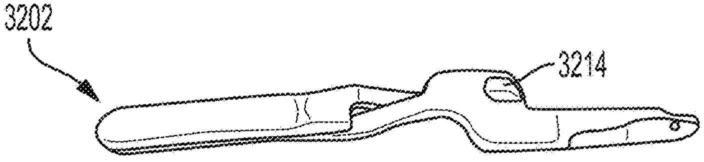


FIG. 24

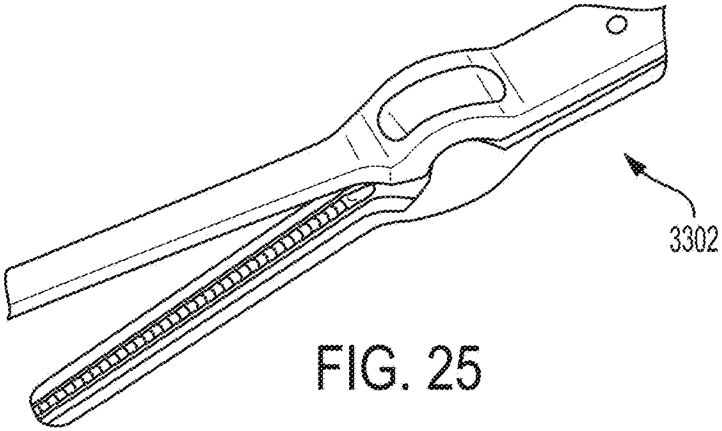


FIG. 25

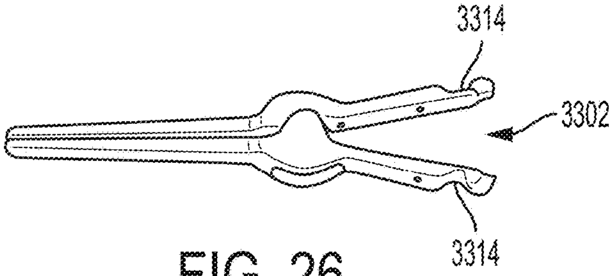


FIG. 26

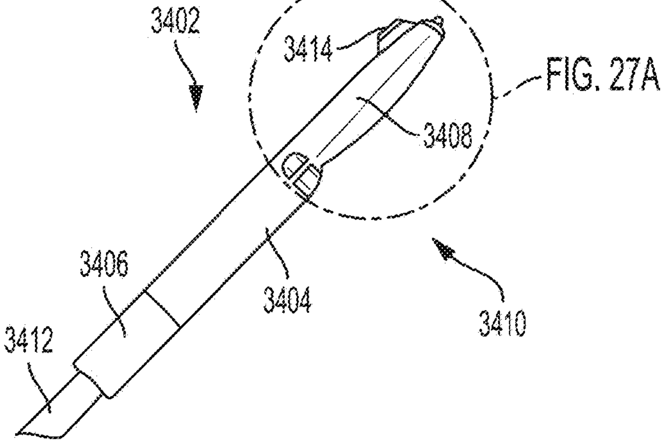


FIG. 27

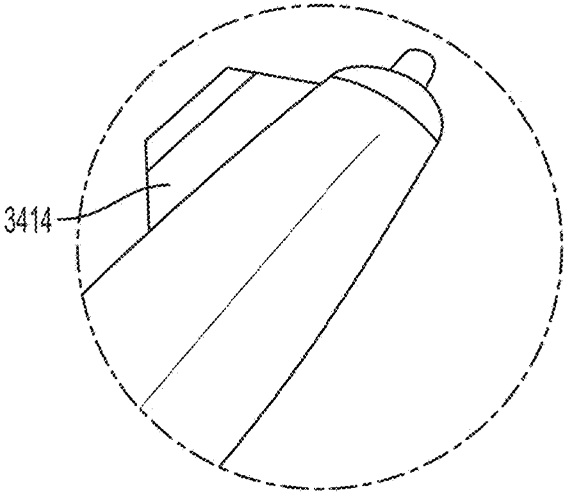


FIG. 27A

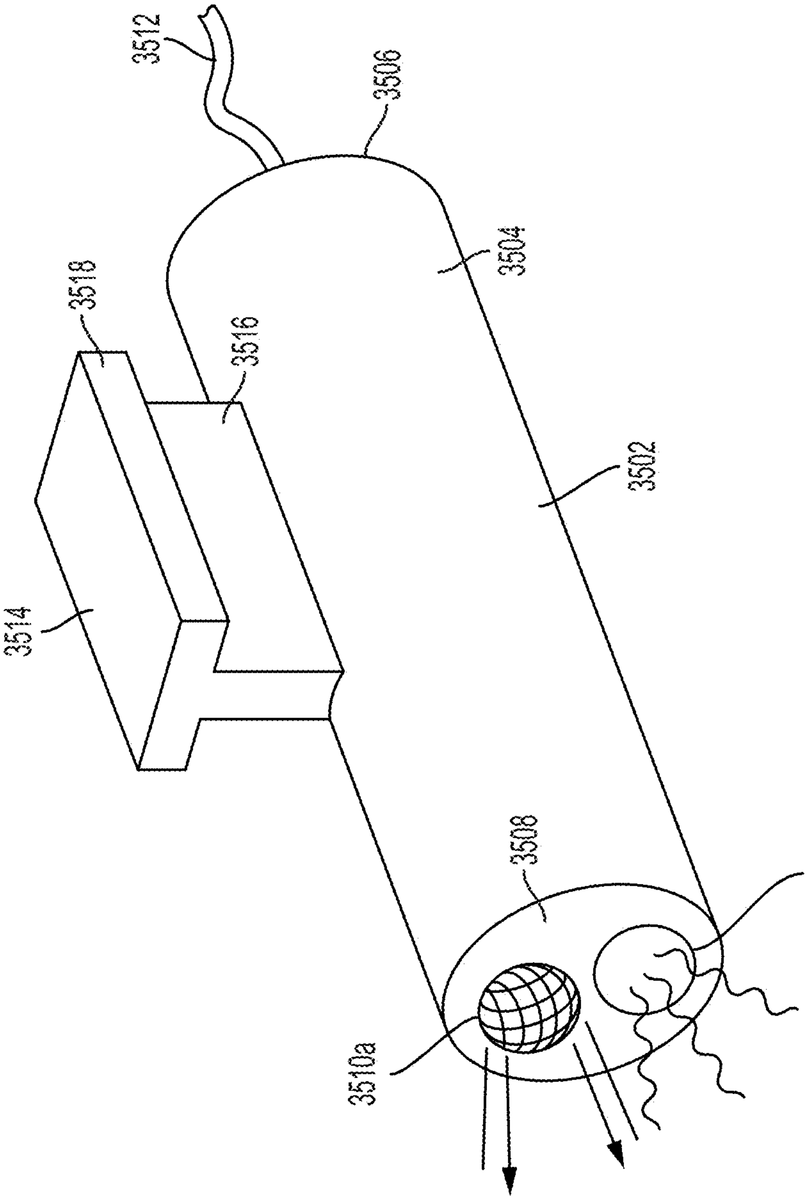


FIG. 28

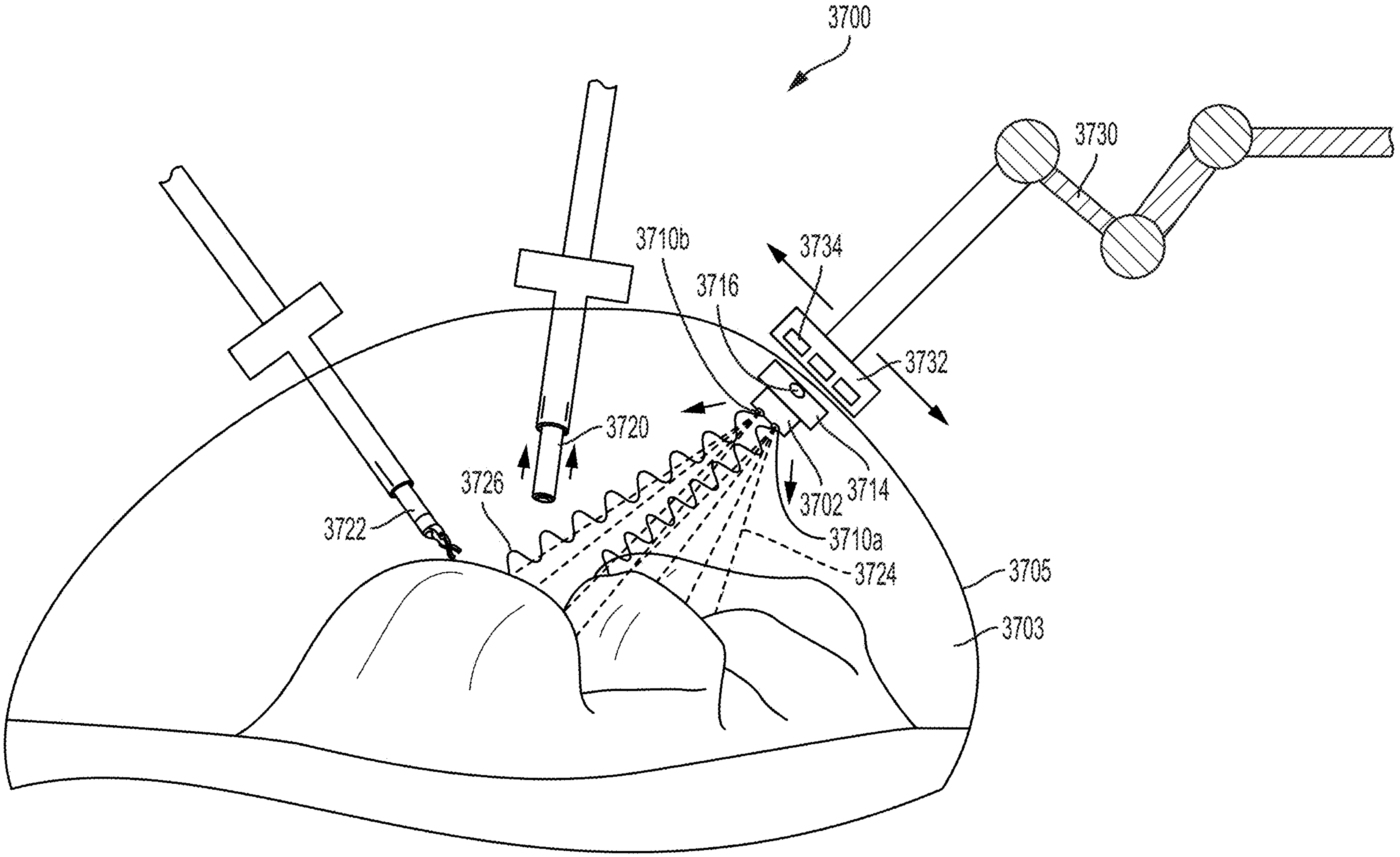

3700
3730
3734
3710b
3716
3732
3720
3726
3722
3702
3714
3710a
3724
3705
3703

FIG. 29

ROBOTIC LIGHT PROJECTION TOOLS

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of priority under 35 U.S.C. § 119(e) to U.S. Provisional Patent Application Ser. No. 62/698,625, titled DIGITAL SURGERY IMAGING/VISUALIZATION SYSTEM, filed Jul. 16, 2018, the disclosure of which is herein incorporated by reference in its entirety.

BACKGROUND

[0002] Surgical systems often incorporate an imaging system, which can allow the clinician(s) to view the surgical site and/or one or more portions thereof on one or more displays such as a monitor, for example. The display(s) can be local and/or remote to a surgical theater. An imaging system can include a scope with a camera that views the surgical site and transmits the view to a display that is viewable by a clinician. Scopes include, but are not limited to, arthroscopes, angioscopes, bronchoscopes, choledochoscopes, colonoscopes, cytoscopes, duodenoscopes, enteroscopes, esophagogastro-duodenoscopes (gastroscopes), endoscopes, laryngoscopes, nasopharyngo-neproscopes, sigmoidoscopes, thoracoscopes, ureteroscopes, and exoscopes. Imaging systems can be limited by the information that they are able to recognize and/or convey to the clinician(s). For example, certain concealed structures, physical contours, and/or dimensions within a three-dimensional space may be unrecognizable intraoperatively by certain imaging systems. Additionally, certain imaging systems may be incapable of communicating and/or conveying certain information to the clinician(s) intraoperatively.

SUMMARY

[0003] A robotic surgical system can comprise a structured light source, a shaft-less tool comprising a projector configured to emit a structured light pattern on a surface of an anatomical structure, and a cable extending from the shaft-less tool to the structured light source.

[0004] A robotic surgical tool can comprise a structured light source and a body comprising a distal end comprising a projector configured to emit a structured light pattern, a proximal end, and a projection extending from the body. The robotic surgical tool can further comprise a cable extending from the proximal end to the structured light source.

[0005] A shaft-less robotic tool can comprise a proximal component comprising a first magnet. The shaft-less robotic tool can further comprise a distal component comprising a second magnet, wherein a magnetic attraction between the first magnet and the second magnet allows the proximal component to maneuver the distal component through tissue. The second component can further comprise a first projector configured to emit a structured light pattern on a surface of an anatomical structure and a second projector configured to emit spectral light in a plurality of wavelengths capable of penetrating the anatomical structure and reaching an embedded structure located below the surface of the anatomical structure.

FIGURES

[0006] The novel features of the various aspects are set forth with particularity in the appended claims. The described aspects, however, both as to organization and methods of operation, may be best understood by reference to the following description, taken in conjunction with the accompanying drawings in which:

[0007] FIG. **1** is a schematic of a surgical visualization system including an imaging device and a surgical device, the surgical visualization system configured to identify a critical structure below a tissue surface, according to at least one aspect of the present disclosure.

[0008] FIG. **2** is a schematic of a control system for a surgical visualization system, according to at least one aspect of the present disclosure.

[0009] FIG. **2**A illustrates a control circuit configured to control aspects of a surgical visualization system, according to at least one aspect of the present disclosure.

[0010] FIG. **2**B illustrates a combinational logic circuit configured to control aspects of a surgical visualization system, according to at least one aspect of the present disclosure.

[0011] FIG. **2**C illustrates a sequential logic circuit configured to control aspects of a surgical visualization system, according to at least one aspect of the present disclosure.

[0012] FIG. **3** is a schematic depicting triangularization between the surgical device, the imaging device, and the critical structure of FIG. **1** to determine a depth d_A of the critical structure below the tissue surface, according to at least one aspect of the present disclosure.

[0013] FIG. **4** is a schematic of a surgical visualization system configured to identify a critical structure below a tissue surface, wherein the surgical visualization system includes a pulsed light source for determining a depth d_A of the critical structure below the tissue surface, according to at least one aspect of the present disclosure.

[0014] FIG. **5** is a schematic of a surgical visualization system including an imaging device and a surgical device, the surgical visualization system configured to identify a critical structure below a tissue surface, according to at least one aspect of the present disclosure.

[0015] FIG. **6** is a schematic of a surgical visualization system including a three-dimensional camera, wherein the surgical visualization system is configured to identify a critical structure that is embedded within tissue, according to at least one aspect of the present disclosure.

[0016] FIGS. **7**A and **7**B are views of the critical structure taken by the three-dimensional camera of FIG. **6**, in which FIG. **7**A is a view from a left-side lens of the three-dimensional camera and FIG. **7**B is a view from a right-side lens of the three-dimensional camera, according to at least one aspect of the present disclosure.

[0017] FIG. **8** is a schematic of the surgical visualization system of FIG. **6**, in which a camera-to-critical structure distance d_w from the three-dimensional camera to the critical structure can be determined, according to at least one aspect of the present disclosure.

[0018] FIG. **9** is a schematic of a surgical visualization system utilizing two cameras to determine the position of an embedded critical structure, according to at least one aspect of the present disclosure.

[0019] FIG. **10**A is a schematic of a surgical visualization system utilizing a camera that is moved axially between a plurality of known positions to determine a position of an embedded critical structure, according to at least one aspect of the present disclosure.

[0020] FIG. **10**B is a schematic of the surgical visualization system of FIG. **10**A, in which the camera is moved axially and rotationally between a plurality of known positions to determine a position of the embedded critical structure, according to at least one aspect of the present disclosure.

[0021] FIG. **11** is a schematic of a control system for a surgical visualization system, according to at least one aspect of the present disclosure.

[0022] FIG. **12** is a schematic of a structured light source for a surgical visualization system, according to at least one aspect of the present disclosure.

