(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
04 July 2019 (04.07.2019)

WIPO | PCT

(10) International Publication Number
WO 2019/130088 A1

(51) International Patent Classification:
G16H 40/63 (2018.01) *A61B 17/068* (2006.01)

(21) International Application Number:
PCT/IB2018/057328

(22) International Filing Date:
21 September 2018 (21.09.2018)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:

62/611,339	28 December 2017 (28.12.2017)	US
62/611,340	28 December 2017 (28.12.2017)	US
62/611,341	28 December 2017 (28.12.2017)	US
62/691,227	28 June 2018 (28.06.2018)	US
16/024,138	29 June 2018 (29.06.2018)	US

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

WO 2019/130088 A1

(54) Title: SYSTEMS FOR DETECTING PROXIMITY OF SURGICAL END EFFECTOR TO CANCEROUS TISSUE

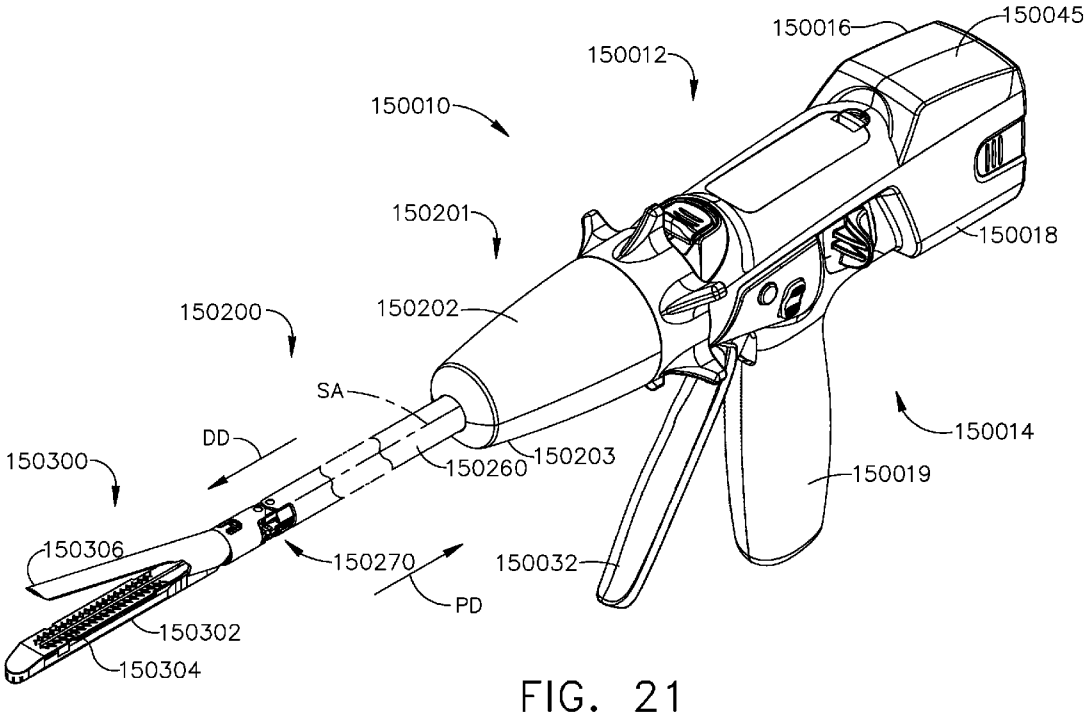


FIG. 21

(57) Abstract: A surgical instrument includes an end effector having a first jaw, a second jaw movable relative to the first jaw to grasp tissue therebetween, an anvil, a staple cartridge comprising staples deployable into the tissue, wherein the staples are deformable by the anvil, and a sensor configured to provide a sensor signal according to a physiological parameter of the tissue. The surgical instrument further includes a control circuit coupled to the sensor, wherein the control circuit is configured to receive the sensor signal, and assess proximity of the sensor to cancerous tissue based on the sensor signal.

[Continued on next page]

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

Published:

— *with international search report (Art. 21(3))*

— *in black and white; the international application as filed contained color or greyscale and is available for download from PATENTSCOPE*

SYSTEMS FOR DETECTING PROXIMITY OF SURGICAL END EFFECTOR TO CANCEROUS TISSUE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of priority under 35 U.S.C. § 119(e) to U.S. Provisional Patent Application Serial No. 62/691,227, titled CONTROLLING A SURGICAL INSTRUMENT ACCORDING TO SENSED CLOSURE PARAMETERS, filed June 28, 2018, the disclosure of which is herein incorporated by reference in its entirety.

[0002] This application claims the benefit of priority under 35 U.S.C. § 119(e) to U.S. Provisional Patent Application Serial No. 62/650,887, titled SURGICAL SYSTEMS WITH OPTIMIZED SENSING CAPABILITIES, filed March 30, 2018, to U.S. Provisional Patent Application Serial No. 62/650,877, titled SURGICAL SMOKE EVACUATION SENSING AND CONTROLS, filed March 30, 2018, to U.S. Provisional Patent Application Serial No. 62/650,882, titled SMOKE EVACUATION MODULE FOR INTERACTIVE SURGICAL PLATFORM, filed March 30, 2018, and to U.S. Provisional Patent Application Serial No. 62/650,898, titled CAPACITIVE COUPLED RETURN PATH PAD WITH SEPARABLE ARRAY ELEMENTS, filed March 30, 2018, the disclosure of each of which is herein incorporated by reference in its entirety.

[0003] This application also claims the benefit of priority under 35 U.S.C. § 119(e) to U.S. Provisional Patent Application Serial No. 62/640,417, titled TEMPERATURE CONTROL IN ULTRASONIC DEVICE AND CONTROL SYSTEM THEREFOR, filed March 8, 2018, and to Provisional Patent Application Serial No. 62/640,415, titled ESTIMATING STATE OF ULTRASONIC END EFFECTOR AND CONTROL SYSTEM THEREFOR, filed March 8, 2018, the disclosure of each of which is herein incorporated by reference in its entirety.

[0004] This application also claims the benefit of priority under 35 U.S.C. § 119(e) to U.S. Provisional Patent Application Serial No. 62/611,341, titled INTERACTIVE SURGICAL PLATFORM, filed December 28, 2017, to U.S. Provisional Patent Application Serial No. 62/611,340, titled CLOUD-BASED MEDICAL ANALYTICS, filed December 28, 2017, and to U.S. Provisional Patent Application Serial No. 62/611,339, titled ROBOT ASSISTED SURGICAL PLATFORM, filed December 28, 2017, the disclosure of each of which is herein incorporated by reference in its entirety.

BACKGROUND

[0005] The present disclosure relates to various surgical systems.

SUMMARY

[0006] A surgical instrument is disclosed. The surgical instrument comprises an end effector and a control circuit. The end effector comprises a first jaw, a second jaw movable relative to the first jaw to

grasp tissue therebetween, an anvil, a staple cartridge comprising staples deployable into the tissue, wherein the staples are deformable by the anvil, and a sensor configured to provide a sensor signal according to a physiological parameter of the tissue. The control circuit is coupled to the sensor, wherein the control circuit is configured to receive the sensor signal, and assess proximity of the sensory to cancerous tissue based on the sensor signal.

[0007] A surgical stapling instrument is disclosed. The surgical stapling instrument comprises an end effector and a control circuit. The end effector comprises a first jaw, a second jaw movable relative to the first jaw to grasp tissue therebetween, an anvil, a staple cartridge comprising staples deployable into the tissue, wherein the staples are deformable by the anvil, and a sensor configured to provide a sensory signal according to a physiological parameter indicative of proximity of the sensor to cancerous tissue. The control circuit is coupled to the sensor, wherein the control circuit is configured to receive the sensor signal, determine a value of the physiological parameter based on the sensor signal, and compare the value of the physiological parameter to a predetermined threshold.