[0023] FIG. **13** is a schematic of a hyperspectral visualization system for imaging terrestrial features or objects, according to at least one aspect of the present disclosure.

[0024] FIG. **14** is a graphical representation of hyperspectral signatures for various terrestrial features or objects, according to at least one aspect of the present disclosure.

[0025] FIGS. **15**A-**15**C show an example of a hyperspectral visualization system for imaging a fried egg, wherein FIG. **15**A is a photograph of the fried egg, FIG. **15**B is a graphical representation of hyperspectral signatures for an egg yolk portion and an egg white portion of the fried egg, and FIG. **15**C is a hyperspectral image (shown in black-and-white) of the fried egg, in which an augmented image differentiates between the egg yolk portion and the egg white portion based on hyperspectral signature data, according to at least one aspect of the present disclosure.

[0026] FIGS. **16**-**18** depict illustrative hyperspectral identifying signatures to differentiate anatomy from obscurants, wherein FIG. **16** is a graphical representation of a ureter signature versus obscurants, FIG. **17** is a graphical representation of an artery signature versus obscurants, and FIG. **18** is a graphical representation of a nerve signature versus obscurants, according to at least one aspect of the present disclosure.

[0027] FIG. **19** is a schematic of a near infrared (NIR) time-of-flight measurement system configured to sense distance to a critical anatomical structure, the time-of-flight measurement system including a transmitter (emitter) and a receiver (sensor) positioned on a common device, according to at least one aspect of the present disclosure.

[0028] FIG. **20** is a schematic of an emitted wave, a received wave, and a delay between the emitted wave and the received wave of the NIR time-of-flight measurement system of FIG. **19**, according to at least one aspect of the present disclosure.

[0029] FIG. **21** illustrates a NIR time-of-flight measurement system configured to sense a distance to different structures, the time-of-flight measurement system including a transmitter (emitter) and a receiver (sensor) on separate devices, according to one aspect of the present disclosure.

[0030] FIG. **22** is a schematic of a robotic tool including a light projector emitting a structured light pattern on a surface of an anatomical structure, according to at least one aspect of the present disclosure.

[0031] FIG. **23** is a perspective view of a robotic grasper and a light projection probe being grasped between jaws of the robotic grasper, wherein the light projection probe is emitting a structured light pattern, according to at least one aspect of the present disclosure.

[0032] FIG. **24** is a plan view of a bulldog clamp having a projection for grasping with a robotic grasper, according to at least one aspect of the present disclosure.

[0033] FIG. **25** is a perspective view of a distal portion of a bulldog clamp, according to at least one aspect of the present disclosure.

[0034] FIG. **26** is an elevation view of the bulldog clamp of FIG. **25** depicting proximal grooves for end-on docking with a robotic tool, according to at least one aspect of the present disclosure.

[0035] FIG. **27** is a perspective view of an ultrasound probe and a portion of a wire protruding therefrom, according to at least one aspect of the present disclosure.

[0036] FIG. **27**A is a close-up view of a distal portion of the ultrasound probe of FIG. **27** depicting a protruding tab for engagement with jaws of a robotic grasper, according to at least one aspect of the present disclosure.

[0037] FIG. **28** is a perspective view of a light projection probe including a projecting grasper pin for engagement with jaws of a robotic grasper, depicting a first projector emitting a structured light pattern and a second projector emitting spectral light waves capable of penetrating anatomical structure and reaching an embedded structure located below the surface of the anatomical structure, according to at least one aspect of the present disclosure.

[0038] FIG. **29** is a schematic of a surgical visualization system including a camera, a surgical device, and a light projection probe including a magnetic attachment portion, according to at least one aspect of the present disclosure.

DESCRIPTION

[0039] Applicant of the present application also owns the following U.S. Patent Applications, filed on Sep. 11, 2018, each of which is herein incorporated by reference in its entirety:

- **[0040]** U.S. patent application Ser. No. ______, titled SURGICAL VISUALIZATION PLATFORM, Attorney Docket No. END8605USNP/180230;
- **[0041]** U.S. patent application Ser. No. ______, titled SURGICAL VISUALIZATION CONTROLS, Attorney Docket No. END8605USNP1/180230-1;
- **[0042]** U.S. patent application Ser. No. ______, titled CONTROLLING AN EMITTER ASSEMBLY PULSE SEQUENCE, Attorney Docket No. END8606USNP/180231;
- **[0043]** U.S. patent application Ser. No. ______, titled COMBINATION EMITTER AND CAMERA ASSEMBLY, Attorney Docket No. END8606USNP1/180231-1;
- **[0044]** U.S. patent application Ser. No. ______, titled SINGULAR EMR SOURCE WITH DUAL OUTPUT EMITTER ASSEMBLY, Attorney Docket No. END8606USNP2/180231-2;
- **[0045]** U.S. patent application Ser. No. ______, titled SURGICAL VISUALIZATION WITH PROXIMITY TRACKING FEATURES, Attorney Docket No. END8607USNP/180232;
- **[0046]** U.S. patent application Ser. No. ______, titled SURGICAL VISUALIZATION OF MULTIPLE TARGETS, Attorney Docket No. END8607USNP1/180232-1;
- **[0047]** U.S. patent application Ser. No. ______, titled VISUALIZATION OF SURGICAL DEVICES, Attorney Docket No. END8607USNP2/180232-2;
- **[0048]** U.S. patent application Ser. No. ______, titled OPERATIVE COMMUNICATION OF LIGHT, Attorney Docket No. END8608USNP/180233;

[0049] U.S. patent application Ser. No. ______, titled SURGICAL VISUALIZATION FEEDBACK SYSTEM, Attorney Docket No. END8610USNP/180235;

[0050] U.S. patent application Ser. No. ______, titled SURGICAL VISUALIZATION AND MONITORING, Attorney Docket No. END8611USNP/180236;

[0051] U.S. patent application Ser. No. ______, titled INTEGRATION OF IMAGING DATA, Attorney Docket No. END8612USNP/180237;

[0052] U.S. patent application Ser. No. ______, titled ROBOTICALLY-ASSISTED SURGICAL SUTURING SYSTEMS, Attorney Docket No. END**8613**USNP/**180238**;

[0053] U.S. patent application Ser. No. ______, titled SAFETY LOGIC FOR SURGICAL SUTURING SYSTEMS, Attorney Docket No. END8613USNP1/180238-1;

[0054] U.S. patent application Ser. No. ______, titled ROBOTIC SYSTEM WITH SEPARATE PHOTOACOUSTIC RECEIVER, Attorney Docket No. END8614USNP/180239; and

[0055] U.S. patent application Ser. No. ______ , titled FORCE SENSOR THROUGH STRUCTURED LIGHT DEFLECTION, Attorney Docket No. END8615USNP/180240.

[0056] Applicant of the present application also owns U.S. Pat. No. 9,072,535, titled SURGICAL STAPLING INSTRUMENTS WITH ROTATABLE STAPLE DEPLOYMENT ARRANGEMENTS, issued Jul. 7, 2015, which is incorporated by reference herein in its entirety.

[0057] Applicant of the present application also owns U.S. Provisional Patent Application No. 62/611,339, titled ROBOT ASSISTED SURGICAL PLATFORM, filed Dec. 28, 2017, which is incorporated by reference herein in its entirety.

[0058] Applicant of the present application also owns the following U.S. Patent Applications, filed on Mar. 29, 2018, each of which is herein incorporated by reference in its entirety:

[0059] U.S. patent application Ser. No. 15/940,627, titled DRIVE ARRANGEMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS;

[0060] U.S. patent application Ser. No. 15/940,676, titled AUTOMATIC TOOL ADJUSTMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS;

[0061] U.S. patent application Ser. No. 15/940,711, titled SENSING ARRANGEMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS; and

[0062] U.S. patent application Ser. No. 15/940,722, titled CHARACTERIZATION OF TISSUE IRREGULARITIES THROUGH THE USE OF MONO-CHROMATIC LIGHT REFRACTIVITY, filed Mar. 29, 2018, which is incorporated by reference herein in its entirety.

[0063] Before explaining various aspects of a surgical visualization platform in detail, it should be noted that the illustrative examples are not limited in application or use to the details of construction and arrangement of parts illustrated in the accompanying drawings and description. The illustrative examples may be implemented or incorporated in other aspects, variations, and modifications, and may be practiced or carried out in various ways. Further, unless otherwise indicated, the terms and expressions employed herein have been chosen for the purpose of describing the illustrative examples for the convenience of the reader and are not for the purpose of limitation thereof. Also, it will be appreciated that one or more of the following-described aspects, expressions of aspects, and/or examples, can be combined with any one or more of the other following-described aspects, expressions of aspects, and/or examples.

[0064] The present disclosure is directed to a surgical visualization platform that leverages "digital surgery" to obtain additional information about a patient's anatomy and/or a surgical procedure. The surgical visualization platform is further configured to convey data and/or information to one or more clinicians in a helpful manner. For example, various aspects of the present disclosure provide improved visualization of the patient's anatomy and/or the surgical procedure.

[0065] "Digital surgery" can embrace robotic systems, advanced imaging, advanced instrumentation, artificial intelligence, machine learning, data analytics for performance tracking and benchmarking, connectivity both inside and outside of the operating room (OR), and more. Although various surgical visualization platforms described herein can be used in combination with a robotic surgical system, surgical visualization platforms are not limited to use with a robotic surgical system. In certain instances, advanced surgical visualization can occur without robotics and/or with limited and/or optional robotic assistance. Similarly, digital surgery can occur without robotics and/or with limited and/or optional robotic assistance.

[0066] In certain instances, a surgical system that incorporates a surgical visualization platform may enable smart dissection in order to identify and avoid critical structures. Critical structures include anatomical structures such as a ureter, an artery such as a superior mesenteric artery, a vein such as a portal vein, a nerve such as a phrenic nerve, and/or a tumor, among other anatomical structures. In other instances, a critical structure can be a foreign structure in the anatomical field, such as a surgical device, surgical fastener, clip, tack, bougie, band, and/or plate, for example. Critical structures can be determined on a patient-by-patient and/or a procedure-by-procedure basis. Example critical structures are further described herein. Smart dissection technology may provide improved intraoperative guidance for dissection and/or can enable smarter decisions with critical anatomy detection and avoidance technology, for example.

[0067] A surgical system incorporating a surgical visualization platform may also enable smart anastomosis technologies that provide more consistent anastomoses at optimal location(s) with improved workflow. Cancer localization technologies may also be improved with the various surgical visualization platforms and procedures described herein. For example, cancer localization technologies can identify and track a cancer location, orientation, and its margins. In certain instances, the cancer localizations technologies may compensate for movement of a tool, a patient, and/or the patient's anatomy during a surgical procedure in order to provide guidance back to the point of interest for the clinician.

[0068] In certain aspects of the present disclosure, a surgical visualization platform may provide improved tissue characterization and/or lymph node diagnostics and mapping. For example, tissue characterization technologies may characterize tissue type and health without the need for physical haptics, especially when dissecting and/or placing stapling devices within the tissue. Certain tissue characterization technologies described herein may be utilized without ionizing radiation and/or contrast agents. With respect to lymph node diagnostics and mapping, a surgical visualization platform may preoperatively locate, map, and ideally diagnose the lymph system and/or lymph nodes involved in cancerous diagnosis and staging, for example.

[0069] These and other related topics are described herein and/or in the aforementioned contemporaneously-filed U.S. Patent Applications, which are incorporated by reference herein in their respective entireties.

[0070] During a surgical procedure, the information available to the clinician via the "naked eye" and/or an imaging system may provide an incomplete view of the surgical site. For example, certain structures, such as structures embedded or buried within an organ, can be at least partially concealed or hidden from view. Additionally, certain dimensions and/or relative distances can be difficult to ascertain with existing sensor systems and/or difficult for the "naked eye" to perceive. Moreover, certain structures can move preoperatively (e.g. before a surgical procedure but after a preoperative scan) and/or intraoperatively. In such instances, the clinician can be unable to accurately determine the location of a critical structure intraoperatively.

[0071] When the position of a critical structure is uncertain and/or when the proximity between the critical structure and a surgical tool is unknown, a clinician's decision-making process can be inhibited. For example, a clinician may avoid certain areas in order to avoid inadvertent dissection of a critical structure; however, the avoided area may be unnecessarily large and/or at least partially misplaced. Due to uncertainty and/or overly/excessive exercises in caution, the clinician may not access certain desired regions. For example, excess caution may cause a clinician to leave a portion of a tumor and/or other undesirable tissue in an effort to avoid a critical structure even if the critical structure is not in the particular area and/or would not be negatively impacted by the clinician working in that particular area. In certain instances, surgical results can be improved with increased knowledge and/or certainty, which can allow a surgeon to be more accurate and, in certain instances, less conservative/more aggressive with respect to particular anatomical areas.

[0072] In various aspects, the present disclosure provides a surgical visualization system for intraoperative identification and avoidance of critical structures. In one aspect, the present disclosure provides a surgical visualization system that enables enhanced intraoperative decision making and improved surgical outcomes. In various aspects, the disclosed surgical visualization system provides advanced visualization capabilities beyond what a clinician sees with the "naked eye" and/or beyond what an imaging system can recognize and/or convey to the clinician. The various surgical visualization systems can augment and enhance what a clinician is able to know prior to tissue treatment (e.g. dissection) and, thus, may improve outcomes in various instances.

[0073] For example, a visualization system can include a first light emitter configured to emit a plurality of spectral waves, a second light emitter configured to emit a light pattern, and one or more receivers, or sensors, configured to detect visible light, molecular responses to the spectral waves (spectral imaging), and/or the light pattern. The surgical visualization system can also include an imaging system and a control circuit in signal communication with the receiver(s) and the imaging system. Based on output from the receiver(s), the control circuit can determine a geometric surface map, i.e. three-dimensional surface topography, of the visible surfaces at the surgical site and one or more distances with respect to the surgical site. In certain instances, the control circuit can determine one more distances to an at least partially concealed structure. Moreover, the imaging system can convey the geometric surface map and the one or more distances to a clinician. In such instances, an augmented view of the surgical site provided to the clinician can provide a representation of the concealed structure within the relevant context of the surgical site. For example, the imaging system can virtually augment the concealed structure on the geometric surface map of the concealing and/or obstructing tissue similar to a line drawn on the ground to indicate a utility line below the surface. Additionally or alternatively, the imaging system can convey the proximity of one or more surgical tools to the visible and obstructing tissue and/or to the at least partially concealed structure and/or the depth of the concealed structure below the visible surface of the obstructing tissue. For example, the visualization system can determine a distance with respect to the augmented line on the surface of the visible tissue and convey the distance to the imaging system.

[0074] In various aspects of the present disclosure, a surgical visualization system is disclosed for intraoperative identification and avoidance of critical structures. Such a surgical visualization system can provide valuable information to a clinician during a surgical procedure. As a result, the clinician can confidently maintain momentum throughout the surgical procedure knowing that the surgical visualization system is tracking a critical structure such as a ureter, specific nerves, and/or critical blood vessels, for example, which may be approached during dissection, for example. In one aspect, the surgical visualization system can provide an indication to the clinician in sufficient time for the clinician to pause and/or slow down the surgical procedure and evaluate the proximity to the critical structure to prevent inadvertent damage thereto. The surgical visualization system can provide an ideal, optimized, and/or customizable amount of information to the clinician to allow the clinician to move confidently and/or quickly through tissue while avoiding inadvertent damage to healthy tissue and/or critical structure(s) and, thus, to minimize the risk of harm resulting from the surgical procedure.

[0075] FIG. **1** is a schematic of a surgical visualization system **100** according to at least one aspect of the present disclosure. The surgical visualization system **100** can create a visual representation of a critical structure **101** within an anatomical field. The surgical visualization system **100** can be used for clinical analysis and/or medical intervention, for example. In certain instances, the surgical visualization system **100** can be used intraoperatively to provide real-time, or near real-time, information to the clinician regarding proximity data, dimensions, and/or distances during a surgical procedure. The surgical visualization system **100** is configured for intraoperative identification of critical structure(s) and/or to facilitate the avoidance of the critical structure(s) **101** by a surgical device. For example, by identifying the critical structure **101**, a clinician can avoid maneuvering a surgical device around the critical structure **101** and/or a region in a predefined proximity of the critical structure **101** during a surgical procedure. The clinician can avoid dissection of and/or near a vein, artery, nerve, and/or vessel, for example, identified as the critical structure **101**, for example. In various instances, the critical structure **101** can be determined on a patient-by-patient and/or a procedure-by-procedure basis.

[0076] The surgical visualization system **100** incorporates tissue identification and geometric surface mapping in combination with a distance sensor system **104**. In combination, these features of the surgical visualization system **100** can determine a position of a critical structure **101** within the anatomical field and/or the proximity of a surgical device **102** to the surface **105** of the visible tissue and/or to the critical structure **101**. Moreover, the surgical visualization system **100** includes an imaging system that includes an imaging device **120**, such as a camera, for example, configured to provide real-time views of the surgical site. In various instances, the imaging device **120** is a spectral camera (e.g. a hyperspectral camera, multispectral camera, or selective spectral camera), which is configured to detect reflected spectral waveforms and generate a spectral cube of images based on the molecular response to the different wavelengths. Views from the imaging device **120** can be provided to a clinician and, in various aspects of the present disclosure, can be augmented with additional information based on the tissue identification, landscape mapping, and the distance sensor system **104**. In such instances, the surgical visualization system **100** includes a plurality of subsystems—an imaging subsystem, a surface mapping subsystem, a tissue identification subsystem, and/or a distance determining subsystem. These subsystems can cooperate to intraoperatively provide advanced data synthesis and integrated information to the clinician(s).

[0077] The imaging device can include a camera or imaging sensor that is configured to detect visible light, spectral light waves (visible or invisible), and a structured light pattern (visible or invisible), for example. In various aspects of the present disclosure, the imaging system can include an imaging device such as an endoscope, for example. Additionally or alternatively, the imaging system can include an imaging device such as an arthroscope, angioscope, bronchoscope, choledochoscope, colonoscope, cytoscope, duodenoscope, enteroscope, esophagogastro-duodenoscope (gastroscope), laryngoscope, nasopharyngo-neproscope, sigmoidoscope, thoracoscope, ureteroscope, or exoscope, for example. In other instances, such as in open surgery applications, the imaging system may not include a scope.

[0078] In various aspects of the present disclosure, the tissue identification subsystem can be achieved with a spectral imaging system. The spectral imaging system can rely on hyperspectral imaging, multispectral imaging, or selective spectral imaging, for example. Hyperspectral imaging of tissue is further described in U.S. Pat. No. 9,274,047, titled SYSTEM AND METHOD FOR GROSS ANATOMIC PATHOLOGY USING HYPERSPECTRAL IMAGING, issued Mar. 1, 2016, which is incorporated by reference herein in its entirety.

[0079] In various aspect of the present disclosure, the surface mapping subsystem can be achieved with a light pattern system, as further described herein. The use of a light pattern (or structured light) for surface mapping is known. Known surface mapping techniques can be utilized in the surgical visualization systems described herein.

[0080] Structured light is the process of projecting a known pattern (often a grid or horizontal bars) on to a surface. U.S. Patent Application Publication No. 2017/0055819, titled SET COMPRISING A SURGICAL INSTRUMENT, published Mar. 2, 2017, and U.S. Patent Application Publication No. 2017/0251900, titled DEPICTION SYSTEM, published Sep. 7, 2017, disclose a surgical system comprising a light source and a projector for projecting a light pattern. U.S. Patent Application Publication No. 2017/0055819, titled SET COMPRISING A SURGICAL INSTRUMENT, published Mar. 2, 2017, and U.S. Patent Application Publication No. 2017/0251900, titled DEPICTION SYSTEM, published Sep. 7, 2017, are incorporated by reference herein in their respective entireties.

[0081] In various aspects of the present disclosure, the distance determining system can be incorporated into the surface mapping system. For example, structured light can be utilized to generate a three-dimensional virtual model of the visible surface and determine various distances with respect to the visible surface. Additionally or alternatively, the distance determining system can rely on time-of-flight measurements to determine one or more distances to the identified tissue (or other structures) at the surgical site.

[0082] FIG. **2** is a schematic diagram of a control system **133**, which can be utilized with the surgical visualization system **100**. The control system **133** includes a control circuit **132** in signal communication with a memory **134**. The memory **134** stores instructions executable by the control circuit **132** to determine and/or recognize critical structures (e.g. the critical structure **101** in FIG. **1**), determine and/or compute one or more distances and/or three-dimensional digital representations, and to communicate certain information to one or more clinicians. For example, the memory **134** stores surface mapping logic **136**, imaging logic **138**, tissue identification logic **140**, or distance determining logic **141** or any combinations of the logic **136**, **138**, **140**, and **141**. The control system **133** also includes an imaging system **142** having one or more cameras **144** (like the imaging device **120** in FIG. **1**), one or more displays **146**, or one or more controls **148** or any combinations of these elements. The camera **144** can include one or more image sensors **135** to receive signals from various light sources emitting light at various visible and invisible spectra (e.g. visible light, spectral imagers, three-dimensional lens, among others). The display **146** can include one or more screens or monitors for depicting real, virtual, and/or virtually-augmented images and/or information to one or more clinicians.

[0083] In various aspects, the heart of the camera **144** is the image sensor **135**. Generally, modern image sensors **135** are solid-state electronic devices containing up to millions of discrete photodetector sites called pixels. The image sensor **135** technology falls into one of two categories: Charge-Coupled Device (CCD) and Complementary Metal Oxide Semiconductor (CMOS) imagers and more recently, short-wave infrared (SWIR) is an emerging technology in imaging. Another type of image sensor **135** employs a hybrid CCD/CMOS architecture (sold under the name "sCMOS") and consists of CMOS readout integrated circuits (ROICs) that are bump bonded to a CCD imaging substrate. CCD and CMOS image sensors **135** are sensitive to wavelengths from approximately 350-1050 nm, although the range is usually given from 400-1000 nm. CMOS sensors are, in general, more sensitive to IR wavelengths than CCD sensors. Solid state image sensors **135** are based on the photoelectric effect and, as a result, cannot distinguish between colors. Accordingly, there are two types of color CCD cameras: single chip and three-chip. Single chip color CCD cameras offer a common, low-cost imaging solution and use a mosaic (e.g. Bayer) optical filter to separate incoming light into a series of colors and employ an interpolation algorithm to resolve full color images. Each color is, then, directed to a different set of pixels. Three-chip color CCD cameras provide higher resolution by employing a prism to direct each section of the incident spectrum to a different chip. More accurate color reproduction is possible, as each point in space of the object has separate RGB intensity values, rather than using an algorithm to determine the color. Three-chip cameras offer extremely high resolutions.

[0084] The control system **133** also includes a spectral light source **150** and a structured light source **152**. In certain instances, a single source can be pulsed to emit wavelengths of light in the spectral light source **150** range and wavelengths of light in the structured light source **152** range. Alternatively, a single light source can be pulsed to provide light in the invisible spectrum (e.g. infrared spectral light) and wavelengths of light on the visible spectrum. The spectral light source **150** can be a hyperspectral light source, a multispectral light source, and/or a selective spectral light source, for example. In various instances, the tissue identification logic **140** can identify critical structure(s) via data from the spectral light source **150** received by the image sensor **135** portion of the camera **144**. The surface mapping logic **136** can determine the surface contours of the visible tissue based on reflected structured light. With time-of-flight measurements, the distance determining logic **141** can determine one or more distance(s) to the visible tissue and/or the critical structure **101**. One or more outputs from the surface mapping logic **136**, the tissue identification logic **140**, and the distance determining logic **141**, can be provided to the imaging logic **138**, and combined, blended, and/or overlaid to be conveyed to a clinician via the display **146** of the imaging system **142**.

[0085] The description now turns briefly to FIGS. **2A-2C** to describe various aspects of the control circuit **132** for controlling various aspects of the surgical visualization system **100**. Turning to FIG. **2A**, there is illustrated a control circuit **400** configured to control aspects of the surgical visualization system **100**, according to at least one aspect of this disclosure. The control circuit **400** can be configured to implement various processes described herein. The control circuit **400** may comprise a microcontroller comprising one or more processors **402** (e.g., microprocessor, microcontroller) coupled to at least one memory circuit **404**. The memory circuit **404** stores machine-executable instructions that, when executed by the processor **402**, cause the processor **402** to execute machine instructions to implement various processes described herein. The processor **402** may be any one of a number of single-core or multicore processors known in the art. The memory circuit **404** may comprise volatile and non-volatile storage media. The processor **402** may include an instruction processing unit **406** and an arithmetic unit **408**. The instruction processing unit may be configured to receive instructions from the memory circuit **404** of this disclosure.

[0086] FIG. **2B** illustrates a combinational logic circuit **410** configured to control aspects of the surgical visualization system **100**, according to at least one aspect of this disclosure. The combinational logic circuit **410** can be configured to implement various processes described herein. The combinational logic circuit **410** may comprise a finite state machine comprising a combinational logic **412** configured to receive data associated with the surgical instrument or tool at an input **414**, process the data by the combinational logic **412**, and provide an output **416**.

[0087] FIG. **2C** illustrates a sequential logic circuit **420** configured to control aspects of the surgical visualization system **100**, according to at least one aspect of this disclosure. The sequential logic circuit **420** or the combinational logic **422** can be configured to implement various processes described herein. The sequential logic circuit **420** may comprise a finite state machine. The sequential logic circuit **420** may comprise a combinational logic **422**, at least one memory circuit **424**, and a clock **429**, for example. The at least one memory circuit **424** can store a current state of the finite state machine. In certain instances, the sequential logic circuit **420** may be synchronous or asynchronous. The combinational logic **422** is configured to receive data associated with a surgical device or system from an input **426**, process the data by the combinational logic **422**, and provide an output **428**. In other aspects, the circuit may comprise a combination of a processor (e.g., processor **402** in FIG. **2A**) and a finite state machine to implement various processes herein. In other aspects, the finite state machine may comprise a combination of a combinational logic circuit (e.g., combinational logic circuit **410**, FIG. **2B**) and the sequential logic circuit **420**.

[0088] Referring again to the surgical visualization system **100** in FIG. **1**, the critical structure **101** can be an anatomical structure of interest. For example, the critical structure **101** can be a ureter, an artery such as a superior mesenteric artery, a vein such as a portal vein, a nerve such as a phrenic nerve, and/or a tumor, among other anatomical structures. In other instances, the critical structure **101** can be a foreign structure in the anatomical field, such as a surgical device, surgical fastener, clip, tack, bougie, band, and/or plate, for example. Example critical structures are further described herein and in the aforementioned contemporaneously-filed U.S. Patent Applications, including U.S. patent application Ser. No. ______, titled VISUALIZATION OF SURGICAL DEVICES, Attorney Docket No. END8607USNP2/180232-2, for example, which are incorporated by reference herein in their respective entireties.

[0089] In one aspect, the critical structure **101** may be embedded in tissue **103**. Stated differently, the critical structure **101** may be positioned below the surface **105** of the tissue **103**. In such instances, the tissue **103** conceals the critical structure **101** from the clinician's view. The critical structure **101** is also obscured from the view of the imaging device **120** by the tissue **103**. The tissue **103** can be fat, connective tissue, adhesions, and/or organs, for example. In other instances, the critical structure **101** can be partially obscured from view.

[0090] FIG. **1** also depicts the surgical device **102**. The surgical device **102** includes an end effector having opposing jaws extending from the distal end of the shaft of the surgical device **102**. The surgical device **102** can be any suitable surgical device such as, for example, a dissector, a stapler, a grasper, a clip applier, and/or an energy device including mono-polar probes, bi-polar probes, ablation probes, and/or an ultrasonic end effector. Additionally or alternatively, the surgical device **102** can include another imaging or diagnostic modality, such as an ultrasound device, for example. In one aspect of the present disclosure, the surgical visualization system **100** can be configured to achieve identification of one or more critical structures **101** and the proximity of the surgical device **102** to the critical structure(s) **101**.

[0091] The imaging device **120** of the surgical visualization system **100** is configured to detect light at various wavelengths, such as, for example, visible light, spectral light waves (visible or invisible), and a structured light pattern (visible or invisible). The imaging device **120** may include a plurality of lenses, sensors, and/or receivers for detecting the different signals. For example, the imaging device **120** can be a hyperspectral, multispectral, or selective spectral camera, as further described herein. The imaging device **120** can also include a waveform sensor **122** (such as a spectral image sensor, detector, and/or three-dimensional camera lens). For example, the imaging device **120** can include a right-side lens and a left-side lens used together to record two two-dimensional images at the same time and, thus, generate a three-dimensional image of the surgical site, render a three-dimensional image of the surgical site, and/or determine one or more distances at the surgical site. Additionally or alternatively, the imaging device **120** can be configured to receive images indicative of the topography of the visible tissue and the identification and position of hidden critical structures, as further described herein. For example, the field of view of the imaging device **120** can overlap with a pattern of light (structured light) on the surface **105** of the tissue, as shown in FIG. **1**.

[0092] In one aspect, the surgical visualization system **100** may be incorporated into a robotic system **110**. For example, the robotic system **110** may include a first robotic arm **112** and a second robotic arm **114**. The robotic arms **112**, **114** include rigid structural members **116** and joints **118**, which can include servomotor controls. The first robotic arm **112** is configured to maneuver the surgical device **102**, and the second robotic arm **114** is configured to maneuver the imaging device **120**. A robotic control unit can be configured to issue control motions to the robotic arms **112**, **114**, which can affect the surgical device **102** and the imaging device **120**, for example.

[0093] The surgical visualization system **100** also includes an emitter **106**, which is configured to emit a pattern of light, such as stripes, grid lines, and/or dots, to enable the determination of the topography or landscape of the surface **105**. For example, projected light arrays **130** can be used for three-dimensional scanning and registration on the surface **105**. The projected light arrays **130** can be emitted from the emitter **106** located on the surgical device **102** and/or one of the robotic arms **112**, **114** and/or the imaging device **120**, for example. In one aspect, the projected light array **130** is employed to determine the shape defined by the surface **105** of the tissue **103** and/or the motion of the surface **105** intraoperatively. The imaging device **120** is configured to detect the projected light arrays **130** reflected from the surface **105** to determine the topography of the surface **105** and various distances with respect to the surface **105**.

[0094] In one aspect, the imaging device **120** also may include an optical waveform emitter **123** that is configured to emit electromagnetic radiation **124** (NIR photons) that can penetrate the surface **105** of the tissue **103** and reach the critical structure **101**. The imaging device **120** and the optical waveform emitter **123** thereon can be positionable by the robotic arm **114**. A corresponding waveform sensor **122** (an image sensor, spectrometer, or vibrational sensor, for example) on the imaging device **120** is configured to detect the effect of the electromagnetic radiation received by the waveform sensor **122**. The wavelengths of the electromagnetic radiation **124** emitted by the optical waveform emitter **123** can be configured to enable the identification of the type of anatomical and/or physical structure, such as the critical structure **101**. The identification of the critical structure **101** can be accomplished through spectral analysis, photo-acoustics, and/or ultrasound, for example. In one aspect, the wavelengths of the electromagnetic radiation **124** may be variable. The waveform sensor **122** and optical waveform emitter **123** may be inclusive of a multispectral imaging system and/or a selective spectral imaging system, for example. In other instances, the waveform sensor **122** and optical waveform emitter **123** may be inclusive of a photoacoustic imaging system, for example. In other instances, the optical waveform emitter **123** can be positioned on a separate surgical device from the imaging device **120**.

[0095] The surgical visualization system **100** also may include the distance sensor system **104** configured to determine one or more distances at the surgical site. In one aspect, the time-of-flight distance sensor system **104** may be a time-of-flight distance sensor system that includes an emitter, such as the emitter **106**, and a receiver **108**, which can be positioned on the surgical device **102**. In other instances, the time-of-flight emitter can be separate from the structured light emitter. In one general aspect, the emitter **106** portion of the time-of-flight distance sensor system **104** may include a very tiny laser source and the receiver **108** portion of the time-of-flight distance sensor system **104** may include a matching sensor. The time-of-flight distance sensor system **104** can detect the "time of flight," or how long the laser light emitted by the emitter **106** has taken to bounce back to the sensor portion of the receiver **108**. Use of a very narrow light source in the emitter **106** enables the distance sensor system **104** to determining the distance to the surface **105** of the tissue **103** directly in front of the distance sensor system **104**. Referring still to FIG. **1**, d_e is the emitter-to-tissue distance from the emitter **106** to the surface **105** of the tissue **103** and d_t is the device-to-tissue distance from the distal end of the surgical device **102** to the surface **105** of the tissue. The distance sensor system **104** can be employed to determine the emitter-to-tissue distance d_e. The device-to-tissue distance d_t is obtainable from the known position of the emitter **106** on the shaft of the surgical device **102** relative to the distal end of the surgical device **102**. In other words, when the distance between the emitter **106** and the distal end of the surgical device **102** is known, the device-to-tissue distance d_t can be determined from the emitter-to-tissue distance d_e. In certain instances, the shaft of the surgical device **102** can include one or more articulation joints, and can be articulatable with respect to the emitter **106** and the jaws. The articulation configuration can include a multi-joint vertebrae-like structure, for example. In certain instances, a three-dimensional camera can be utilized to triangulate one or more distances to the surface **105**.