[0008] A surgical instrument is disclosed. The surgical instrument comprises an end effector and a control circuit. The end effector comprises a first jaw, a second jaw movable relative to the first jaw to grasp tissue therebetween, an anvil, a staple cartridge comprising staples deployable into the tissue, wherein the staples are deformable by the anvil, and a sensor assembly configured to provide sensor signals according to a physiological parameter indicative of proximity of the sensors to cancerous tissue. The sensor assembly comprises a first sensor on a first side of a longitudinal axis extending through the staple cartridge and a second sensor on a second side of the longitudinal axis. The control circuit is coupled to the sensor assembly, wherein the control circuit is configured to receive a first sensor signal from the first sensor, receive a second sensor signal from the second sensor, determine a first value of the physiological parameter based on the first sensor signal, determine a second value of the physiological parameter based on the second sensor signal, and compare the first value and the second value to a predetermined threshold.

FIGURES

[0009] The features of various aspects are set forth with particularity in the appended claims. The various aspects, however, both as to organization and methods of operation, together with further objects and advantages thereof, may best be understood by reference to the following description, taken in conjunction with the accompanying drawings as follows.

[0010] FIG. 1 is a block diagram of a computer-implemented interactive surgical system, in accordance with at least one aspect of the present disclosure.

[0011] FIG. 2 is a surgical system being used to perform a surgical procedure in an operating room, in accordance with at least one aspect of the present disclosure.

[0012] FIG. 3 is a surgical hub paired with a visualization system, a robotic system, and an intelligent instrument, in accordance with at least one aspect of the present disclosure.

[0013] FIG. 4 is a partial perspective view of a surgical hub enclosure, and of a combo generator module slidably receivable in a drawer of the surgical hub enclosure, in accordance with at least one aspect of the present disclosure.

[0014] FIG. 5 is a perspective view of a combo generator module with bipolar, ultrasonic, and monopolar contacts and a smoke evacuation component, in accordance with at least one aspect of the present disclosure.

[0015] FIG. 6 illustrates individual power bus attachments for a plurality of lateral docking ports of a lateral modular housing configured to receive a plurality of modules, in accordance with at least one aspect of the present disclosure.

[0016] FIG. 7 illustrates a vertical modular housing configured to receive a plurality of modules, in accordance with at least one aspect of the present disclosure.

[0017] FIG. 8 illustrates a surgical data network comprising a modular communication hub configured to connect modular devices located in one or more operating theaters of a healthcare facility, or any room in a healthcare facility specially equipped for surgical operations, to the cloud, in accordance with at least one aspect of the present disclosure.

[0018] FIG. 9 illustrates a computer-implemented interactive surgical system, in accordance with at least one aspect of the present disclosure.

[0019] FIG. 10 illustrates a surgical hub comprising a plurality of modules coupled to the modular control tower, in accordance with at least one aspect of the present disclosure.

[0020] FIG. 11 illustrates one aspect of a Universal Serial Bus (USB) network hub device, in accordance with at least one aspect of the present disclosure.

[0021] FIG. 12 illustrates a logic diagram of a control system of a surgical instrument or tool, in accordance with at least one aspect of the present disclosure.

[0022] FIG. 13 illustrates a control circuit configured to control aspects of the surgical instrument or tool, in accordance with at least one aspect of the present disclosure.

[0023] FIG. 14 illustrates a combinational logic circuit configured to control aspects of the surgical instrument or tool, in accordance with at least one aspect of the present disclosure.

[0024] FIG. 15 illustrates a sequential logic circuit configured to control aspects of the surgical instrument or tool, in accordance with at least one aspect of the present disclosure.

[0025] FIG. 16 illustrates a surgical instrument or tool comprising a plurality of motors which can be activated to perform various functions, in accordance with at least one aspect of the present disclosure.

[0026] FIG. 17 is a schematic diagram of a robotic surgical instrument configured to operate a surgical tool described herein, in accordance with at least one aspect of the present disclosure.

[0027] FIG. 18 illustrates a block diagram of a surgical instrument programmed to control the distal translation of a displacement member, in accordance with at least one aspect of the present disclosure.

[0028] FIG. 19 is a schematic diagram of a surgical instrument configured to control various functions, in accordance with at least one aspect of the present disclosure.

[0029] FIG. 20 is a schematic illustration of a tissue contact circuit showing the completion of the circuit upon contact of tissue with a pair of spaced-apart contact plates, in accordance with at least one aspect of this disclosure.

[0030] FIG. 21 is a perspective view of a surgical instrument that has an interchangeable shaft assembly operably coupled thereto, in accordance with at least one aspect of this disclosure.

[0031] FIG. 22 is an exploded assembly view of a portion of the surgical instrument of FIG. 21, in accordance with at least one aspect of this disclosure.

[0032] FIG. 23 is an exploded assembly view of portions of the interchangeable shaft assembly, in accordance with at least one aspect of this disclosure.

[0033] FIG. 24 is an exploded view of an end effector of the surgical instrument of FIG. 21, in accordance with at least one aspect of this disclosure.

[0034] FIG. 25A is a block diagram of a control circuit of the surgical instrument of FIG. 21 spanning two drawing sheets, in accordance with at least one aspect of this disclosure.

[0035] FIG. 25B is a block diagram of a control circuit of the surgical instrument of FIG. 21 spanning two drawing sheets, in accordance with at least one aspect of this disclosure.

[0036] FIG. 26 is a block diagram of the control circuit of the surgical instrument of FIG. 21 illustrating interfaces between the handle assembly, the power assembly, and the handle assembly and the interchangeable shaft assembly, in accordance with at least one aspect of this disclosure.

[0037] FIG. 27 illustrates a tumor surrounded by healthy tissue, and a clear margin defined in the healthy tissue, in accordance with at least one aspect of the present disclosure.

[0038] FIG. 28 is a graph illustrating of a physiological parameter of tissue plotted against distance from a tumor, in accordance with at least one aspect of the present disclosure.

[0039] FIG. 29 is a logic flow diagram of a process depicting a control program or a logic configuration for assessing proximity of an end effector of a surgical instrument to cancerous tissue, in accordance with at least one aspect of the present disclosure.

[0040] FIG. 30 illustrates a logic flow diagram of a process depicting a control program or a logic configuration for assessing proximity of an end effector to cancerous tissue, in accordance with at least one aspect of the present disclosure.

[0041] FIG. 31 illustrates an end effector of a surgical instrument, in accordance with at least one aspect of the present disclosure.

[0042] FIG. 32 illustrates a control system of a surgical instrument, in accordance with at least one aspect of the present disclosure.

[0043] FIG. 33 illustrates a proximity index correlating a sensor signal to proximity from an end effector, in accordance with at least one aspect of the present disclosure.

[0044] FIG. 34 illustrates a logic flow diagram of a process depicting a control program or a logic configuration for determining the direction at which cancerous tissue is located with respect to an end effector, in accordance with at least one aspect of the present disclosure.

[0045] FIG. 35 illustrates a top view of an end effector of a surgical instrument, in accordance with at least one aspect of the present disclosure.

[0046] FIG. 36 is a graph illustrating sensor signals representing a physiological parameter of tissue plotted against time, in accordance with at least one aspect of the present disclosure.

[0047] FIG. 37 illustrates a partial view of an end effector of a surgical instrument, in accordance with at least one aspect of the present disclosure.

[0048] FIG. 38 is a graph illustrating sensor signals representing a physiological parameter of tissue plotted against time, in accordance with at least one aspect of the present disclosure.

[0049] FIG. 39 is a logic flow diagram of a process depicting a control program or a logic configuration for providing instructions for navigating an end effector with respect to cancerous tissue, in accordance with at least one aspect of the present disclosure.

[0050] FIG. 40 is a logic flow diagram of a process depicting a control program or a logic configuration for providing instructions for navigating an end effector with respect to cancerous tissue, in accordance with at least one aspect of the present disclosure.

[0051] FIG. 41 is a graph illustrating sensor signals representing a physiological parameter of tissue plotted against time, in accordance with at least one aspect of the present disclosure.

Error! No sequence specified. FIG. 42 illustrates a glucose sensor, in accordance with at least one aspect of the present disclosure.