[0096] In various instances, the receiver **108** for the time-of-flight distance sensor system **104** can be mounted on a separate surgical device instead of the surgical device **102**. For example, the receiver **108** can be mounted on a cannula or trocar through which the surgical device **102** extends to reach the surgical site. In still other instances, the receiver **108** for the time-of-flight distance sensor system **104** can be mounted on a separate robotically-controlled arm (e.g. the robotic arm **114**), on a movable arm that is operated by another robot, and/or to an operating room (OR) table or fixture. In certain instances, the imaging device **120** includes the time-of-flight receiver **108** to determine the distance from the emitter **106** to the surface **105** of the tissue **103** using a line between the emitter **106** on the surgical device **102** and the imaging device **120**. For example, the distance d_e can be triangulated based on known positions of the emitter **106** (on the surgical device **102**) and the receiver **108** (on the imaging device **120**) of the time-of-flight distance sensor system **104**. The three-dimensional position of the receiver **108** can be known and/or registered to the robot coordinate plane intraoperatively.

[0097] In certain instances, the position of the emitter **106** of the time-of-flight distance sensor system **104** can be controlled by the first robotic arm **112** and the position of the receiver **108** of the time-of-flight distance sensor system **104** can be controlled by the second robotic arm **114**. In other instances, the surgical visualization system **100** can be utilized apart from a robotic system. In such instances, the distance sensor system **104** can be independent of the robotic system.

[0098] In certain instances, one or more of the robotic arms **112**, **114** may be separate from a main robotic system used in the surgical procedure. At least one of the robotic arms **112**, **114** can be positioned and registered to a particular coordinate system without a servomotor control. For example, a closed-loop control system and/or a plurality of sensors for the robotic arms **110** can control and/or register the position of the robotic arm(s) **112**, **114** relative to the particular coordinate system. Similarly, the position of the surgical device **102** and the imaging device **120** can be registered relative to a particular coordinate system.

[0099] Referring still to FIG. **1**, d_w is the camera-to-critical structure distance from the optical waveform emitter **123** located on the imaging device **120** to the surface of the critical structure **101**, and d_A is the depth of the critical structure **101** below the surface **105** of the tissue **103** (i.e., the distance between the portion of the surface **105** closest to the surgical device **102** and the critical structure **101**). In various aspects, the time-of-flight of the optical waveforms emitted from the optical waveform emitter **123** located on the imaging device **120** can be configured to determine the camera-to-critical structure distance d_w. The use of spectral imaging in combination with time-of-flight sensors is further described herein. Moreover, referring now to FIG. **3**, in various aspects of the present disclosure, the depth d_A of the critical structure **101** relative to the surface **105** of the tissue **103** can be determined by triangulating from the distance d_w and known positions of the emitter **106** on the surgical device **102** and the optical waveform emitter **123** on the imaging device **120** (and, thus, the known distance d_w therebetween) to determine the distance d_y, which is the sum of the distances d_e and d_A.

[0100] Additionally or alternatively, time-of-flight from the optical waveform emitter **123** can be configured to determine the distance from the optical waveform emitter **123** to the surface **105** of the tissue **103**. For example, a first waveform (or range of waveforms) can be utilized to determine the camera-to-critical structure distance d_w and a second waveform (or range of waveforms) can be utilized to determine the distance to the surface **105** of the tissue **103**. In such instances, the different waveforms can be utilized to determine the depth of the critical structure **101** below the surface **105** of the tissue **103**.

[0101] Additionally or alternatively, in certain instances, the distance d_A can be determined from an ultrasound, a registered magnetic resonance imaging (MRI) or computerized tomography (CT) scan. In still other instances, the distance d_A can be determined with spectral imaging because the detection signal received by the imaging device can vary based on the type of material. For example, fat can decrease the detection signal in a first way, or a first amount, and collagen can decrease the detection signal in a different, second way, or a second amount.

[0102] Referring now to a surgical visualization system **160** in FIG. **4**, in which a surgical device **162** includes the optical waveform emitter **123** and the waveform sensor **122** that is configured to detect the reflected waveforms. The optical waveform emitter **123** can be configured to emit waveforms for determining the distances d_t and d_w from a common device, such as the surgical device **162**, as further described herein. In such instances, the distance d_A from the surface **105** of the tissue **103** to the surface of the critical structure **101** can be determined as follows:

$$d_A=d_w-d_t.$$

[0103] As disclosed herein, various information regarding visible tissue, embedded critical structures, and surgical devices can be determined by utilizing a combination approach that incorporates one or more time-of-flight distance sensors, spectral imaging, and/or structured light arrays in combination with an image sensor configured to detect the spectral wavelengths and the structured light arrays. Moreover, the image sensor can be configured to receive visible light and, thus, provide images of the surgical site to an imaging system. Logic or algorithms are employed to discern the information received from the time-of-flight sensors, spectral wavelengths, structured light, and visible light and render three-dimensional images of the surface tissue and underlying anatomical structures. In various instances, the imaging device **120** can include multiple image sensors.

[0104] The camera-to-critical structure distance d_w can also be detected in one or more alternative ways. In one aspect, a fluoroscopy visualization technology, such as fluorescent indosciedine green (ICG), for example, can be utilized to illuminate a critical structure **201**, as shown in FIGS. **6-8**. A camera **220** can include two optical waveforms sensors **222**, **224**, which take simultaneous left-side and right-side images of the critical structure **201** (FIG. **7**A and **7**B). In such instances, the camera **220** can depict a glow of the critical structure **201** below the surface **205** of the tissue **203**, and the distance d_w can be determined by the known distance between the sensors **222** and **224**. In certain instances, distances can be determined more accurately by utilizing more than one camera or by moving a camera between multiple locations. In certain aspects, one camera can be controlled by a first robotic arm and a second camera by another robotic arm. In such a robotic system, one camera can be a follower camera on a follower arm, for example. The follower arm, and camera thereon, can be programmed to track the other camera and to maintain a particular distance and/or lens angle, for example.

[0105] In still other aspects, the surgical visualization system **100** may employ two separate waveform receivers (i.e. cameras/image sensors) to determine d_w. Referring now to FIG. **9**, if a critical structure **301** or the contents thereof (e.g. a vessel or the contents of the vessel) can emit a signal

302, such as with fluoroscopy, then the actual location can be triangulated from two separate cameras **320***a*, **320***b* at known locations.

[0106] In another aspect, referring now to FIGS. **10**A and **10**B, a surgical visualization system may employ a dithering or moving camera **440** to determine the distance d_w. The camera **440** is robotically-controlled such that the three-dimensional coordinates of the camera **440** at the different positions are known. In various instances, the camera **440** can pivot at a cannula or patient interface. For example, if a critical structure **401** or the contents thereof (e.g. a vessel or the contents of the vessel) can emit a signal, such as with fluoroscopy, for example, then the actual location can be triangulated from the camera **440** moved rapidly between two or more known locations. In FIG. **10**A, the camera **440** is moved axially along an axis A. More specifically, the camera **440** translates a distance d_1 closer to the critical structure **401** along the axis A to the location indicated as a location **440'**, such as by moving in and out on a robotic arm. As the camera **440** moves the distance d_1 and the size of view change with respect to the critical structure **401**, the distance to the critical structure **401** can be calculated. For example, a 4.28 mm axial translation (the distance d_1) can correspond to an angle θ_1 of 6.28 degrees and an angle θ_2 of 8.19 degrees. Additionally or alternatively, the camera **440** can rotate or sweep along an arc between different positions. Referring now to FIG. **10**B, the camera **440** is moved axially along the axis A and is rotated an angle θ_3 about the axis A. A pivot point **442** for rotation of the camera **440** is positioned at the cannula/patient interface. In FIG. **10**B, the camera **440** is translated and rotated to a location **440"**. As the camera **440** moves and the edge of view changes with respect to the critical structure **401**, the distance to the critical structure **401** can be calculated. In FIG. **10**B, a distance d_2 can be 9.01 mm, for example, and the angle θ_3 can be 0.9 degrees, for example.

[0107] FIG. **5** depicts a surgical visualization system **500**, which is similar to the surgical visualization system **100** in many respects. In various instances, the surgical visualization system **500** can be a further exemplification of the surgical visualization system **100**. Similar to the surgical visualization system **100**, the surgical visualization system **500** includes a surgical device **502** and an imaging device **520**. The imaging device **520** includes a spectral light emitter **523**, which is configured to emit spectral light in a plurality of wavelengths to obtain a spectral image of hidden structures, for example. The imaging device **520** can also include a three-dimensional camera and associated electronic processing circuits in various instances. The surgical visualization system **500** is shown being utilized intraoperatively to identify and facilitate avoidance of certain critical structures, such as a ureter **501***a* and vessels **501***b* in an organ **503** (the uterus in this example), that are not visible on the surface.

[0108] The surgical visualization system **500** is configured to determine an emitter-to-tissue distance d_e from an emitter **506** on the surgical device **502** to a surface **505** of the uterus **503** via structured light. The surgical visualization system **500** is configured to extrapolate a device-to-tissue distance d_t from the surgical device **502** to the surface **505** of the uterus **503** based on the emitter-to-tissue distance d_e. The surgical visualization system **500** is also configured to determine a tissue-to-ureter distance d_A from the ureter **501***a* to the surface **505** and a camera-to ureter distance d_w from the imaging device **520** to the ureter **501***a*. As described herein with respect to FIG. **1**, for example, the surgical visualization system **500** can determine the distance d_w with spectral imaging and time-of-flight sensors, for example. In various instances, the surgical visualization system **500** can determine (e.g. triangulate) the tissue-to-ureter distance d_A (or depth) based on other distances and/or the surface mapping logic described herein.

[0109] Referring now to FIG. **11**, where a schematic of a control system **600** for a surgical visualization system, such as the surgical visualization system **100**, for example, is depicted. The control system **600** is a conversion system that integrates spectral signature tissue identification and structured light tissue positioning to identify critical structures, especially when those structures are obscured by other tissue, such as fat, connective tissue, blood, and/or other organs, for example. Such technology could also be useful for detecting tissue variability, such as differentiating tumors and/or non-healthy tissue from healthy tissue within an organ.

[0110] The control system **600** is configured for implementing a hyperspectral imaging and visualization system in which a molecular response is utilized to detect and identify anatomy in a surgical field of view. The control system **600** includes a conversion logic circuit **648** to convert tissue data to surgeon usable information. For example, the variable reflectance based on wavelengths with respect to obscuring material can be utilized to identify the critical structure in the anatomy. Moreover, the control system **600** combines the identified spectral signature and the structural light data in an image. For example, the control system **600** can be employed to create of three-dimensional data set for surgical use in a system with augmentation image overlays. Techniques can be employed both intraoperatively and preoperatively using additional visual information. In various instances, the control system **600** is configured to provide warnings to a clinician when in the proximity of one or more critical structures. Various algorithms can be employed to guide robotic automation and semi-automated approaches based on the surgical procedure and proximity to the critical structure(s).

[0111] A projected array of lights is employed to determine tissue shape and motion intraoperatively. Alternatively, flash Lidar may be utilized for surface mapping of the tissue.

[0112] The control system **600** is configured to detect the critical structure(s) and provide an image overlay of the critical structure and measure the distance to the surface of the visible tissue and the distance to the embedded/buried critical structure(s). In other instances, the control system **600** can measure the distance to the surface of the visible tissue or detect the critical structure(s) and provide an image overlay of the critical structure.

[0113] The control system **600** includes a spectral control circuit **602**. The spectral control circuit **602** can be a field programmable gate array (FPGA) or another suitable circuit configuration as described herein in connection with FIGS. **2**A-**2**C, for example. The spectral control circuit **602** includes a processor **604** to receive video input signals from a video input processor **606**. The processor **604** can be configured for hyperspectral processing and can utilize C/C++ code, for example. The video input processor **606** receives video-in of control (metadata) data such as shutter time, wave length, and sensor analytics, for example. The processor **604** is configured to process the video input signal from the video input processor **606** and provide a video output signal to a video output processor **608**, which includes a hyperspectral video-out of interface control (metadata) data, for example. The video output processor **608** provides the video output signal to an image overlay controller **610**.

[0114] The video input processor **606** is coupled to a camera **612** at the patient side via a patient isolation circuit **614**. As previously discussed, the camera **612** includes a solid state image sensor **634**. The patient isolation circuit can include a plurality of transformers so that the patient is isolated from other circuits in the system. The camera **612** receives intraoperative images through optics **632** and the image sensor **634**. The image sensor **634** can include a CMOS image sensor, for example, or may include any of the image sensor technologies discussed herein in connection with FIG. **2**, for example. In one aspect, the camera **612** outputs images in 14 bit/pixel signals. It will be appreciated that higher or lower pixel resolutions may be employed without departing from the scope of the present disclosure. The isolated camera output signal **613** is provided to a color RGB fusion circuit **616**, which employs a hardware register **618** and a Nios2 co-processor **620** to process the camera output signal **613**. A color RGB fusion output signal is provided to the video input processor **606** and a laser pulsing control circuit **622**.

[0115] The laser pulsing control circuit **622** controls a laser light engine **624**. The laser light engine **624** outputs light in a plurality of wavelengths (λ_1, λ_2, λ_3 . . . λ_n) including near infrared (NIR). The laser light engine **624** can operate in a plurality of modes. In one aspect, the laser light engine **624** can operate in two modes, for example. In a first mode, e.g. a normal operating mode, the laser light engine **624** outputs an illuminating signal. In a second mode, e.g. an identification mode, the laser light engine **624** outputs RGBG and NIR light. In various instances, the laser light engine **624** can operate in a polarizing mode.

[0116] Light output **626** from the laser light engine **624** illuminates targeted anatomy in an intraoperative surgical site **627**. The laser pulsing control circuit **622** also controls a laser pulse controller **628** for a laser pattern projector **630** that projects a laser light pattern **631**, such as a grid or pattern of lines and/or dots, at a predetermined wavelength (λ_2) on the operative tissue or organ at the surgical site **627**. The camera **612** receives the patterned light as well as the reflected light output through the camera optics **632**. The image sensor **634** converts the received light into a digital signal.

[0117] The color RGB fusion circuit **616** also outputs signals to the image overlay controller **610** and a video input module **636** for reading the laser light pattern **631** projected onto the targeted anatomy at the surgical site **627** by the laser pattern projector **630**. A processing module **638** processes the laser light pattern **631** and outputs a first video output signal **640** representative of the distance to the visible tissue at the surgical site **627**. The data is provided to the image overlay controller **610**. The processing module **638** also outputs a second video signal **642** representative of a three-dimensional rendered shape of the tissue or organ of the targeted anatomy at the surgical site.

[0118] The first and second video output signals **640**, **642** include data representative of the position of the critical structure on a three-dimensional surface model, which is provided to an integration module **643**. In combination with data from the video out processor **608** of the spectral control circuit **602**, the integration module **643** can determine the distance d_A (FIG. **1**) to a buried critical structure (e.g. via triangularization algorithms **644**), and the distance d_A can be provided to the image overlay controller **610** via a video out processor **646**. The foregoing conversion logic can encompass the conversion logic circuit **648** intermediate video monitors **652** and the camera **624**/laser pattern projector **630** positioned at the surgical site **627**.

[0119] Preoperative data **650** from a CT or MRI scan can be employed to register or align certain three-dimensional deformable tissue in various instances. Such preoperative data **650** can be provided to the integration module **643** and ultimately to the image overlay controller **610** so that such information can be overlaid with the views from the camera **612** and provided to the video monitors **652**. Registration of preoperative data is further described herein and in the aforementioned contemporaneously-filed U.S. Patent Applications, including U.S. patent application Ser. No.______, titled INTEGRATION OF IMAGING DATA, Attorney Docket No. END8612USNP/180237, for example, which are incorporated by reference herein in their respective entireties.

[0120] The video monitors **652** can output the integrated/augmented views from the image overlay controller **610**. A clinician can select and/or toggle between different views on one or more monitors. On a first monitor **652***a*, the clinician can toggle between (A) a view in which a three-dimensional rendering of the visible tissue is depicted and (B) an augmented view in which one or more hidden critical structures are depicted over the three-dimensional rendering of the visible tissue. On a second monitor **652***b*, the clinician can toggle on distance measurements to one or more hidden critical structures and/or the surface of visible tissue, for example.

[0121] The control system **600** and/or various control circuits thereof can be incorporated into various surgical visualization systems disclosed herein.

[0122] FIG. **12** illustrates a structured (or patterned) light system **700**, according to at least one aspect of the present disclosure. As described herein, structured light in the form of stripes or lines, for example, can be projected from a light source and/or projector **706** onto the surface **705** of targeted anatomy to identify the shape and contours of the surface **705**. A camera **720**, which can be similar in various respects to the imaging device **120** (FIG. **1**), for example, can be configured to detect the projected pattern of light on the surface **705**. The way that the projected pattern deforms upon striking the surface **705** allows vision systems to calculate the depth and surface information of the targeted anatomy.

[0123] In certain instances, invisible (or imperceptible) structured light can be utilized, in which the structured light is used without interfering with other computer vision tasks for which the projected pattern may be confusing. For example, infrared light or extremely fast frame rates of visible light that alternate between two exact opposite patterns can be utilized to prevent interference. Structured light is further described at en.wikipedia.org/wiki/Structured_light.

[0124] Referring now to FIG. **13**, by way example to illustrate the concept of hyperspectral imaging, a terrestrial hyperspectral imaging system **800** is shown. The terrestrial hyperspectral imaging system **800** is configured to image terrestrial features or objects, such as soil, water, and/or vegetation, for example. The terrestrial hyperspectral imaging system **700** includes a space-borne hyperspectral sensor **822** on a spacecraft **820** to conduct hyperspectral imaging of a portion of the Earth's surface **805**. The spectral dimension includes several layers. Each pixel of the images contains a sampled spectrum that is used to identify the materials present in the pixel by their reflectance. The data can be converted to graphical representations **850**, **852**, **854** of reflectance as a function of wavelength for soil, water, and vegetation, respectively, for example. Terrestrial hyperspectral imaging is further described at www.markelowitz.com/Hyperspectral.html.

[0125] Also by way example to illustrate the concept of hyperspectral imaging, FIG. **14** is a graphical representation **850** of hyperspectral signatures for various terrestrial features or objects, according to at least one aspect of the present disclosure. Percent reflectance is shown along the vertical axis and wavelength (nm) is shown along the horizontal axis. As shown, each object—pinewoods, grasslands, red sand pit, and silty water—has a unique hyperspectral signature that can be used to identify the object.

[0126] The hyperspectral imaging concepts described in connection with FIGS. **13** and **14** may be employed for different materials that have different wavelengths and bands of absorption, according to at least one aspect of the present disclosure. The following table illustrates the wavelengths and bands of absorption for various materials. A first range of wavelengths between 400 nm and 700 nm represents the visible light spectrum. A second range of wavelengths between 700 nm and 1400 nm represents the near infrared (NIR) spectrum. A third range of wavelengths between 1400 nm and 3000 nm represents a shortwave infrared (SWIR) spectrum. A first band centered at 1250 nm represents iron absorption and leaf moisture content. A second band between 1500 nm and 1750 nm represents plastics, fiberglass, and petroleum. A third band between 200 nm and 2400 nm represents mineral ID.

[0127] TABLE 1 specifies wavelengths and bands of absorption for various materials.

TABLE 1

Wavelength (nm)	Region	Band(s)	Material
400-700	Visible		
700-1400	NIR		
1400-3000	SWIR	1 - centered at 1250	Iron adsorption Leaf moisture content
		2 - 1500-1750	Plastics Fiberglass Petroleum
		3 - 200-2400 nm	Mineral ID

[0128] Referring now to FIGS. **15**A-**15**C, as a further illustration of hyperspectral imaging concepts, tests were conducted in which spectral imaging was applied to a fried egg **952**. An image of the fried egg **952** with a yellow egg yolk **954** and an egg white **956** surrounding the egg yolk **954** is shown in FIG. **15**A. A graphical representation **950** of spectral signatures for the fried egg **952** are shown in FIG. **15**B. Specifically, the graphical representation **950** shows absorption units versus wavelength (nm) for the egg yolk **954** and the egg white **956** of the fried egg **952**. In FIG. **15**C, a spectral image (in black-and-white) of the fried egg **952** is shown, in which the image is augmented to differentiate between the egg yolk portion and the egg white portion based on the hyperspectral signature data.

[0129] In various instances, hyperspectral imaging technology, as described herein for illustrative purposes with respect to terrestrial features and objects and a fried egg, can be employed to identify signatures in anatomical structures in order to differentiate a critical structure from obscurants. Hyperspectral imaging technology may provide a visualization system that can provide a way to identify critical structures such as ureters and/or blood vessels, for example, especially when those structures are obscured by fat, connective tissue, blood, or other organs, for example. The use of the difference in reflectance of different wavelengths in the infrared (IR) spectrum may be employed to determine the presence of key structures versus obscurants. Referring now to FIGS. **16-18**, illustrative hyperspectral signatures for a ureter, an artery, and nerve tissue with respect to obscurants such as fat, lung tissue, and blood, for example, are depicted.

[0130] FIG. **16** is a graphical representation **1050** of an illustrative ureter signature versus obscurants. The plots represent reflectance as a function of wavelength (nm) for wavelengths for fat, lung tissue, blood, and a ureter. FIG. **17** is a graphical representation **1052** of an illustrative artery signature versus obscurants. The plots represent reflectance as a function of wavelength (nm) for fat, lung tissue, blood, and a vessel. FIG. **18** is a graphical representation **1054** of an illustrative nerve signature versus obscurants. The plots represent reflectance as a function of wavelength (nm) for fat, lung tissue, blood, and a nerve.

[0131] In various instances, select wavelengths for spectral imaging can be identified and utilized based on the anticipated critical structures and/or obscurants at a surgical site (i.e. "selective spectral" imaging). By utilizing selective spectral imaging, the amount of time required to obtain the spectral image can be minimized such that the information can be obtained in real-time, or near real-time, and utilized intraoperatively. In various instances, the wavelengths can be selected by a clinician or by a control circuit based on input by the clinician. In certain instances, the wavelengths can be selected based on machine learning and/or big data accessible to the control circuit via a cloud, for example.

[0132] The foregoing application of spectral imaging to tissue can be utilized intraoperatively to measure the distance between a waveform emitter and a critical structure that is obscured by tissue. In one aspect of the present disclosure, referring now to FIGS. **19** and **20**, a time-of-flight sensor system **1104** utilizing waveforms **1124**, **1125** is shown. The time-of-flight sensor system **1104** can be incorporated into the surgical visualization system **100** (FIG. **1**) in certain instances. The time-of-flight sensor system **1104** includes a waveform emitter **1106** and a waveform receiver **1108** on the same surgical device **1102**. The emitted wave **1124** extends to the critical structure **1101** from the emitter **1106** and the received wave **1125** is reflected back to by the receiver **1108** from the critical structure **1101**. The surgical device **1102** is positioned through a trocar **1110** that extends into a cavity **1107** in a patient.

[0133] The waveforms **1124**, **1125** are configured to penetrate obscuring tissue **1103**. For example, the wavelengths of the waveforms **1124**, **1125** can be in the NIR or SWIR spectrum of wavelengths. In one aspect, a spectral signal (e.g. hyperspectral, multispectral, or selective spectral) or a photoacoustic signal can be emitted from the emitter **1106**

and can penetrate the tissue **1103** in which the critical structure **1101** is concealed. The emitted waveform **1124** can be reflected by the critical structure **1101**. The received waveform **1125** can be delayed due to the distance d between the distal end of the surgical device **1102** and the critical structure **1101**. In various instances, the waveforms **1124**, **1125** can be selected to target the critical structure **1101** within the tissue **1103** based on the spectral signature of the critical structure **1101**, as further described herein. In various instances, the emitter **1106** is configured to provide a binary signal on and off, as shown in FIG. **20**, for example, which can be measured by the receiver **1108**.

[0134] Based on the delay between the emitted wave **1124** and the received wave **1125**, the time-of-flight sensor system **1104** is configured to determine the distance d (FIG. **19**). A time-of-flight timing diagram **1130** for the emitter **1106** and the receiver **1108** of FIG. **19** is shown in FIG. **20**. The delay is a function of the distance d and the distance d is given by:

$$d = \frac{ct}{2} \cdot \frac{q_2}{q_1 + q_2}$$

where:

[0135] c=the speed of light;

[0136] t=length of pulse;

[0137] q_1=accumulated charge while light is emitted; and

[0138] q_2=accumulated charge while light is not being emitted.

[0139] As provided herein, the time-of-flight of the waveforms **1124**, **1125** corresponds to the distance din FIG. **19**. In various instances, additional emitters/receivers and/or pulsing signals from the emitter **1106** can be configured to emit a non-penetrating signal. The non-penetrating tissue can be configured to determine the distance from the emitter to the surface **1105** of the obscuring tissue **1103**. In various instances, the depth of the critical structure **1101** can be determined by:

$$d_A = d_w - d_1.$$

where:

[0140] d_A=the depth of the critical structure **1101**;

[0141] d_w=the distance from the emitter **1106** to the critical structure **1101** (d in FIG. **19**); and

[0142] d_1=the distance from the emitter **1106** (on the distal end of the surgical device **1102**) to the surface **1105** of the obscuring tissue **1103**.

[0143] In one aspect of the present disclosure, referring now to FIG. **21**, a time-of-flight sensor system **1204** utilizing waves **1224***a*, **1224***b*, **1224***c*, **1225***a*, **1225***b*, **1225***c* is shown. The time-of-flight sensor system **1204** can be incorporated into the surgical visualization system **100** (FIG. **1**) in certain instances. The time-of-flight sensor system **1204** includes a waveform emitter **1206** and a waveform receiver **1208**. The waveform emitter **1206** is positioned on a first surgical device **1202***a*, and the waveform receiver **1208** is positioned on a second surgical device **1202***b*. The surgical devices **1202***a*, **1202***b* are positioned through their respective trocars **1210***a*, **1210***b*, respectively, which extend into a cavity **1207** in a patient. The emitted waves **1224***a*, **1224***b*, **1224***c* extend toward a surgical site from the emitter **1206** and the received waves **1225***a*, **1225***b*, **1225***c* are reflected back to the receiver **1208** from various structures and/or surfaces at the surgical site.

[0144] The different emitted waves **1224***a*, **1224***b*, **1224***c* are configured to target different types of material at the surgical site. For example, the wave **1224***a* targets the obscuring tissue **1203**, the wave **1224***b* targets a first critical structure **1201***a* (e.g. a vessel), and the wave **1224***c* targets a second critical structure **1201***b* (e.g. a cancerous tumor). The wavelengths of the waves **1224***a*,**1224***b*, **1224***c* can be in the visible light, NIR, or SWIR spectrum of wavelengths. For example, visible light can be reflected off a surface **1205** of the tissue **1203** and NIR and/or SWIR waveforms can be configured to penetrate the surface **1205** of the tissue **1203**. In various aspects, as described herein, a spectral signal (e.g. hyperspectral, multispectral, or selective spectral) or a photoacoustic signal can be emitted from the emitter **1206**. In various instances, the waves **1224***b*, **1224***c* can be selected to target the critical structures **1201***a*, **1201***b* within the tissue **1203** based on the spectral signature of the critical structure **1201***a*, **1201***b*, as further described herein. Photoacoustic imaging is further described herein and in the aforementioned contemporaneously-filed U.S. Patent Applications, which are incorporated by reference herein in their respective entireties.

[0145] The emitted waves **1224***a*, **1224***b*, **1224***c* can be reflected off the targeted material (i.e. the surface **1205**, the first critical structure **1201***a*, and the second structure **1201***b*, respectively). The received waveforms **1225***a*, **1225***b*, **1225***c* can be delayed due to the distances d_{1a}, d_{2a}, d_{3a}, d_{1b}, d_{2b}, d_{2c} indicated in FIG. **21**.

[0146] In the time-of-flight sensor system **1204**, in which the emitter **1206** and the receiver **1208** are independently positionable (e.g., on separate surgical devices **1202***a*, **1202***b* and/or controlled by separate robotic arms), the various distances d_{1a}, d_{2a}, d_{3a}, d_{1b}, d_{2b}, d_{2c} can be calculated from the known position of the emitter **1206** and the receiver **1208**. For example, the positions can be known when the surgical devices **1202***a*, **1202***b* are robotically-controlled. Knowledge of the positions of the emitter **1206** and the receiver **1208**, as well as the time of the photon stream to target a certain tissue and the information received by the receiver **1208** of that particular response can allow a determination of the distances d_{1a}, d_{2a}, d_{3a}, d_{1b}, d_{2b}, d_{2c}. In one aspect, the distance to the obscured critical structures **1201***a*, **1201***b* can be triangulated using penetrating wavelengths. Because the speed of light is constant for any wavelength of visible or invisible light, the time-of-flight sensor system **1204** can determine the various distances.

[0147] Referring still to FIG. **21**, in various instances, in the view provided to the clinician, the receiver **1208** can be rotated such that the center of mass of the target structure in the resulting images remains constant, i.e., in a plane perpendicular to the axis of a select target structures **1203**, **1201***a*, or **1201***b*. Such an orientation can quickly communicate one or more relevant distances and/or perspectives with respect to the critical structure. For example, as shown in FIG. **21**, the surgical site is displayed from a viewpoint in which the critical structure **1201***a* is perpendicular to the viewing plane (i.e. the vessel is oriented in/out of the page). In various instances, such an orientation can be default setting; however, the view can be rotated or otherwise adjusted by a clinician. In certain instances, the clinician can toggle between different surfaces and/or target structures that define the viewpoint of the surgical site provided by the imaging system.

[0148] In various instances, the receiver **1208** can be mounted on a trocar or cannula, such as the trocar **1210***b*, for example, through which the surgical device **1202***b* is positioned. In other instances, the receiver **1208** can be mounted on a separate robotic arm for which the three-dimensional position is known. In various instances, the receiver **1208** can be mounted on a movable arm that is separate from the robot that controls the surgical device **1202***a* or can be mounted to an operating room (OR) table that is intraoperatively registerable to the robot coordinate plane. In such instances, the position of the emitter **1206** and the receiver **1208** can be registerable to the same coordinate plane such that the distances can be triangulated from outputs from the time-of-flight sensor system **1204**.

[0149] Combining time-of-flight sensor systems and near-infrared spectroscopy (NIRS), termed TOF-N IRS, which is capable of measuring the time-resolved profiles of NIR light with nanosecond resolution can be found in the article titled TIME-OF-FLIGHT NEAR-INFRARED SPECTROSCOPY FOR NONDESTRUCTIVE MEASUREMENT OF INTERNAL QUALITY IN GRAPEFRUIT, in the Journal of the American Society for Horticultural Science, May 2013 vol. 138 no. 3 225-228, which is incorporated by reference herein in its entirety, and is accessible at journal.ashspublications.org/content/138/3/225.full.

[0150] In various instances, time-of-flight spectral waveforms are configured to determine the depth of the critical structure and/or the proximity of a surgical device to the critical structure. Moreover, the various surgical visualization systems disclosed herein include surface mapping logic that is configured to create three-dimensional rendering of the surface of the visible tissue. In such instances, even when the visible tissue obstructs a critical structure, the clinician can be aware of the proximity (or lack thereof) of a surgical device to the critical structure. In one instances, the topography of the surgical site is provided on a monitor by the surface mapping logic. If the critical structure is close to the surface of the tissue, spectral imaging can convey the position of the critical structure to the clinician. For example, spectral imaging may detect structures within 5 or 10 mm of the surface. In other instances, spectral imaging may detect structures 10 or 20 mm below the surface of the tissue. Based on the known limits of the spectral imaging system, the system is configured to convey that a critical structure is out-of-range if it is simply not detected by the spectral imaging system. Therefore, the clinician can continue to move the surgical device and/or manipulate the tissue. When the critical structure moves into range of the spectral imaging system, the system can identify the structure and, thus, communicate that the structure is within range. In such instances, an alert can be provided when a structure is initially identified and/or moved further within a predefined proximity zone. In such instances, even non-identification of a critical structure by a spectral imaging system with known bounds/ranges can provide proximity information (i.e. the lack of proximity) to the clinician.