[0052] FIG. 43 illustrates an expanded view of the glucose sensor of FIG. 42.

[0053] FIG. 44 is a graph illustrating Current plotted against Potential, in accordance with at least one aspect of the present disclosure.

[0054] FIG. 45 is a graph illustrating Net Current plotted against Glucose level, in accordance with at least one aspect of the present disclosure.

[0055] FIG. 46 is a timeline depicting situational awareness of a surgical hub, in accordance with at least one aspect of the present disclosure.

DESCRIPTION

[0056] Applicant of the present application owns the following U.S. Patent Applications, filed on June 29, 2018, the disclosure of each of which is herein incorporated by reference in its entirety:

- U.S. Patent Application Serial No. _____, titled CAPACITIVE COUPLED RETURN PATH PAD WITH SEPARABLE ARRAY ELEMENTS, Attorney Docket No. END8542USNP/170755;

- U.S. Patent Application Serial No. _____, titled CONTROLLING A SURGICAL INSTRUMENT ACCORDING TO SENSED CLOSURE PARAMETERS, Attorney Docket No. END8543USNP/170760;
- U.S. Patent Application Serial No. _____, titled SYSTEMS FOR ADJUSTING END EFFECTOR PARAMETERS BASED ON PERIOPERATIVE INFORMATION, Attorney Docket No. END8543USNP1/170760-1;
- U.S. Patent Application Serial No. _____, titled SAFETY SYSTEMS FOR SMART POWERED SURGICAL STAPLING, Attorney Docket No. END8543USNP2/170760-2;
- U.S. Patent Application Serial No. _____, titled SAFETY SYSTEMS FOR SMART POWERED SURGICAL STAPLING, Attorney Docket No. END8543USNP3/170760-3;
- U.S. Patent Application Serial No. _____, titled SURGICAL SYSTEMS FOR DETECTING END EFFECTOR TISSUE DISTRIBUTION IRREGULARITIES, Attorney Docket No. END8543USNP4/170760-4;
- U.S. Patent Application Serial No. _____, titled SURGICAL INSTRUMENT CARTRIDGE SENSOR ASSEMBLIES, Attorney Docket No. END8543USNP6/170760-6;
- U.S. Patent Application Serial No. _____, titled VARIABLE OUTPUT CARTRIDGE SENSOR ASSEMBLY, Attorney Docket No. END8543USNP7/170760-7;
- U.S. Patent Application Serial No. _____, titled SURGICAL INSTRUMENT HAVING A FLEXIBLE ELECTRODE, Attorney Docket No. END8544USNP/170761;
- U.S. Patent Application Serial No. _____, titled SURGICAL INSTRUMENT HAVING A FLEXIBLE CIRCUIT, Attorney Docket No. END8544USNP1/170761-1;
- U.S. Patent Application Serial No. _____, titled SURGICAL INSTRUMENT WITH A TISSUE MARKING ASSEMBLY, Attorney Docket No. END8544USNP2/170761-2;
- U.S. Patent Application Serial No. _____, titled SURGICAL SYSTEMS WITH PRIORITIZED DATA TRANSMISSION CAPABILITIES, Attorney Docket No. END8544USNP3/170761-3;
- U.S. Patent Application Serial No. _____, titled SURGICAL EVACUATION SENSING AND MOTOR CONTROL, Attorney Docket No. END8545USNP/170762;
- U.S. Patent Application Serial No. _____, titled SURGICAL EVACUATION SENSOR ARRANGEMENTS, Attorney Docket No. END8545USNP1/170762-1;
- U.S. Patent Application Serial No. _____, titled SURGICAL EVACUATION FLOW PATHS, Attorney Docket No. END8545USNP2/170762-2;
- U.S. Patent Application Serial No. _____, titled SURGICAL EVACUATION SENSING AND GENERATOR CONTROL, Attorney Docket No. END8545USNP3/170762-3;

- U.S. Patent Application Serial No. _____, titled SURGICAL EVACUATION SENSING AND DISPLAY, Attorney Docket No. END8545USNP4/170762-4;
- U.S. Patent Application Serial No. _____, titled COMMUNICATION OF SMOKE EVACUATION SYSTEM PARAMETERS TO HUB OR CLOUD IN SMOKE EVACUATION MODULE FOR INTERACTIVE SURGICAL PLATFORM, Attorney Docket No. END8546USNP/170763;
- U.S. Patent Application Serial No. _____, titled SMOKE EVACUATION SYSTEM INCLUDING A SEGMENTED CONTROL CIRCUIT FOR INTERACTIVE SURGICAL PLATFORM, Attorney Docket No. END8546USNP1/170763-1;
- U.S. Patent Application Serial No. _____, titled SURGICAL EVACUATION SYSTEM WITH A COMMUNICATION CIRCUIT FOR COMMUNICATION BETWEEN A FILTER AND A SMOKE EVACUATION DEVICE, Attorney Docket No. END8547USNP/170764; and
- U.S. Patent Application Serial No. _____, titled DUAL IN-SERIES LARGE AND SMALL DROPLET FILTERS, Attorney Docket No. END8548USNP/170765.

[0057] Applicant of the present application owns the following U.S. Provisional Patent Applications, filed on June 28, 2018, the disclosure of each of which is herein incorporated by reference in its entirety:

- U.S. Provisional Patent Application Serial No. 62/691,228, titled A METHOD OF USING REINFORCED FLEX CIRCUITS WITH MULTIPLE SENSORS WITH ELECTROSURGICAL DEVICES;
- U.S. Provisional Patent Application Serial No. 62/691,227, titled CONTROLLING A SURGICAL INSTRUMENT ACCORDING TO SENSED CLOSURE PARAMETERS;
- U.S. Provisional Patent Application Serial No. 62/691,230, titled SURGICAL INSTRUMENT HAVING A FLEXIBLE ELECTRODE;
- U.S. Provisional Patent Application Serial No. 62/691,219, titled SURGICAL EVACUATION SENSING AND MOTOR CONTROL;
- U.S. Provisional Patent Application Serial No. 62/691,257, titled COMMUNICATION OF SMOKE EVACUATION SYSTEM PARAMETERS TO HUB OR CLOUD IN SMOKE EVACUATION MODULE FOR INTERACTIVE SURGICAL PLATFORM;
- U.S. Provisional Patent Application Serial No. 62/691,262, titled SURGICAL EVACUATION SYSTEM WITH A COMMUNICATION CIRCUIT FOR COMMUNICATION BETWEEN A FILTER AND A SMOKE EVACUATION DEVICE; and
- U.S. Provisional Patent Application Serial No. 62/691,251, titled DUAL IN-SERIES LARGE AND SMALL DROPLET FILTERS.

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

- U.S. Patent Application Serial No. 15/940,641, titled INTERACTIVE SURGICAL SYSTEMS WITH ENCRYPTED COMMUNICATION CAPABILITIES;
- U.S. Patent Application Serial No. 15/940,648, titled INTERACTIVE SURGICAL SYSTEMS WITH CONDITION HANDLING OF DEVICES AND DATA CAPABILITIES;
- U.S. Patent Application Serial No. 15/940,656, titled SURGICAL HUB COORDINATION OF CONTROL AND COMMUNICATION OF OPERATING ROOM DEVICES;
- U.S. Patent Application Serial No. 15/940,666, titled SPATIAL AWARENESS OF SURGICAL HUBS IN OPERATING ROOMS;
- U.S. Patent Application Serial No. 15/940,670, titled COOPERATIVE UTILIZATION OF DATA DERIVED FROM SECONDARY SOURCES BY INTELLIGENT SURGICAL HUBS;
- U.S. Patent Application Serial No. 15/940,677, titled SURGICAL HUB CONTROL ARRANGEMENTS;
- U.S. Patent Application Serial No. 15/940,632, titled DATA STRIPPING METHOD TO INTERROGATE PATIENT RECORDS AND CREATE ANONYMIZED RECORD;
- U.S. Patent Application Serial No. 15/940,640, titled COMMUNICATION HUB AND STORAGE DEVICE FOR STORING PARAMETERS AND STATUS OF A SURGICAL DEVICE TO BE SHARED WITH CLOUD BASED ANALYTICS SYSTEMS;
- U.S. Patent Application Serial No. 15/940,645, titled SELF DESCRIBING DATA PACKETS GENERATED AT AN ISSUING INSTRUMENT;
- U.S. Patent Application Serial No. 15/940,649, titled DATA PAIRING TO INTERCONNECT A DEVICE MEASURED PARAMETER WITH AN OUTCOME;
- U.S. Patent Application Serial No. 15/940,654, titled SURGICAL HUB SITUATIONAL AWARENESS;
- U.S. Patent Application Serial No. 15/940,663, titled SURGICAL SYSTEM DISTRIBUTED PROCESSING;
- U.S. Patent Application Serial No. 15/940,668, titled AGGREGATION AND REPORTING OF SURGICAL HUB DATA;
- U.S. Patent Application Serial No. 15/940,671, titled SURGICAL HUB SPATIAL AWARENESS TO DETERMINE DEVICES IN OPERATING THEATER;
- U.S. Patent Application Serial No. 15/940,686, titled DISPLAY OF ALIGNMENT OF STAPLE CARTRIDGE TO PRIOR LINEAR STAPLE LINE;
- U.S. Patent Application Serial No. 15/940,700, titled STERILE FIELD INTERACTIVE CONTROL DISPLAYS;
- U.S. Patent Application Serial No. 15/940,629, titled COMPUTER IMPLEMENTED INTERACTIVE SURGICAL SYSTEMS;

- U.S. Patent Application Serial No. 15/940,704, titled USE OF LASER LIGHT AND RED-GREEN-BLUE COLORATION TO DETERMINE PROPERTIES OF BACK SCATTERED LIGHT;
- U.S. Patent Application Serial No. 15/940,722, titled CHARACTERIZATION OF TISSUE IRREGULARITIES THROUGH THE USE OF MONO-CHROMATIC LIGHT REFRACTIVITY; and
- U.S. Patent Application Serial No. 15/940,742, titled DUAL CMOS ARRAY IMAGING.

[0059] Applicant of the present application owns the following U.S. Patent Applications, filed on March 29, 2018, the disclosure of each of which is herein incorporated by reference in its entirety:

- U.S. Patent Application Serial No. 15/940,636, titled ADAPTIVE CONTROL PROGRAM UPDATES FOR SURGICAL DEVICES;
- U.S. Patent Application Serial No. 15/940,653, titled ADAPTIVE CONTROL PROGRAM UPDATES FOR SURGICAL HUBS;
- U.S. Patent Application Serial No. 15/940,660, titled CLOUD-BASED MEDICAL ANALYTICS FOR CUSTOMIZATION AND RECOMMENDATIONS TO A USER;
- U.S. Patent Application Serial No. 15/940,679, titled CLOUD-BASED MEDICAL ANALYTICS FOR LINKING OF LOCAL USAGE TRENDS WITH THE RESOURCE ACQUISITION BEHAVIORS OF LARGER DATA SET;
- U.S. Patent Application Serial No. 15/940,694, titled CLOUD-BASED MEDICAL ANALYTICS FOR MEDICAL FACILITY SEGMENTED INDIVIDUALIZATION OF INSTRUMENT FUNCTION;
- U.S. Patent Application Serial No. 15/940,634, titled CLOUD-BASED MEDICAL ANALYTICS FOR SECURITY AND AUTHENTICATION TRENDS AND REACTIVE MEASURES;
- U.S. Patent Application Serial No. 15/940,706, titled DATA HANDLING AND PRIORITIZATION IN A CLOUD ANALYTICS NETWORK; and
- U.S. Patent Application Serial No. 15/940,675, titled CLOUD INTERFACE FOR COUPLED SURGICAL DEVICES.

[0060] Applicant of the present application owns the following U.S. Patent Applications, filed on March 29, 2018, the disclosure of each of which is herein incorporated by reference in its entirety:

- U.S. Patent Application Serial No. 15/940,627, titled DRIVE ARRANGEMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS;
- U.S. Patent Application Serial No. 15/940,637, titled COMMUNICATION ARRANGEMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS;
- U.S. Patent Application Serial No. 15/940,642, titled CONTROLS FOR ROBOT-ASSISTED SURGICAL PLATFORMS;

- U.S. Patent Application Serial No. 15/940,676, titled AUTOMATIC TOOL ADJUSTMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS;
- U.S. Patent Application Serial No. 15/940,680, titled CONTROLLERS FOR ROBOT-ASSISTED SURGICAL PLATFORMS;
- U.S. Patent Application Serial No. 15/940,683, titled COOPERATIVE SURGICAL ACTIONS FOR ROBOT-ASSISTED SURGICAL PLATFORMS;
- U.S. Patent Application Serial No. 15/940,690, titled DISPLAY ARRANGEMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS; and
- U.S. Patent Application Serial No. 15/940,711, titled SENSING ARRANGEMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS.

[0061] Applicant of the present application owns the following U.S. Provisional Patent Applications, filed on March 28, 2018, the disclosure of each of which is herein incorporated by reference in its entirety:

- U.S. Provisional Patent Application Serial No. 62/649,302, titled INTERACTIVE SURGICAL SYSTEMS WITH ENCRYPTED COMMUNICATION CAPABILITIES;
- U.S. Provisional Patent Application Serial No. 62/649,294, titled DATA STRIPPING METHOD TO INTERROGATE PATIENT RECORDS AND CREATE ANONYMIZED RECORD;
- U.S. Provisional Patent Application Serial No. 62/649,300, titled SURGICAL HUB SITUATIONAL AWARENESS;
- U.S. Provisional Patent Application Serial No. 62/649,309, titled SURGICAL HUB SPATIAL AWARENESS TO DETERMINE DEVICES IN OPERATING THEATER;
- U.S. Provisional Patent Application Serial No. 62/649,310, titled COMPUTER IMPLEMENTED INTERACTIVE SURGICAL SYSTEMS;
- U.S. Provisional Patent Application Serial No. 62/649,291, titled USE OF LASER LIGHT AND RED-GREEN-BLUE COLORATION TO DETERMINE PROPERTIES OF BACK SCATTERED LIGHT;
- U.S. Provisional Patent Application Serial No. 62/649,296, titled ADAPTIVE CONTROL PROGRAM UPDATES FOR SURGICAL DEVICES;
- U.S. Provisional Patent Application Serial No. 62/649,333, titled CLOUD-BASED MEDICAL ANALYTICS FOR CUSTOMIZATION AND RECOMMENDATIONS TO A USER;
- U.S. Provisional Patent Application Serial No. 62/649,327, titled CLOUD-BASED MEDICAL ANALYTICS FOR SECURITY AND AUTHENTICATION TRENDS AND REACTIVE MEASURES;
- U.S. Provisional Patent Application Serial No. 62/649,315, titled DATA HANDLING AND PRIORITIZATION IN A CLOUD ANALYTICS NETWORK;

- U.S. Provisional Patent Application Serial No. 62/649,313, titled CLOUD INTERFACE FOR COUPLED SURGICAL DEVICES;
- U.S. Provisional Patent Application Serial No. 62/649,320, titled DRIVE ARRANGEMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS;
- U.S. Provisional Patent Application Serial No. 62/649,307, titled AUTOMATIC TOOL ADJUSTMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS; and
- U.S. Provisional Patent Application Serial No. 62/649,323, titled SENSING ARRANGEMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS.

[0062] Applicant of the present application owns the following U.S. Provisional Patent Application, filed on April 19, 2018, the disclosure of each of which is herein incorporated by reference in its entirety:

- U.S. Provisional Patent Application Serial No. 62/659,900, titled METHOD OF HUB COMMUNICATION.