[0151] Various surgical visualization systems disclosed herein can be configured to identify intraoperatively the presence of and/or proximity to critical structure(s) and to alert a clinician prior to damaging the critical structure(s) by inadvertent dissection and/or transection. In various aspects, the surgical visualization systems are configured to identify one or more of the following critical structures: ureters, bowel, rectum, nerves (including the phrenic nerve, recurrent laryngeal nerve [RLN], promontory facial nerve, vagus nerve, and branches thereof), vessels (including the pulmonary and lobar arteries and veins, inferior mesenteric artery [IMA] and branches thereof, superior rectal artery, sigmoidal arteries, and left colic artery), superior mesenteric artery (SMA) and branches thereof (including middle colic artery, right colic artery, ilecolic artery), hepatic artery and branches thereof, portal vein and branches thereof, splenic artery/vein and branches thereof, external and internal (hypogastric) ileac vessels, short gastric arteries, uterine arteries, middle sacral vessels, and lymph nodes, for example. Moreover, the surgical visualization systems are configured to indicate proximity of surgical device(s) to the critical structure(s) and/or warn the clinician when surgical device(s) are getting close to the critical structure(s).

[0152] Various aspects of the present disclosure provide intraoperative critical structure identification (e.g., identification of ureters, nerves, and/or vessels) and instrument proximity monitoring. For example, various surgical visualization systems disclosed herein can include spectral imaging and surgical instrument tracking, which enable the visualization of critical structures below the surface of the tissue, such as 1.0-1.5 cm below the surface of the tissue, for example. In other instances, the surgical visualization system can identify structures less than 1.0 cm or more the 1.5 cm below the surface of the tissue. For example, even a surgical visualization system that can identify structures only within 0.2 mm of the surface, for example, can be valuable if the structure cannot otherwise be seen due to the depth. In various aspects, the surgical visualization system can augment the clinician's view with a virtual depiction of the critical structure as a visible white-light image overlay on the surface of visible tissue, for example. The surgical visualization system can provide real-time, three-dimensional spatial tracking of the distal tip of surgical instruments and can provide a proximity alert when the distal tip of a surgical instrument moves within a certain range of the critical structure, such as within 1.0 cm of the critical structure, for example.

[0153] Various surgical visualization systems disclosed herein can identify when dissection is too close to a critical structure. Dissection may be "too close" to a critical structure based on the temperature (i.e. too hot within a proximity of the critical structure that may risk damaging/heating/melting the critical structure) and/or based on tension (i.e. too much tension within a proximity of the critical structure that may risk damaging/tearing/pulling the critical structure). Such a surgical visualization system can facilitate dissection around vessels when skeletonizing the vessels prior to ligation, for example. In various instances, a thermal imaging camera can be utilized to read the heat at the surgical site and provide a warning to the clinician that is based on the detected heat and the distance from a tool to the structure. For example, if the temperature of the tool is over a predefined threshold (such as 120 degrees F., for example), an alert can be provided to the clinician at a first distance (such as 10 mm, for example), and if the temperature of the tool is less than or equal to the predefined threshold, the alert can be provided to the clinician at a second distance (such as 5 mm, for example). The predefined thresholds and/or warning distances can be default settings and/or programmable by the clinician. Additionally or alternatively, a proximity alert can be linked to thermal measurements made by the tool itself, such as a thermocouple that measures the heat in a distal jaw of a monopolar or bipolar dissector or vessel sealer, for example.

[0154] Various surgical visualization systems disclosed herein can provide adequate sensitivity with respect to a critical structure and specificity to enable a clinician to proceed with confidence in a quick but safe dissection based on the standard of care and/or device safety data. The system can function intraoperatively and in real-time during a surgical procedure with minimal ionizing radiation risk to a patient or a clinician and, in various instances, no risk of ionizing radiation risk to the patient or the clinician. Conversely, in a fluoroscopy procedure, the patient and clinician (s) may be exposed to ionizing radiation via an X-ray beam, for example, that is utilized to view the anatomical structures in real-time.

[0155] Various surgical visualization system disclosed herein can be configured to detect and identify one or more desired types of critical structures in a forward path of a surgical device, such as when the path of the surgical device is robotically controlled, for example. Additionally or alternatively, the surgical visualization system can be configured to detect and identify one or more types of critical structures in a surrounding area of the surgical device and/or in multiple planes/dimensions, for example.

[0156] Various surgical visualization systems disclosed herein can be easy to operate and/or interpret. Moreover, various surgical visualization systems can incorporate an "override" feature that allows the clinician to override a default setting and/or operation. For example, a clinician can selectively turn off alerts from the surgical visualization system and/or get closer to a critical structure than suggested by the surgical visualization system such as when the risk to the critical structure is less than risk of avoiding the area (e.g. when removing cancer around a critical structure the risk of leaving the cancerous tissue can be greater than the risk of damage to the critical structure).

[0157] Various surgical visualization systems disclosed herein can be incorporated into a surgical system and/or used during a surgical procedure with limited impact to the workflow. In other words, implementation of the surgical visualization system may not change the way the surgical procedure is implemented. Moreover, the surgical visualization system can be economical in comparison to the costs of an inadvertent transection. Data indicates the reduction in inadvertent damage to a critical structure can drive incremental reimbursement.

[0158] Various surgical visualization systems disclosed herein can operate in real-time, or near real-time, and far enough in advance to enable a clinician to anticipate critical structure(s). For example, a surgical visualization system can provide enough time to "slow down, evaluate, and avoid" in order to maximize efficiency of the surgical procedure.

[0159] Various surgical visualization systems disclosed herein may not require a contrast agent, or dye, that is injected into tissue. For example, spectral imaging is configured to visualize hidden structures intraoperatively without the use of a contrast agent or dye. In other instances, the contrast agent can be easier to inject into the proper layer(s) of tissue than other visualization systems. The time between injection of the contrast agent and visualization of the critical structure can be less than two hours, for example.

[0160] Various surgical visualization systems disclosed herein can be linked with clinical data and/or device data. For example, data can provide boundaries for how close energy-enabled surgical devices (or other potentially damaging devices) should be from tissue that the surgeon does not want to damage. Any data modules that interface with the surgical visualization systems disclosed herein can be provided integrally or separately from a robot to enable use with stand-alone surgical devices in open or laparoscopic procedures, for example. The surgical visualization systems can be compatible with robotic surgical systems in various instances. For example, the visualization images/information can be displayed in a robotic console.

[0161] In various instances, visualization of a surgical site can provide numerous advantages, as described throughout the present disclosure. However, the various surgical visualization systems disclosed herein rely on one or more light projectors to visualize the surgical site. For example, structured light can be utilized to generate a three-dimensional representation of the visible anatomical structure and spectral imaging can be utilized to identify one or more hidden structures. As further described herein, a projector can be positioned on a robotic tool.

[0162] For example, FIG. **22** depicts a surgical visualization system **3000** including a camera **3020** and a robotic tool **3002** that includes a light projector **3006** is depicted. The surgical visualization system **3000** can be similar to the surgical visualization system **100** (FIG. **1**) in many respects. For example, the light projector **3006** is configured to emit a structured light pattern **3007** on a surface **3005** of an anatomical structure **3003**. The robotic tool **3002** includes a pair of opposing jaws and can be a surgical stapler, dissector, and/or grasper, for example. In other instances, the robotic tool **3002** can be a clip applier, an energy device, such as mono-polar probe, bi-polar probe, ablation probe, and/or an ultrasonic end effector, for example, or an imaging or diagnostic tool, such as an ultrasound transducer, for example. The camera **3020** includes an image sensor that is configured to detect the structured light pattern **3007** and generate a three-dimensional representation of the surface **3005** based on the detected structured light pattern **3007**.

[0163] The robotic tool **3002** is a dedicated tool for projecting structured light. In various aspects, the robotic tool **3002** can also be configured to emit spectral light waves and/or photoacoustic signals, for example. In other instances, a clinician may want to visualize the surgical site without the use of a dedicated tool including a light projector. For example, a clinician may want to use a particular surgical tool that doesn't include a projector and doesn't support the visualization capabilities disclosed herein. Additionally or alternatively, the robotic arms may be occupied by other tools that do not have integrated light projectors and visualization capabilities. In certain instances, exchanging surgical tools can be inconvenient and a clinician may not want to withdraw a robotic arm from the surgical site to exchange the surgical tools.

[0164] In such instances, it can be advantageous to utilize a light projector without the use of a specific or dedicated robotic tool. For example, a light projection probe can be positioned at the surgical site and maneuvered around the surgical site by one or more other surgical tools, such as a robotic grasper, for example. The light projection probe can be configured to emit a structured light pattern on a surface of an anatomical structure and/or spectral light waves and/or photoacoustic signals to detect hidden structures and/or determine one or more distances, for example. The light projection probe can be a shaft-less robotic surgical tool, for example. In various aspects, the shaft-less robotic surgical tool can include a body having a distal end comprising a projector configured to emit a structured light pattern, a proximal end, and an attachment feature, such as a magnet of a projection, which can be held by a robotic tool. A flexible cable can extend from the proximal end of the shaft-less robotic surgical tool to a light source.

[0165] In various aspects, such a light projection probe can be positioned in tighter cavities than a camera or a dedicated robotic surgical tool. For example, it may be impractical to intraoperatively position a camera or another surgical tool at certain locations and/or angles; however, a smaller and compact shaft-less light projection probe can easily maneuver into small and/or tighter areas. Additionally, wristed robotic control of the light projection probe via an articulating robotic tool can allow more variety and/or improved approach positions for the probe. As described herein, a camera can be configured to emit the structured light pattern, spectral light waves and/or photoacoustic signals. However, by utilizing a separate light source, the camera does not need a laser light engine that emits the above-described waves. In other words, the camera can have a simplified architecture that includes CMOS spectral sensing and three-dimensional light detection and sensing without a laser light engine to project structure light, spectral light waves, and/or near infrared light waves, for example. Additionally, the camera can maintain a better surgical approach for viewing the emitted light in certain instances.

[0166] Referring now to FIG. **23**, a light projection probe **3102** is shown. The light projection probe **3102** includes a body **3104** between a proximal end **3106** and a distal end **3108** of the light projection probe **3102**. The distal end **3108** includes a projector **3110**, which is configured to emit a structured light pattern onto a surface, such as an anatomical structure/tissue. The body **3104** is a compact structure. For example, the length of the body **3104** can be about the same length as the length of the grasper jaws **3121**, **3122**. In other instances, the length of the body **3104** can be less than or more than the length of the grasper jaws **3121**, **3122**. The probe **3102** is considered to be a shaft-less probe because the probe **3102** does not include a tool shaft that extends through a trocar. Moreover, the probe **3102** is not coupled to a robotic arm. Rather, a robotic tool grabs or otherwise engages the shaft-less probe and a flexible cable **3112** extends from the proximal end **3106** of the body **3104**. The flexible cable **3112** can extend through a trocar and connect the light projection probe **3102** with a power source for powering the lights and/or electronics within the body **3104**. The flexibility of the cable **3112** enables the light projection probe **3102** to reach tight and/or small areas because the cable **3112** can flex, twist, or fold to reach a desired location at the surgical site. The cable **3112** can be a fiber optic cable in certain instances.

[0167] The light projection probe **3102** also includes an attachment portion **3114** for attaching the light projection probe **3102** to a surgical tool. For example, the attachment portion **3114** is a projection that extends radially outward from the body **3104**. The attachment portion **3114** includes a central flange **3116** and an orthogonal flange **3118** oriented at an angle relative to the central flange **3116**.

[0168] A robotic grasper **3120** is configured to hold the attachment portion **3114** at a particular location. The robotic grasper **3120** is configured to manipulate or maneuver the light projection probe **3102**. For example, the robotic grasper **3120** includes opposing jaws **3121**, **3122**, and the attachment portion **3114** is held between the jaws **3121**, **3122**. More specifically, the central flange **3116** is sandwiched between the jaws **3121**, **3122**, and the orthogonal flange **3118** is positioned through an opening in at least one of the jaws **3121**, **3122**. A clearance between the attachment portion **3114** and the jaws **3121**, **3122** is minimized such that the location of the attachment portion **3114** relative to the jaws **3121**, **3122** is known and fixed. For example, when the jaws **3121**, **3122** clamp onto the attachment portion **3114**, the body **3104** can be spaced a predefined lateral distance from a central longitudinal axis of the grasper **3120**. Additionally, the projector **3110** is spaced a predefined longitudinal distance from the distal end of the grasper **3120**. One or more alignment features (e.g. notches, grooves, ridges, cutouts, apertures, slots, teeth, etc.) can ensure the attachment portion **3114** is properly seated within the jaws **3121**, **3122**.

[0169] In other instances, a shaft-less light projection probe can define a simple stick without a designated attachment portion. In such instances, the shaft-less light projection probe can be clamped between opposing jaws **3121**, **3122**. The structure of the jaws **3121**, **3122** can ensure the shaft-less light projection probe is properly seated. For example, the stick-shaped probe can fit snuggly within and/or in mechanical engagement with central openings defined between the jaws **3121**, **3122**.

[0170] The light projection probe **3102** can be used in connection with a camera, such as the camera **3020** (FIG. **22**) to realize one or more of the visualization features described herein. For example, the camera **3020** can determine the surface topography and distances to the surface based on the structured light emitted from the projector **3110**. Moreover, the distance to other robotic tools is enabled because a robotic surgical system includes tracking of the tools within the robotic coordinate system. The tissue geometry and distances to the light projection probe **3102** are known from the structured light and surface mapping logic, the distance from the light projection probe **3102** to the holding tool (e.g. the grasper **3120**) is known from the alignment feature(s), and the distance between the holding tool and the other robotic tool(s) is known by the robotic system. Therefore, the distance from any robotic tool to the tissue detected by the structured light is known. In such instances, the light projection probe **3102** can guide the use of all of the robotic tools utilized by the robotic system.

[0171] Referring now to FIGS. **24**-**27**A, alternative alignment features for a drop-in tool, such as the light projection probe **3102**, are shown. FIG. **24** shows a bulldog clamp **3202** having a projection **3214**. The projection **3214** is structured such that a robotic grasper can grasp the projection **3214** to maneuver the bulldog clamp **3202** around the surgical site. The projection **3214** is a tab. FIGS. **25** and **26** show another bulldog clamp **3302** having proximal grooves **3314** for end-on docking with a robotic tool. Bulldog clamps can be used in temporary intraoperative vessel occlusion in connection with a robotic surgical procedure. In such instances, the bulldog clamp is configured to be grasped, positioned, and activated by a robotic grasper. Bulldog clamps are further described in the article, "Robotic Partial Nephrectomy Using Robotic Bulldog Clamps" by Sukumar, S., Petros, F., Mander, N., Chen, R., Menon, M., & Rogers, C. G. in JSLS : Journal of the Society of Laparoendoscopic Surgeons, 15(4), 520-526, which is incorporated by reference herein in its entirety, and is available at doi.org/10.4293/108680811X13176785204274.

[0172] FIGS. **27** and **27**A depict an ultrasound probe **3402** having a cable **3412** extending from a proximal end **3406** of a body **3404**. The ultrasound probe **3402** also includes a distal ultrasound emitter **3410** at a distal end **3408** of the ultrasound probe **3402**. The ultrasound probe can be a curved linear array drop-in ultrasound transducer, which can provide a wider field of view for faster navigation, such as faster kidney navigation for difficult to access endophytic and exophytic tumors, for example. The ultrasound probe **3402** also includes a manipulation tab or fin **3414**, which is designed for maximum control and organ contact. The fin **3414** is T-shaped and defines a central portion and orthogonal portion. The central portion can be grasped by a robotic grasper, for example, and the orthogonal portion can ensure proper alignment with the robotic grasper, for example. Drop-in Transducers are further described at https://bkultrasound.com/transducers/x12c4-robotic-drop-in.

[0173] The reader will appreciate that various attachment and/or alignment features described herein with respect to FIGS. **24-27**A can be incorporated into a light projection probe for providing structured light, spectral light waves, and/or photoacoustic signals.