[0063] Applicant of the present application owns the following U.S. Provisional Patent Applications, filed on March 30, 2018, the disclosure of each of which is herein incorporated by reference in its entirety:

- U.S. Provisional Patent Application Serial No. 62/650,887, titled SURGICAL SYSTEMS WITH OPTIMIZED SENSING CAPABILITIES;
- U.S. Provisional Patent Application Serial No. 62/650,877, titled SURGICAL SMOKE EVACUATION SENSING AND CONTROLS;
- U.S. Provisional Patent Application Serial No. 62/650,882, titled SMOKE EVACUATION MODULE FOR INTERACTIVE SURGICAL PLATFORM; and
- U.S. Provisional Patent Application Serial No. 62/650,898, titled CAPACITIVE COUPLED RETURN PATH PAD WITH SEPARABLE ARRAY ELEMENTS.

[0064] Applicant of the present application owns the following U.S. Provisional Patent Applications, filed on March 8, 2018, the disclosure of each of which is herein incorporated by reference in its entirety:

- U.S. Provisional Patent Application Serial No. 62/640,417, titled TEMPERATURE CONTROL IN ULTRASONIC DEVICE AND CONTROL SYSTEM THEREFOR; and
- U.S. Provisional Patent Application Serial No. 62/640,415, titled ESTIMATING STATE OF ULTRASONIC END EFFECTOR AND CONTROL SYSTEM THEREFOR.

[0065] Applicant of the present application owns the following U.S. Provisional Patent Applications, filed on December 28, 2017, the disclosure of each of which is herein incorporated by reference in its entirety:

- U.S. Provisional Patent Application Serial No. 62/611,341, titled INTERACTIVE SURGICAL PLATFORM;

- U.S. Provisional Patent Application Serial No. 62/611,340, titled CLOUD-BASED MEDICAL ANALYTICS; and
- U.S. Provisional Patent Application Serial No. 62/611,339, titled ROBOT ASSISTED SURGICAL PLATFORM.

[0066] Before explaining various aspects of surgical devices and systems 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.

[0067] Aspects of the present disclosure present various surgical instruments utilized in cancer treatment, which employ various sensors and algorithms for assessing proximity to cancerous tissue and/or assisting a user in navigating a safe distance away from cancerous tissue. The surgical instruments can be utilized alone or as components of a computer-implemented interactive surgical system.

[0068] Referring to FIG. 1, a computer-implemented interactive surgical system 100 includes one or more surgical systems 102 and a cloud-based system (e.g., the cloud 104 that may include a remote server 113 coupled to a storage device 105). Each surgical system 102 includes at least one surgical hub 106 in communication with the cloud 104 that may include a remote server 113. In one example, as illustrated in FIG. 1, the surgical system 102 includes a visualization system 108, a robotic system 110, and a handheld intelligent surgical instrument 112, which are configured to communicate with one another and/or the hub 106. In some aspects, a surgical system 102 may include an M number of hubs 106, an N number of visualization systems 108, an O number of robotic systems 110, and a P number of handheld intelligent surgical instruments 112, where M, N, O, and P are integers greater than or equal to one.

[0069] FIG. 3 depicts an example of a surgical system 102 being used to perform a surgical procedure on a patient who is lying down on an operating table 114 in a surgical operating room 116. One or more of the surgical instruments of the present disclosure can be implemented as robotic tools for use with a robotic system. A robotic system 110 is used in the surgical procedure as a part of the surgical system 102. The robotic system 110 includes a surgeon's console 118, a patient side cart 120 (surgical robot), and a surgical robotic hub 122. The patient side cart 120 can manipulate at least one removably coupled surgical tool 117 through a minimally invasive incision in the body of the patient while the surgeon views

the surgical site through the surgeon's console 118. An image of the surgical site can be obtained by a medical imaging device 124, which can be manipulated by the patient side cart 120 to orient the imaging device 124. The robotic hub 122 can be used to process the images of the surgical site for subsequent display to the surgeon through the surgeon's console 118.

[0070] Other types of robotic systems can be readily adapted for use with the surgical system 102. Various examples of robotic systems and surgical tools that are suitable for use with the present disclosure are described in U.S. Provisional Patent Application Serial No. 62/611,339, titled ROBOT ASSISTED SURGICAL PLATFORM, filed December 28, 2017, the disclosure of which is herein incorporated by reference in its entirety.

[0071] Various examples of cloud-based analytics that are performed by the cloud 104, and are suitable for use with the present disclosure, are described in U.S. Provisional Patent Application Serial No. 62/611,340, titled CLOUD-BASED MEDICAL ANALYTICS, filed December 28, 2017, the disclosure of which is herein incorporated by reference in its entirety.

[0072] In various aspects, the imaging device 124 includes at least one image sensor and one or more optical components. Suitable image sensors include, but are not limited to, Charge-Coupled Device (CCD) sensors and Complementary Metal-Oxide Semiconductor (CMOS) sensors.

[0073] The optical components of the imaging device 124 may include one or more illumination sources and/or one or more lenses. The one or more illumination sources may be directed to illuminate portions of the surgical field. The one or more image sensors may receive light reflected or refracted from the surgical field, including light reflected or refracted from tissue and/or surgical instruments.

[0074] The one or more illumination sources may be configured to radiate electromagnetic energy in the visible spectrum as well as the invisible spectrum. The visible spectrum, sometimes referred to as the optical spectrum or luminous spectrum, is that portion of the electromagnetic spectrum that is visible to (i.e., can be detected by) the human eye and may be referred to as visible light or simply light. A typical human eye will respond to wavelengths in air that are from about 380 nm to about 750 nm.

[0075] The invisible spectrum (i.e., the non-luminous spectrum) is that portion of the electromagnetic spectrum that lies below and above the visible spectrum (i.e., wavelengths below about 380 nm and above about 750 nm). The invisible spectrum is not detectable by the human eye. Wavelengths greater than about 750 nm are longer than the red visible spectrum, and they become invisible infrared (IR), microwave, and radio electromagnetic radiation. Wavelengths less than about 380 nm are shorter than the violet spectrum, and they become invisible ultraviolet, x-ray, and gamma ray electromagnetic radiation.

[0076] In various aspects, the imaging device 124 is configured for use in a minimally invasive procedure. Examples of imaging devices suitable for use with the present disclosure include, but not limited to, an arthroscope, angioscope, bronchoscope, choledochoscope, colonoscope, cytoscope,

duodenoscope, enteroscope, esophagogastro-duodenoscope (gastroscope), endoscope, laryngoscope, nasopharyngo-neproscope, sigmoidoscope, thoracoscope, and ureteroscope.

[0077] In one aspect, the imaging device employs multi-spectrum monitoring to discriminate topography and underlying structures. A multi-spectral image is one that captures image data within specific wavelength ranges across the electromagnetic spectrum. The wavelengths may be separated by filters or by the use of instruments that are sensitive to particular wavelengths, including light from frequencies beyond the visible light range, e.g., IR and ultraviolet. Spectral imaging can allow extraction of additional information the human eye fails to capture with its receptors for red, green, and blue. The use of multi-spectral imaging is described in greater detail under the heading "Advanced Imaging Acquisition Module" in U.S. Provisional Patent Application Serial No. 62/611,341, titled INTERACTIVE SURGICAL PLATFORM, filed December 28, 2017, the disclosure of which is herein incorporated by reference in its entirety. Multi-spectrum monitoring can be a useful tool in relocating a surgical field after a surgical task is completed to perform one or more of the previously described tests on the treated tissue.

[0078] It is axiomatic that strict sterilization of the operating room and surgical equipment is required during any surgery. The strict hygiene and sterilization conditions required in a "surgical theater," i.e., an operating or treatment room, necessitate the highest possible sterility of all medical devices and equipment. Part of that sterilization process is the need to sterilize anything that comes in contact with the patient or penetrates the sterile field, including the imaging device 124 and its attachments and components. It will be appreciated that the sterile field may be considered a specified area, such as within a tray or on a sterile towel, that is considered free of microorganisms, or the sterile field may be considered an area, immediately around a patient, who has been prepared for a surgical procedure. The sterile field may include the scrubbed team members, who are properly attired, and all furniture and fixtures in the area.