[0174] Referring now to FIG. **28**, a light projection probe **3502** is shown. The light projection probe **3502** includes a body **3504** between a proximal end **3506** and a distal end **3508** of the light projection probe **3502**. The light projection probe **3502** is a combination probe having a plurality of projectors. For example, the distal end **3508** includes a first projector **3510***a*, which is configured to emit a structured light pattern onto a surface, such as an anatomical structure/tissue. The distal end **3508** also includes a second projector **3510***b*, which is configured to emit spectral light waves in a plurality of tissue-penetrating wavelengths. In other instances, the second projector **3510***b* can be configured to emit photoacoustic signals, which are configured to penetrate tissue and indicate hidden structures, for example. The probe **3502** is considered to be a shaft-less probe because it does not include a shaft that is coupled to a robotic arm. Rather, a flexible cable **3512** extends from the proximal end **3506** of the body **3504**. The flexible cable **3512** can connect the light projection probe **3502** with a power source for powering the lights and/or electronics within the body **3504**. The flexibility of the cable **3512** enables the light projection probe **3502** to reach tight and/or small areas because the cable **3512** can flex, twist, or fold to reach a desired location at the surgical site. The cable **3512** in FIG. **28** is a laser light fiber optic tether. Other cables are also envisioned. In certain instances, the laser source can be in the body **3504**, similar to a laser pointer. In such instances, the cable **3512** can be a simple electric wire. In various instances, wireless configurations are envisioned. For example, the probe **3502** can include a battery, and on, off, and/or a pulsing scheme can be controlled by a Bluetooth signal.

[0175] The light projection probe **3502** also includes an attachment portion **3514** for attaching the light projection probe **3502** to a surgical tool. For example, the attachment portion **3514** is a fin that extends radially outward from the body **3504**. The attachment portion **3514** includes a central flange **3516** and an orthogonal flange **3518** oriented at an angle relative to the central flange **3516**. The central flange **3516** and the orthogonal flange **3518** form a "T", which is structured to align the jaws of the robotic grasper in a particular location with respect to the light projection probe **3502**. For example, the central flange **3516** can be sandwiched between the jaws of the grasper, and the orthogonal flange **3518** can be positioned through an opening in one of the jaws. A clearance between the attachment portion **3514** and the jaws can be minimized such that the location of the attachment portion **3514** relative to the jaws is known and fixed. For example, when the jaws clamp onto the attachment portion **3514**, the body **3504** can be spaced a predefined lateral distance from a central longitudinal axis of the grasper. Additionally, the projectors **3510***a*, **3510***b* can be spaced a predefined longitudinal distance from the distal end of the grasper. In various instances, additional alignment features (e.g. notches, grooves, ridges, cutouts, apertures, slots, teeth, etc.) can ensure the attachment portion **3514** is properly seated within the jaws. Alternative attachment and alignment features are envisioned.

[0176] The light projection probe **3502** can be used in connection with a camera, such as the camera **3020** (FIG. **22**) to realize one or more of the visualization features described herein. For example, the camera **3020** can determine the surface topography and distances to the surface based on the structured light emitted from the first projector **3510***a*. Additionally, one or more distances from the light projection probe **3502** to a hidden structure can be determined. For example, spectral/infrared time-of-flight sensors can be utilized to determine the distance from the second projector **3510***b* to hidden structure(s). Moreover, the distance to other robotic tools is enabled because a robotic surgical system includes tracking of the tools within the robotic coordinate system. The tissue geometry and distances to the light projection probe **3502** are known, the distance from the light projection probe **3502** to the holding tool is known from the alignment feature(s), and the distance between the holding tool and the other robotic tool(s) is known by the robotic system. Therefore, the distance from any robotic tool to the tissue detected by the structured light and/or a hidden structure is known. In such instances, the light projection probe **3502** can guide the use of all of the robotic tools utilized by the robotic system.

[0177] The combination light projection probe **3502** allows for a simplified camera architecture that includes a hyperspectral sensor, such as a CMOS image sensor, for example, and three-dimensional structured light detection and processing. Such a camera does not need a laser light engine to project structured light and spectral/near infrared light waves in a plurality of wavelengths. The laser light engine, including near infrared wavelength emission, for example, can be outside of the camera. Moreover, the combination light projection probe **3502** can be positioned intraoperatively in tighter/narrower cavities and to meet certain size specifications that would be impractical for positioning a camera. The attachment portion **3514** and wristed robotic control can allow near infinite positions of approach for the light projection probe **3502**. Additionally, the camera is configured to maintain the best surgical approach position without having to project spectral/near infrared wavelengths.

[0178] In various instances, an attachment feature for a light projection probe, such as the probes **3102** (FIG. **23**) and

3502 (FIG. **28**) can include a magnetic alignment feature. For example, the light projection probe can include one or more magnets and a magnetic attraction between the light projection probe and the robotic tool can facilitate attachment and alignment of the light projection probe with the robotic tool. In certain instances, a magnetic attraction can attach the light projection probe to a robotic tool and/or robotic arm. For example, the magnetic attraction can facilitate manipulation of the light projection probe through tissue. In such instances, a surgical tool outside of the patient's body, such as a surgical device and/or robotic arm having a magnet thereon, can be configured to attract the light projection probe and draw the light projection probe into a desired location. The use magnetic forces to manipulate medical devices within a patient is further described in U.S. Patent Application Publication No. 2010/0152539, titled POSITIONABLE IMAGING MEDICAL DEVICES, which published on Jun. 17, 2018, which is incorporated by reference herein in its entirety.

[0179] Referring now to FIG. **29**, a surgical visualization system **3700** including a camera **3720** and a light projection probe **3702** having a magnetic attachment portion **3714** is shown. For example, the surgical visualization system **3700** can be configured to identify one or more critical structures embedded in tissue or otherwise hidden from view, and to determine one or more distances with respect to the visible tissue and/or critical structure(s). The surgical visualization system **3700** can be used together with one or more surgical tools, such as a surgical tool **3722**, which is a grasper. The light projection probe **3702** is similar in many respects to the light projection probe **3502**. For example, the light projection probe **3702** is a combination probe that is configured to emit a structured light pattern **3724** from a first projector **3710***a* and spectral light waves **3726** in a plurality of wavelengths from a second projector **3710***b*. In such instances, the light projection probe **3702** facilitates identification of hidden structures in combination with three-dimensional surface mapping of the visible structures.

[0180] The attachment portion **3714** of the light projection probe **3702** includes a magnet **3716**. In other instances, the attachment portion **3714** can includes an array of magnets. In one aspect, the attachment portion **3714** can include a metal plate comprised of a ferrous material. Additionally or alternatively, a plurality of magnets, such as rare earth magnets, for example, can be embedded in the attachment portion **3714**.

[0181] The light projection probe **3702** is maneuverable by a manipulation tool **3732** that is releasably coupled to a robotic arm **3730**. For example, the manipulation tool **3732** includes a magnetic interface **3734**. The manipulation tool **3732** and the magnetic interface **3734** are positioned outside of a wall **3705** of the patient **3703**. Magnetic forces between the magnetic interface **3734** and the magnet **3716** are configured to draw the attachment portion **3714** toward the manipulation tool **3732** and the wall **3705** of the patient **3703**. The manipulation tool **3732** is configured to remotely position the light projection probe **3702** at a desired position and desired angle from outside the patient.

[0182] In other instances, the light projection probe **3702** can be manipulated by a non-robotic surgical device. For example, the magnetic interface **3734** can be coupled to a handle in certain instances.

[0183] In certain instances, the magnetic interface **3734** can comprise an array of magnetic elements. For example, the north and south poles of the magnetic elements can be arranged to draw the attachment portion **3714** into an aligned position relative to the magnetic interface **3734**. In such instances, one or more of the magnetic elements can be alignment features and attachment features. In certain instances, the magnetic interface **3734** can include electromagnets, which can be controlled by the robotic system.

Example Clinical Applications

[0184] Various surgical visualization systems disclosed herein may be employed in one or more of the following clinical applications. The following clinical applications are non-exhaustive and merely illustrative applications for one or more of the various surgical visualization systems disclosed herein.

[0185] A surgical visualization system, as disclosed herein, can be employed in a number of different types of procedures for different medical specialties, such as urology, gynecology, oncology, colorectal, thoracic, bariatric/gastric, and hepato-pancreato-biliary (HPB), for example. In urological procedures, such as a prostatectomy, for example, the ureter may be detected in fat or connective tissue and/or nerves may be detected in fat, for example. In gynecological oncology procedures, such as a hysterectomy, for example, and in colorectal procedures, such as a low anterior resection (LAR) procedure, for example, the ureter may be detected in fat and/or in connective tissue, for example. In thoracic procedures, such as a lobectomy, for example, a vessel may be detected in the lung or in connective tissue and/or a nerve may be detected in connective tissue (e.g., an esophagostomy). In bariatric procedures, a vessel may be detected in fat. In HPB procedures, such as a hepatectomy or pancreatectomy, for example, a vessel may be detected in fat (extrahepatic), in connective tissue (extrahepatic), and the bile duct may be detected in parenchyma (liver or pancreas) tissue.

[0186] In one example, a clinician may want to remove an endometrial myoma. From a preoperative magnetic resonance imaging (MRI) scan, the clinician may know that the endometrial myoma is located on the surface of the bowel. Therefore, the clinician may want to know, intraoperatively, what tissue constitute a portion of the bowel and what tissue constitutes a portion of the rectum. In such instances, a surgical visualization system, as disclosed herein, can indicate the different types of tissue (bowel versus rectum) and convey that information to a clinician via an imaging system. Moreover, the imaging system can determine and communicate the proximity of a surgical device to the select tissue. In such instances, the surgical visualization system can provide increased procedural efficiency without critical complications.

[0187] In another example, a clinician (e.g. a gynecologist) may stay away from certain anatomic regions to avoid getting too close to critical structures and, thus, the clinician may not remove all of the endometriosis, for example. A surgical visualization system, as disclosed herein, can enable the gynecologist to mitigate the risk of getting too close to the critical structure such that the gynecologist can get close enough with the surgical device to remove all the endometriosis, which can improve the patient outcomes (democratizing surgery). Such a system can enable the surgeon to "keep moving" during the surgical procedure instead of repeatedly stopping and restarting in order to identify areas to avoid, especially during the application of therapeutic energy such as ultrasonic or electrosurgical energy, for example. In gynecological applications, uterine arteries and ureters are important critical structures and the system may be particularly useful for hysterectomy and endometriosis procedures given the presentation and/or thickness of tissue involved.

[0188] In another example, a clinician may risk dissection of a vessel at a location that is too proximal and, thus, which can affect blood supply to a lobe other than the target lobe. Moreover, anatomic differences from patient to patient may lead to dissection of a vessel (e.g. a branch) that affects a different lobe based on the particular patient. A surgical visualization system, as disclosed herein, can enable the identification of the correct vessel at the desired location, which enables the clinician to dissect with appropriate anatomic certainty. For example, the system can confirm that the correct vessel is in the correct place and then the clinician can safely divide the vessel.

[0189] In another example, a clinician may make multiple dissections before dissecting at the best location due to uncertainty about the anatomy of the vessel. However, it is desirable to dissect in the best location in the first instance because more dissection can increase the risk of bleeding. A surgical visualization system, as disclosed herein, can minimize the number of dissections by indicating the correct vessel and the best location for dissection. Ureters and cardinal ligaments, for example, are dense and provide unique challenges during dissection. In such instances, it can be especially desirable to minimize the number of dissections.

[0190] In another example, a clinician (e.g. a surgical oncologist) removing cancerous tissue may want to know the identification of critical structures, localization of the cancer, staging of the cancer, and/or an evaluation of tissue health. Such information is beyond what a clinician sees with the “naked eye”. A surgical visualization system, as disclosed herein, can determine and/or convey such information to the clinician intraoperatively to enhance intraoperative decision making and improve surgical outcomes. In certain instances, the surgical visualization system can be compatible with minimally invasive surgery (MIS), open surgery, and/or robotic approaches using either an endoscope or exoscope, for example.

[0191] In another example, a clinician (e.g. a surgical oncologist) may want to turn off one or more alerts regarding the proximity of a surgical tool to one or more critical structure to avoid being overly conservative during a surgical procedure. In other instances, the clinician may want to receive certain types of alerts, such as haptic feedback (e.g. vibrations/buzzing) to indicate proximity and/or or “no fly zones” to stay sufficiently far away from one or more critical structures. A surgical visualization system, as disclosed herein, can provide flexibility based on the experience of the clinician and/or desired aggressiveness of the procedure, for example. In such instances, the system provides a balance between “knowing too much” and “knowing enough” to anticipate and avoid critical structures. The surgical visualization system can assist in planning the next step(s) during a surgical procedure.

EXAMPLES

[0192] Various aspects of the subject matter described herein are set out in the following numbered examples.

[0193] Example 1—A robotic surgical system comprising a structured light source, a shaft-less tool comprising a projector configured to emit a structured light pattern on a surface of an anatomical structure, and a cable extending from the shaft-less tool to the structured light source.

[0194] Example 2—The robotic surgical system of Example 1, further comprising an image sensor configured to detect the structured light pattern.

[0195] Example 3—The robotic surgical system of Example 2, further comprising a robotic arm and a grasper operably coupled to the robotic arm, wherein the grasper is configured to grasp the shaft-less tool at a particular location.

[0196] Example 4—The robotic surgical system of Example 3, wherein the shaft-less tool further comprises a tab, and wherein the grasper is configured to releasably grasp the tab to maneuver the shaft-less tool.

[0197] Example 5—The robotic surgical system of Examples 2 or 4, further comprising a control circuit in signal communication with the image sensor, wherein the control circuit is configured to determine a distance from the projector to the surface of the anatomical structure.

[0198] Example 6—The robotic surgical system of Example 5, wherein the control circuit is further configured to determine the coordinates of the shaft-less tool in a robotic coordinate system.

[0199] Example 7—The robotic surgical system of Examples 5 or 6, further comprising a second robotic arm and a second tool operably coupled to the second robotic arm, wherein the control circuit is further configured to determine a tool-to-tool distance between the shaft-less tool and the second tool and a second distance between the second tool and the anatomical structure.

[0200] Example 8—The robotic surgical system of Example 2, further comprising a spectral light source, wherein the shaft-less tool further comprises a second projector configured to emit spectral light waves in a plurality of wavelengths capable of penetrating the anatomical structure and reaching an embedded structure located below the surface of the anatomical structure, wherein the cable extends to the spectral light source.

[0201] Example 9—The robotic surgical system of Example 8, further comprising a control circuit in signal communication with the image sensor, wherein the control circuit is configured to determine a depth of the embedded structure below the surface of the anatomical structure.

[0202] Example 10—The robotic surgical system of Examples 1, 2, 3, 4, 5, 6, 7, 8, or 9, wherein the shaft-less tool further comprises a first magnet, and wherein the robotic surgical system further comprises a robotic arm and a second magnet operably coupled to the robotic arm, wherein a magnetic attraction between the first magnet and the second magnet allows the robotic arm to maneuver the shaft-less tool.

[0203] Example 11—The robotic surgical system of Examples 1, 2, 3, 4, 5, 6, or 7, wherein the shaft-less tool further comprises a second projector configured to emit photoacoustic signals in a plurality of wavelengths capable of penetrating the anatomical structure and reaching an embedded structure located below the surface of the anatomical structure.

[0204] Example 12—The robotic surgical system of Example 11, further comprising a receiver configured to detect ultrasonic vibrations of the photoacoustic signals.

[0205] Example 13—A robotic surgical tool comprising a structured light source and a body. The body comprises a distal end comprising a projector configured to emit a structured light pattern. The body further comprises a proximal end and a projection extending from the body. The robotic surgical tool further comprises a cable extending from the proximal end to the structured light source.

[0206] Example 14—The robotic surgical tool of Example 13, further comprising a spectral light source, and wherein the distal end further comprises a spectral projector configured to emit spectral light in a plurality of wavelengths.

[0207] Example 15—The robotic surgical tool of Examples 13 or 14, wherein the cable comprises a fiber optic cable.

[0208] Example 16—The robotic surgical tool of Examples 13, 14, or 15, wherein the projection comprises a central portion extending radially from the body. The projection further comprises an alignment flange extending from the central portion.

[0209] Example 17—The robotic surgical tool of Examples 13, 14, 15, or 16, further comprising a second projector configured to emit photoacoustic signals in a plurality of wavelengths capable of penetrating an anatomical structure and reaching an embedded structure located below the surface of the anatomical structure.