[0079] In various aspects, the visualization system 108 includes one or more imaging sensors, one or more image-processing units, one or more storage arrays, and one or more displays that are strategically arranged with respect to the sterile field, as illustrated in FIG. 2. In one aspect, the visualization system 108 includes an interface for Health Level-7, picture archive and communication system, and electronic medical record (EMR). Various components of the visualization system 108 are described under the heading "Advanced Imaging Acquisition Module" in U.S. Provisional Patent Application Serial No. 62/611,341, titled INTERACTIVE SURGICAL PLATFORM, filed December 28, 2017, the disclosure of which is herein incorporated by reference in its entirety.

[0080] As illustrated in FIG. 2, a primary display 119 is positioned in the sterile field to be visible to an operator at the operating table 114. In addition, a visualization tower 111 is positioned outside the sterile field. The visualization tower 111 includes a first non-sterile display 107 and a second non-sterile display 109, which face away from each other. The visualization system 108, guided by the hub 106, is

configured to utilize the displays 107, 109, and 119 to coordinate information flow to operators inside and outside the sterile field. For example, the hub 106 may cause the visualization system 108 to display a snapshot of a surgical site, as recorded by an imaging device 124, on a non-sterile display 107 or 109, while maintaining a live feed of the surgical site on the primary display 119. The snapshot on the non-sterile display 107 or 109 can permit a non-sterile operator to perform a diagnostic step relevant to the surgical procedure, for example.

[0081] In one aspect, the hub 106 is also configured to route a diagnostic input or feedback entered by a non-sterile operator at the visualization tower 111 to the primary display 119 within the sterile field, where it can be viewed by a sterile operator at the operating table. In one example, the input can be in the form of a modification to the snapshot displayed on the non-sterile display 107 or 109, which can be routed to the primary display 119 by the hub 106.

[0082] Referring to FIG. 2, a surgical instrument 112 is being used in the surgical procedure as part of the surgical system 102. The hub 106 is also configured to coordinate information flow to a display of the surgical instrument 112. For example, in U.S. Provisional Patent Application Serial No. 62/611,341, titled INTERACTIVE SURGICAL PLATFORM, filed December 28, 2017, the disclosure of which is herein incorporated by reference in its entirety. A diagnostic input or feedback entered by a non-sterile operator at the visualization tower 111 can be routed by the hub 106 to the surgical instrument display 115 within the sterile field, where it can be viewed by the operator of the surgical instrument 112. Example surgical instruments that are suitable for use with the surgical system 102 are described under the heading "Surgical Instrument Hardware" and in U.S. Provisional Patent Application Serial No. 62/611,341, titled INTERACTIVE SURGICAL PLATFORM, filed December 28, 2017, the disclosure of which is herein incorporated by reference in its entirety, for example.

[0083] Referring now to FIG. 3, a hub 106 is depicted in communication with a visualization system 108, a robotic system 110, and a handheld intelligent surgical instrument 112. The hub 106 includes a monitor 135, an imaging module 138, a generator module 140, a communication module 130, a processor module 132, and a storage array 134. In certain aspects, as illustrated in FIG. 3, the hub 106 further includes a smoke evacuation module 126 and/or a suction/irrigation module 128.

[0084] During a surgical procedure, energy application to tissue, for sealing and/or cutting, is generally associated with smoke evacuation, suction of excess fluid, and/or irrigation of the tissue. Fluid, power, and/or data lines from different sources are often entangled during the surgical procedure. Valuable time can be lost addressing this issue during a surgical procedure. Detangling the lines may necessitate disconnecting the lines from their respective modules, which may require resetting the modules. The hub modular enclosure 136 offers a unified environment for managing the power, data, and fluid lines, which reduces the frequency of entanglement between such lines.

[0085] Aspects of the present disclosure present a surgical hub for use in a surgical procedure that involves energy application to tissue at a surgical site. The surgical hub includes a hub enclosure and a

combo generator module slidably receivable in a docking station of the hub enclosure. The docking station includes data and power contacts. The combo generator module includes two or more of an ultrasonic energy generator component, a bipolar radio frequency (RF) energy generator component, and a monopolar RF energy generator component that are housed in a single unit. In one aspect, the combo generator module also includes a smoke evacuation component, at least one energy delivery cable for connecting the combo generator module to a surgical instrument, at least one smoke evacuation component configured to evacuate smoke, fluid, and/or particulates generated by the application of therapeutic energy to the tissue, and a fluid line extending from the remote surgical site to the smoke evacuation component.

[0086] In one aspect, the fluid line is a first fluid line and a second fluid line extends from the remote surgical site to a suction and irrigation module slidably received in the hub enclosure. In one aspect, the hub enclosure comprises a fluid interface.

[0087] Certain surgical procedures may require the application of more than one energy type to the tissue. One energy type may be more beneficial for cutting the tissue, while another different energy type may be more beneficial for sealing the tissue. For example, a bipolar generator can be used to seal the tissue while an ultrasonic generator can be used to cut the sealed tissue. Aspects of the present disclosure present a solution where a hub modular enclosure 136 is configured to accommodate different generators and facilitate an interactive communication therebetween. One of the advantages of the hub modular enclosure 136 is enabling the quick removal and/or replacement of various modules.

[0088] Aspects of the present disclosure present a modular surgical enclosure for use in a surgical procedure that involves energy application to tissue. The modular surgical enclosure includes a first energy-generator module, configured to generate a first energy for application to the tissue, and a first docking station comprising a first docking port that includes first data and power contacts, wherein the first energy-generator module is slidably movable into an electrical engagement with the power and data contacts and wherein the first energy-generator module is slidably movable out of the electrical engagement with the first power and data contacts.

[0089] Further to the above, the modular surgical enclosure also includes a second energy-generator module configured to generate a second energy, different than the first energy, for application to the tissue, and a second docking station comprising a second docking port that includes second data and power contacts, wherein the second energy-generator module is slidably movable into an electrical engagement with the power and data contacts, and wherein the second energy-generator module is slidably movable out of the electrical engagement with the second power and data contacts.

[0090] In addition, the modular surgical enclosure also includes a communication bus between the first docking port and the second docking port, configured to facilitate communication between the first energy-generator module and the second energy-generator module.

[0091] Referring to FIGS. 3-7, aspects of the present disclosure are presented for a hub modular enclosure 136 that allows the modular integration of a generator module 140, a smoke evacuation module 126, and a suction/irrigation module 128. The hub modular enclosure 136 further facilitates interactive communication between the modules 140, 126, 128. As illustrated in FIG. 5, the generator module 140 can be a generator module with integrated monopolar, bipolar, and ultrasonic components supported in a single housing unit 139 slidably insertable into the hub modular enclosure 136. As illustrated in FIG. 5, the generator module 140 can be configured to connect to a monopolar device 146, a bipolar device 147, and an ultrasonic device 148. Alternatively, the generator module 140 may comprise a series of monopolar, bipolar, and/or ultrasonic generator modules that interact through the hub modular enclosure 136. The hub modular enclosure 136 can be configured to facilitate the insertion of multiple generators and interactive communication between the generators docked into the hub modular enclosure 136 so that the generators would act as a single generator.

[0092] One or more of the monopolar device 146, bipolar device 147, and ultrasonic device 148 can be equipped with sensors and algorithms for assessing proximity to cancerous tissue and/or assisting a user in navigating a safe distance away from cancerous tissue, as described in greater detail below.

[0093] In one aspect, the hub modular enclosure 136 comprises a modular power and communication backplane 149 with external and wireless communication headers to enable the removable attachment of the modules 140, 126, 128, and interactive communication therebetween.

[0094] In one aspect, the hub modular enclosure 136 includes docking stations, or drawers, 151, herein also referred to as drawers, which are configured to slidably receive the modules 140, 126, 128. FIG. 4 illustrates a partial perspective view of a surgical hub enclosure 136, and a combo generator module 145 slidably receivable in a docking station 151 of the surgical hub enclosure 136. A docking port 152 with power and data contacts on a rear side of the combo generator module 145 is configured to engage a corresponding docking port 150 with power and data contacts of a corresponding docking station 151 of the hub modular enclosure 136 as the combo generator module 145 is slid into position within the corresponding docking station 151 of the hub module enclosure 136. In one aspect, the combo generator module 145 includes a bipolar, ultrasonic, and monopolar module and a smoke evacuation module integrated together into a single housing unit 139, as illustrated in FIG. 5.