[0210] Example 18—A shaft-less robotic tool comprising a proximal component comprising a first magnet, and a distal component comprising a second magnet. A magnetic attraction between the first magnet and the second magnet allows the proximal component to maneuver the distal component through tissue. The distal component further comprises a first projector configured to emit a structured light pattern on a surface of an anatomical structure. The distal component further comprises a second projector configured to emit spectral light in a plurality of wavelengths capable of penetrating the anatomical structure and reaching an embedded structure located below the surface of the anatomical structure.

[0211] Example 19—The shaft-less robotic tool of Example 18, further comprising a flexible cable extending from the distal component to a light source.

[0212] Example 20—The shaft-less robotic tool of Example 19, wherein the light source is configured to provide light to the first projector and the second projector.

[0213] While several forms have been illustrated and described, it is not the intention of Applicant to restrict or limit the scope of the appended claims to such detail. Numerous modifications, variations, changes, substitutions, combinations, and equivalents to those forms may be implemented and will occur to those skilled in the art without departing from the scope of the present disclosure. Moreover, the structure of each element associated with the described forms can be alternatively described as a means for providing the function performed by the element. Also, where materials are disclosed for certain components, other materials may be used. It is therefore to be understood that the foregoing description and the appended claims are intended to cover all such modifications, combinations, and variations as falling within the scope of the disclosed forms. The appended claims are intended to cover all such modifications, variations, changes, substitutions, modifications, and equivalents.

[0214] The foregoing detailed description has set forth various forms of the devices and/or processes via the use of block diagrams, flowcharts, and/or examples. Insofar as such block diagrams, flowcharts, and/or examples contain one or more functions and/or operations, it will be understood by those within the art that each function and/or operation within such block diagrams, flowcharts, and/or examples can be implemented, individually and/or collectively, by a wide range of hardware, software, firmware, or virtually any combination thereof. Those skilled in the art will recognize that some aspects of the forms disclosed herein, in whole or in part, can be equivalently implemented in integrated circuits, as one or more computer programs running on one or more computers (e.g., as one or more programs running on one or more computer systems), as one or more programs running on one or more processors (e.g., as one or more programs running on one or more microprocessors), as firmware, or as virtually any combination thereof, and that designing the circuitry and/or writing the code for the software and or firmware would be well within the skill of one of skill in the art in light of this disclosure. In addition, those skilled in the art will appreciate that the mechanisms of the subject matter described herein are capable of being distributed as one or more program products in a variety of forms, and that an illustrative form of the subject matter described herein applies regardless of the particular type of signal bearing medium used to actually carry out the distribution.

[0215] Instructions used to program logic to perform various disclosed aspects can be stored within a memory in the system, such as dynamic random access memory (DRAM), cache, flash memory, or other storage. Furthermore, the instructions can be distributed via a network or by way of other computer readable media. Thus a machine-readable medium may include any mechanism for storing or transmitting information in a form readable by a machine (e.g., a computer), but is not limited to, floppy diskettes, optical disks, compact disc, read-only memory (CD-ROMs), and magneto-optical disks, read-only memory (ROMs), random access memory (RAM), erasable programmable read-only memory (EPROM), electrically erasable programmable read-only memory (EEPROM), magnetic or optical cards, flash memory, or a tangible, machine-readable storage used in the transmission of information over the Internet via electrical, optical, acoustical or other forms of propagated signals (e.g., carrier waves, infrared signals, digital signals, etc.). Accordingly, the non-transitory computer-readable medium includes any type of tangible machine-readable medium suitable for storing or transmitting electronic instructions or information in a form readable by a machine (e.g., a computer).

[0216] As used in any aspect herein, the term “control circuit” may refer to, for example, hardwired circuitry, programmable circuitry (e.g., a computer processor including one or more individual instruction processing cores, processing unit, processor, microcontroller, microcontroller unit, controller, digital signal processor (DSP), programmable logic device (PLD), programmable logic array (PLA), or field programmable gate array (FPGA)), state machine circuitry, firmware that stores instructions executed by programmable circuitry, and any combination thereof. The control circuit may, collectively or individually, be embodied as circuitry that forms part of a larger system, for example, an integrated circuit (IC), an application-specific integrated circuit (ASIC), a system on-chip (SoC), desktop computers, laptop computers, tablet computers, servers, smart phones, etc. Accordingly, as used herein “control circuit” includes, but is not limited to, electrical circuitry having at least one discrete electrical circuit, electrical circuitry having at least one integrated circuit, electrical circuitry having at least one application specific integrated circuit, electrical circuitry forming a general purpose computing device configured by a computer program (e.g., a general purpose computer configured by a computer program which at least partially carries out processes and/or devices described herein, or a microprocessor configured by a computer program which at least partially carries out processes and/or devices described herein), electrical circuitry forming a memory device (e.g., forms of random access memory), and/or electrical circuitry forming a communications device (e.g., a modem, communications switch, or optical-electrical equipment). Those having skill in the art will recognize that the subject matter described herein may be implemented in an analog or digital fashion or some combination thereof.

[0217] As used in any aspect herein, the term "logic" may refer to an app, software, firmware and/or circuitry configured to perform any of the aforementioned operations. Software may be embodied as a software package, code, instructions, instruction sets and/or data recorded on non-transitory computer readable storage medium. Firmware may be embodied as code, instructions or instruction sets and/or data that are hard-coded (e.g., nonvolatile) in memory devices.

[0218] As used in any aspect herein, the terms "component," "system," "module" and the like can refer to a computer-related entity, either hardware, a combination of hardware and software, software, or software in execution.

[0219] As used in any aspect herein, an "algorithm" refers to a self-consistent sequence of steps leading to a desired result, where a "step" refers to a manipulation of physical quantities and/or logic states which may, though need not necessarily, take the form of electrical or magnetic signals capable of being stored, transferred, combined, compared, and otherwise manipulated. It is common usage to refer to these signals as bits, values, elements, symbols, characters, terms, numbers, or the like. These and similar terms may be associated with the appropriate physical quantities and are merely convenient labels applied to these quantities and/or states.

[0220] A network may include a packet switched network. The communication devices may be capable of communicating with each other using a selected packet switched network communications protocol. One example communications protocol may include an Ethernet communications protocol which may be capable permitting communication using a Transmission Control Protocol/Internet Protocol (TCP/IP). The Ethernet protocol may comply or be compatible with the Ethernet standard published by the Institute of Electrical and Electronics Engineers (IEEE) titled "IEEE 802.3 Standard", published in December, 2008 and/or later versions of this standard. Alternatively or additionally, the communication devices may be capable of communicating with each other using an X.25 communications protocol. The X.25 communications protocol may comply or be compatible with a standard promulgated by the International Telecommunication Union-Telecommunication Standardization Sector (ITU-T). Alternatively or additionally, the communication devices may be capable of communicating with each other using a frame relay communications protocol. The frame relay communications protocol may comply or be compatible with a standard promulgated by Consultative Committee for International Telegraph and Telephone (CCITT) and/or the American National Standards Institute (ANSI). Alternatively or additionally, the transceivers may be capable of communicating with each other using an Asynchronous Transfer Mode (ATM) communications protocol. The ATM communications protocol may comply or be compatible with an ATM standard published by the ATM Forum titled "ATM-MPLS Network Interworking 2.0" published August 2001, and/or later versions of this standard. Of course, different and/or after-developed connection-oriented network communication protocols are equally contemplated herein.

[0221] Unless specifically stated otherwise as apparent from the foregoing disclosure, it is appreciated that, throughout the foregoing disclosure, discussions using terms such as "processing," "computing," "calculating," "determining," "displaying," or the like, refer to the action and processes of a computer system, or similar electronic computing device, that manipulates and transforms data represented as physical (electronic) quantities within the computer system's registers and memories into other data similarly represented as physical quantities within the computer system memories or registers or other such information storage, transmission or display devices.

[0222] One or more components may be referred to herein as "configured to," "configurable to," "operable/operative to," "adapted/adaptable," "able to," "conformable/conformed to," etc. Those skilled in the art will recognize that "configured to" can generally encompass active-state components and/or inactive-state components and/or standby-state components, unless context requires otherwise.

[0223] The terms "proximal" and "distal" are used herein with reference to a clinician manipulating the handle portion of the surgical instrument. The term "proximal" refers to the portion closest to the clinician and the term "distal" refers to the portion located away from the clinician. It will be further appreciated that, for convenience and clarity, spatial terms such as "vertical", "horizontal", "up", and "down" may be used herein with respect to the drawings. However, surgical instruments are used in many orientations and positions, and these terms are not intended to be limiting and/or absolute.

[0224] Those skilled in the art will recognize that, in general, terms used herein, and especially in the appended claims (e.g., bodies of the appended claims) are generally intended as "open" terms (e.g., the term "including" should be interpreted as "including but not limited to," the term "having" should be interpreted as "having at least," the term "includes" should be interpreted as "includes but is not limited to," etc.). It will be further understood by those within the art that if a specific number of an introduced claim recitation is intended, such an intent will be explicitly recited in the claim, and in the absence of such recitation no such intent is present. For example, as an aid to understanding, the following appended claims may contain usage of the introductory phrases "at least one" and "one or more" to introduce claim recitations. However, the use of such phrases should not be construed to imply that the introduction of a claim recitation by the indefinite articles "a" or "an" limits any particular claim containing such introduced claim recitation to claims containing only one such recitation, even when the same claim includes the introductory phrases "one or more" or "at least one" and indefinite articles such as "a" or "an" (e.g., "a" and/or "an" should typically be interpreted to mean "at least one" or "one or more"); the same holds true for the use of definite articles used to introduce claim recitations.

[0225] In addition, even if a specific number of an introduced claim recitation is explicitly recited, those skilled in the art will recognize that such recitation should typically be interpreted to mean at least the recited number (e.g., the bare recitation of "two recitations," without other modifiers, typically means at least two recitations, or two or more recitations). Furthermore, in those instances where a convention analogous to "at least one of A, B, and C, etc." is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., "a system having at least one of A, B, and C" would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). In those instances where a convention analogous to "at least one of A, B, or C, etc." is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., "a system having at least one of A, B, or C" would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). It will be further understood by those within the art that typically a disjunctive word and/or phrase presenting two or more alternative terms, whether in the description, claims, or drawings, should be understood to contemplate the possibilities of including one of the terms, either of the terms, or both terms unless context dictates otherwise. For example, the phrase "A or B" will be typically understood to include the possibilities of "A" or "B" or "A and B."

[0226] With respect to the appended claims, those skilled in the art will appreciate that recited operations therein may generally be performed in any order. Also, although various operational flow diagrams are presented in a sequence(s), it should be understood that the various operations may be performed in other orders than those which are illustrated, or may be performed concurrently. Examples of such alternate orderings may include overlapping, interleaved, interrupted, reordered, incremental, preparatory, supplemental, simultaneous, reverse, or other variant orderings, unless context dictates otherwise. Furthermore, terms like "responsive to," "related to," or other past-tense adjectives are generally not intended to exclude such variants, unless context dictates otherwise.

[0227] It is worthy to note that any reference to "one aspect," "an aspect," "an exemplification," "one exemplification," and the like means that a particular feature, structure, or characteristic described in connection with the aspect is included in at least one aspect. Thus, appearances of the phrases "in one aspect," "in an aspect," "in an exemplification," and "in one exemplification" in various places throughout the specification are not necessarily all referring to the same aspect. Furthermore, the particular features, structures or characteristics may be combined in any suitable manner in one or more aspects.

[0228] Any patent application, patent, non-patent publication, or other disclosure material referred to in this specification and/or listed in any Application Data Sheet is incorporated by reference herein, to the extent that the incorporated materials is not inconsistent herewith. As such, and to the extent necessary, the disclosure as explicitly set forth herein supersedes any conflicting material incorporated herein by reference. Any material, or portion thereof, that is said to be incorporated by reference herein, but which conflicts with existing definitions, statements, or other disclosure material set forth herein will only be incorporated to the extent that no conflict arises between that incorporated material and the existing disclosure material.

[0229] In summary, numerous benefits have been described which result from employing the concepts described herein. The foregoing description of the one or more forms has been presented for purposes of illustration and description. It is not intended to be exhaustive or limiting to the precise form disclosed. Modifications or variations are possible in light of the above teachings. The one or more forms were chosen and described in order to illustrate principles and practical application to thereby enable one of ordinary skill in the art to utilize the various forms and with various modifications as are suited to the particular use contemplated. It is intended that the claims submitted herewith define the overall scope.

What is claimed is:

1. A robotic surgical system, comprising:

a structured light source;

a shaft-less tool comprising a projector configured to emit a structured light pattern on a surface of an anatomical structure; and

a cable extending from the shaft-less tool to the structured light source.

2. The robotic surgical system of claim **1**, further comprising an image sensor configured to detect the structured light pattern.

3. The robotic surgical system of claim **2**, further comprising:

a robotic arm; and

a grasper operably coupled to the robotic arm, wherein the grasper is configured to grasp the shaft-less tool at a particular location.

4. The robotic surgical system of claim **3**, wherein the shaft-less tool further comprises a tab, and wherein the grasper is configured to releasably grasp the tab to maneuver the shaft-less tool.

5. The robotic surgical system of claim **4**, further comprising a control circuit in signal communication with the image sensor, wherein the control circuit is configured to determine a distance from the projector to the surface of the anatomical structure.

6. The robotic surgical system of claim **5**, wherein the control circuit is further configured to determine the coordinates of the shaft-less tool in a robotic coordinate system.

7. The robotic surgical system of claim **6**, further comprising:

a second robotic arm; and

a second tool operably coupled to the second robotic arm, wherein the control circuit is further configured to determine a tool-to-tool distance between the shaft-less tool and the second tool and a second distance between the second tool and the anatomical structure.

8. The robotic surgical system of claim **2**, further comprising a spectral light source, wherein the shaft-less tool further comprises a second projector configured to emit spectral light waves in a plurality of wavelengths capable of penetrating the anatomical structure and reaching an embedded structure located below the surface of the anatomical structure, wherein the cable extends to the spectral light source.

9. The robotic surgical system of claim **8**, further comprising a control circuit in signal communication with the image sensor, wherein the control circuit is configured to determine a depth of the embedded structure below the surface of the anatomical structure.

10. The robotic surgical system of claim **1**, wherein the shaft-less tool further comprises a first magnet, and wherein the robotic surgical system further comprises:

a robotic arm; and

a second magnet operably coupled to the robotic arm, wherein a magnetic attraction between the first magnet and the second magnet allows the robotic arm to maneuver the shaft-less tool.

11. The robotic surgical system of claim **1**, wherein the shaft-less tool further comprises a second projector configured to emit photoacoustic signals in a plurality of wavelengths capable of penetrating the anatomical structure and reaching an embedded structure located below the surface of the anatomical structure.

12. The robotic surgical system of claim **11**, further comprising a receiver configured to detect ultrasonic vibrations of the photoacoustic signals.

13. A robotic surgical tool, comprising:

a structured light source;

a body, comprising:

a distal end comprising a projector configured to emit a structured light pattern;

a proximal end; and

a projection extending from the body; and

a cable extending from the proximal end to the structured light source.

14. The robotic surgical tool of claim **13**, further comprising a spectral light source, and wherein the distal end further comprises a spectral projector configured to emit spectral light in a plurality of wavelengths.

15. The robotic surgical tool of claim **14**, wherein the cable comprises a fiber optic cable.

16. The robotic surgical tool of claim **13**, wherein the projection comprises:

a central portion extending radially from the body; and

an alignment flange extending from the central portion.

17. The robotic surgical tool of claim **13**, further comprising a second projector configured to emit photoacoustic signals in a plurality of wavelengths capable of penetrating an anatomical structure and reaching an embedded structure located below the surface of the anatomical structure.

18. A shaft-less robotic tool, comprising:

a proximal component comprising a first magnet; and

a distal component, comprising:

a second magnet, wherein a magnetic attraction between the first magnet and the second magnet allows the proximal component to maneuver the distal component through tissue;

a first projector configured to emit a structured light pattern on a surface of an anatomical structure; and

a second projector configured to emit spectral light in a plurality of wavelengths capable of penetrating the anatomical structure and reaching an embedded structure located below the surface of the anatomical structure.

19. The shaft-less robotic tool of claim **18**, further comprising a flexible cable extending from the distal component to a light source.

20. The shaft-less robotic tool of claim **19**, wherein the light source is configured to provide light to the first projector and the second projector.

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