[0095] In various aspects, the smoke evacuation module 126 includes a fluid line 154 that conveys captured/collected smoke and/or fluid away from a surgical site and to, for example, the smoke evacuation module 126. Vacuum suction originating from the smoke evacuation module 126 can draw the smoke into an opening of a utility conduit at the surgical site. The utility conduit, coupled to the fluid line, can be in the form of a flexible tube terminating at the smoke evacuation module 126. The utility conduit and the fluid line define a fluid path extending toward the smoke evacuation module 126 that is received in the hub enclosure 136.

[0096] In various aspects, the suction/irrigation module 128 is coupled to a surgical tool comprising an aspiration fluid line and a suction fluid line. In one example, the aspiration and suction fluid lines are in the form of flexible tubes extending from the surgical site toward the suction/irrigation module 128. One or more drive systems can be configured to cause irrigation and aspiration of fluids to and from the surgical site.

[0097] In one aspect, the surgical tool includes a shaft having an end effector at a distal end thereof and at least one energy treatment associated with the end effector, an aspiration tube, and an irrigation tube. The aspiration tube can have an inlet port at a distal end thereof and the aspiration tube extends through the shaft. Similarly, an irrigation tube can extend through the shaft and can have an inlet port in proximity to the energy delivery implement. The energy delivery implement is configured to deliver ultrasonic and/or RF energy to the surgical site and is coupled to the generator module 140 by a cable extending initially through the shaft.

[0098] The irrigation tube can be in fluid communication with a fluid source, and the aspiration tube can be in fluid communication with a vacuum source. The fluid source and/or the vacuum source can be housed in the suction/irrigation module 128. In one example, the fluid source and/or the vacuum source can be housed in the hub enclosure 136 separately from the suction/irrigation module 128. In such example, a fluid interface can be configured to connect the suction/irrigation module 128 to the fluid source and/or the vacuum source.

[0099] In one aspect, the modules 140, 126, 128, and/or their corresponding docking stations on the hub modular enclosure 136 may include alignment features that are configured to align the docking ports of the modules into engagement with their counterparts in the docking stations of the hub modular enclosure 136. For example, as illustrated in FIG. 4, the combo generator module 145 includes side brackets 155 that are configured to slidably engage with corresponding brackets 156 of the corresponding docking station 151 of the hub modular enclosure 136. The brackets cooperate to guide the docking port contacts of the combo generator module 145 into an electrical engagement with the docking port contacts of the hub modular enclosure 136.

[0100] In some aspects, the drawers 151 of the hub modular enclosure 136 are the same, or substantially the same size, and the modules are adjusted in size to be received in the drawers 151. For example, the side brackets 155 and/or 156 can be larger or smaller depending on the size of the module. In other aspects, the drawers 151 are different in size and are each designed to accommodate a particular module.

[0101] Furthermore, the contacts of a particular module can be keyed for engagement with the contacts of a particular drawer to avoid inserting a module into a drawer with mismatching contacts.

[0102] As illustrated in FIG. 4, the docking port 150 of one drawer 151 can be coupled to the docking port 150 of another drawer 151 through a communications link 157 to facilitate an interactive communication between the modules housed in the hub modular enclosure 136. The docking ports 150

of the hub modular enclosure 136 may alternatively, or additionally, facilitate a wireless interactive communication between the modules housed in the hub modular enclosure 136. Any suitable wireless communication can be employed, such as for example Air Titan-Bluetooth.

[0103] FIG. 6 illustrates individual power bus attachments for a plurality of lateral docking ports of a lateral modular housing 160 configured to receive a plurality of modules of a surgical hub 206. The lateral modular housing 160 is configured to laterally receive and interconnect the modules 161. The modules 161 are slidably inserted into docking stations 162 of lateral modular housing 160, which includes a backplane for interconnecting the modules 161. As illustrated in FIG. 6, the modules 161 are arranged laterally in the lateral modular housing 160. Alternatively, the modules 161 may be arranged vertically in a vertical modular housing.

[0104] FIG. 7 illustrates a vertical modular housing 164 configured to receive a plurality of modules 165 of the surgical hub 106. The modules 165 are slidably inserted into docking stations, or drawers, 167 of vertical modular housing 164, which includes a backplane for interconnecting the modules 165. Although the drawers 167 of the vertical modular housing 164 are arranged vertically, in certain instances, a vertical modular housing 164 may include drawers that are arranged laterally. Furthermore, the modules 165 may interact with one another through the docking ports of the vertical modular housing 164. In the example of FIG. 7, a display 177 is provided for displaying data relevant to the operation of the modules 165. In addition, the vertical modular housing 164 includes a master module 178 housing a plurality of sub-modules that are slidably received in the master module 178.

[0105] In various aspects, the imaging module 138 comprises an integrated video processor and a modular light source and is adapted for use with various imaging devices. In one aspect, the imaging device is comprised of a modular housing that can be assembled with a light source module and a camera module. The housing can be a disposable housing. In at least one example, the disposable housing is removably coupled to a reusable controller, a light source module, and a camera module. The light source module and/or the camera module can be selectively chosen depending on the type of surgical procedure. In one aspect, the camera module comprises a CCD sensor. In another aspect, the camera module comprises a CMOS sensor. In another aspect, the camera module is configured for scanned beam imaging. Likewise, the light source module can be configured to deliver a white light or a different light, depending on the surgical procedure.

[0106] During a surgical procedure, removing a surgical device from the surgical field and replacing it with another surgical device that includes a different camera or a different light source can be inefficient. Temporarily losing sight of the surgical field may lead to undesirable consequences. The module imaging device of the present disclosure is configured to permit the replacement of a light source module or a camera module midstream during a surgical procedure, without having to remove the imaging device from the surgical field.

[0107] In one aspect, the imaging device comprises a tubular housing that includes a plurality of channels. A first channel is configured to slidably receive the camera module, which can be configured for a snap-fit engagement with the first channel. A second channel is configured to slidably receive the light source module, which can be configured for a snap-fit engagement with the second channel. In another example, the camera module and/or the light source module can be rotated into a final position within their respective channels. A threaded engagement can be employed in lieu of the snap-fit engagement.

[0108] In various examples, multiple imaging devices are placed at different positions in the surgical field to provide multiple views. The imaging module 138 can be configured to switch between the imaging devices to provide an optimal view. In various aspects, the imaging module 138 can be configured to integrate the images from the different imaging device.

[0109] Various image processors and imaging devices suitable for use with the present disclosure are described in U.S. Patent No. 7,995,045, titled COMBINED SBI AND CONVENTIONAL IMAGE PROCESSOR, which issued on August 9, 2011, which is herein incorporated by reference in its entirety. In addition, U.S. Patent No. 7,982,776, titled SBI MOTION ARTIFACT REMOVAL APPARATUS AND METHOD, which issued on July 19, 2011, which is herein incorporated by reference in its entirety, describes various systems for removing motion artifacts from image data. Such systems can be integrated with the imaging module 138. Furthermore, U.S. Patent Application Publication No. 2011/0306840, titled CONTROLLABLE MAGNETIC SOURCE TO FIXTURE INTRACORPOREAL APPARATUS, published on December 15, 2011, and U.S. Patent Application Publication No. 2014/0243597, titled SYSTEM FOR PERFORMING A MINIMALLY INVASIVE SURGICAL PROCEDURE, published on August 28, 2014, the disclosure of each of which is herein incorporated by reference in its entirety.

[0110] FIG. 8 illustrates a surgical data network 201 comprising a modular communication hub 203 configured to connect modular devices located in one or more operating theaters of a healthcare facility, or any room in a healthcare facility specially equipped for surgical operations, to a cloud-based system (e.g., the cloud 204 that may include a remote server 213 coupled to a storage device 205). In one aspect, the modular communication hub 203 comprises a network hub 207 and/or a network switch 209 in communication with a network router. The modular communication hub 203 also can be coupled to a local computer system 210 to provide local computer processing and data manipulation. The surgical data network 201 may be configured as passive, intelligent, or switching. A passive surgical data network serves as a conduit for the data, enabling it to go from one device (or segment) to another and to the cloud computing resources. An intelligent surgical data network includes additional features to enable the traffic passing through the surgical data network to be monitored and to configure each port in the network hub 207 or network switch 209. An intelligent surgical data network may be referred to as a

manageable hub or switch. A switching hub reads the destination address of each packet and then forwards the packet to the correct port.

[0111] Modular devices 1a-1n located in the operating theater may be coupled to the modular communication hub 203. The network hub 207 and/or the network switch 209 may be coupled to a network router 211 to connect the devices 1a-1n to the cloud 204 or the local computer system 210. Data associated with the devices 1a-1n may be transferred to cloud-based computers via the router for remote data processing and manipulation. Data associated with the devices 1a-1n may also be transferred to the local computer system 210 for local data processing and manipulation. Modular devices 2a-2m located in the same operating theater also may be coupled to a network switch 209. The network switch 209 may be coupled to the network hub 207 and/or the network router 211 to connect to the devices 2a-2m to the cloud 204. Data associated with the devices 2a-2n may be transferred to the cloud 204 via the network router 211 for data processing and manipulation. Data associated with the devices 2a-2m may also be transferred to the local computer system 210 for local data processing and manipulation.

[0112] It will be appreciated that the surgical data network 201 may be expanded by interconnecting multiple network hubs 207 and/or multiple network switches 209 with multiple network routers 211. The modular communication hub 203 may be contained in a modular control tower configured to receive multiple devices 1a-1n/2a-2m. The local computer system 210 also may be contained in a modular control tower. The modular communication hub 203 is connected to a display 212 to display images obtained by some of the devices 1a-1n/2a-2m, for example during surgical procedures. In various aspects, the devices 1a-1n/2a-2m may include, for example, various modules such as an imaging module 138 coupled to an endoscope, a generator module 140 coupled to an energy-based surgical device, a smoke evacuation module 126, a suction/irrigation module 128, a communication module 130, a processor module 132, a storage array 134, a surgical device coupled to a display, and/or a non-contact sensor module, among other modular devices that may be connected to the modular communication hub 203 of the surgical data network 201.

[0113] In one aspect, the surgical data network 201 may comprise a combination of network hub(s), network switch(es), and network router(s) connecting the devices 1a-1n/2a-2m to the cloud. Any one of or all of the devices 1a-1n/2a-2m coupled to the network hub or network switch may collect data in real time and transfer the data to cloud computers for data processing and manipulation. It will be appreciated that cloud computing relies on sharing computing resources rather than having local servers or personal devices to handle software applications. The word “cloud” may be used as a metaphor for “the Internet,” although the term is not limited as such. Accordingly, the term “cloud computing” may be used herein to refer to “a type of Internet-based computing,” where different services—such as servers, storage, and applications—are delivered to the modular communication hub 203 and/or computer system 210 located in the surgical theater (e.g., a fixed, mobile, temporary, or field operating room or space) and to devices connected to the modular communication hub 203 and/or computer system 210 through the Internet. The

cloud infrastructure may be maintained by a cloud service provider. In this context, the cloud service provider may be the entity that coordinates the usage and control of the devices 1a-1n/2a-2m located in one or more operating theaters. The cloud computing services can perform a large number of calculations based on the data gathered by smart surgical instruments, robots, and other computerized devices located in the operating theater. The hub hardware enables multiple devices or connections to be connected to a computer that communicates with the cloud computing resources and storage.

[0114] Applying cloud computer data processing techniques on the data collected by the devices 1a-1n/2a-2m, the surgical data network provides improved surgical outcomes, reduced costs, and improved patient satisfaction. At least some of the devices 1a-1n/2a-2m may be employed to view tissue states to assess leaks or perfusion of sealed tissue after a tissue sealing and cutting procedure. At least some of the devices 1a-1n/2a-2m may be employed to identify pathology, such as the effects of diseases, using the cloud-based computing to examine data including images of samples of body tissue for diagnostic purposes. This includes localization and margin confirmation of tissue and phenotypes. At least some of the devices 1a-1n/2a-2m may be employed to identify anatomical structures of the body using a variety of sensors integrated with imaging devices and techniques such as overlaying images captured by multiple imaging devices. The data gathered by the devices 1a-1n/2a-2m, including image data, may be transferred to the cloud 204 or the local computer system 210 or both for data processing and manipulation including image processing and manipulation. The data may be analyzed to improve surgical procedure outcomes by determining if further treatment, such as the application of endoscopic intervention, emerging technologies, a targeted radiation, targeted intervention, and precise robotics to tissue-specific sites and conditions, may be pursued. Such data analysis may further employ outcome analytics processing, and using standardized approaches may provide beneficial feedback to either confirm surgical treatments and the behavior of the surgeon or suggest modifications to surgical treatments and the behavior of the surgeon.

[0115] In one implementation, the operating theater devices 1a-1n may be connected to the modular communication hub 203 over a wired channel or a wireless channel depending on the configuration of the devices 1a-1n to a network hub. The network hub 207 may be implemented, in one aspect, as a local network broadcast device that works on the physical layer of the Open System Interconnection (OSI) model. The network hub provides connectivity to the devices 1a-1n located in the same operating theater network. The network hub 207 collects data in the form of packets and sends them to the router in half duplex mode. The network hub 207 does not store any media access control/Internet Protocol (MAC/IP) to transfer the device data. Only one of the devices 1a-1n can send data at a time through the network hub 207. The network hub 207 has no routing tables or intelligence regarding where to send information and broadcasts all network data across each connection and to a remote server 213 (FIG. 9) over the cloud 204. The network hub 207 can detect basic network errors such as collisions, but having all information broadcast to multiple ports can be a security risk and cause bottlenecks.

[0116] In another implementation, the operating theater devices 2a-2m may be connected to a network switch 209 over a wired channel or a wireless channel. The network switch 209 works in the data link layer of the OSI model. The network switch 209 is a multicast device for connecting the devices 2a-2m located in the same operating theater to the network. The network switch 209 sends data in the form of frames to the network router 211 and works in full duplex mode. Multiple devices 2a-2m can send data at the same time through the network switch 209. The network switch 209 stores and uses MAC addresses of the devices 2a-2m to transfer data.

[0117] The network hub 207 and/or the network switch 209 are coupled to the network router 211 for connection to the cloud 204. The network router 211 works in the network layer of the OSI model. The network router 211 creates a route for transmitting data packets received from the network hub 207 and/or network switch 209 to cloud-based computer resources for further processing and manipulation of the data collected by any one of or all the devices 1a-1n/2a-2m. The network router 211 may be employed to connect two or more different networks located in different locations, such as, for example, different operating theaters of the same healthcare facility or different networks located in different operating theaters of different healthcare facilities. The network router 211 sends data in the form of packets to the cloud 204 and works in full duplex mode. Multiple devices can send data at the same time. The network router 211 uses IP addresses to transfer data.

[0118] In one example, the network hub 207 may be implemented as a USB hub, which allows multiple USB devices to be connected to a host computer. The USB hub may expand a single USB port into several tiers so that there are more ports available to connect devices to the host system computer. The network hub 207 may include wired or wireless capabilities to receive information over a wired channel or a wireless channel. In one aspect, a wireless USB short-range, high-bandwidth wireless radio communication protocol may be employed for communication between the devices 1a-1n and devices 2a-2m located in the operating theater.

[0119] In other examples, the operating theater devices 1a-1n/2a-2m may communicate to the modular communication hub 203 via Bluetooth wireless technology standard for exchanging data over short distances (using short-wavelength UHF radio waves in the ISM band from 2.4 to 2.485 GHz) from fixed and mobile devices and building personal area networks (PANs). In other aspects, the operating theater devices 1a-1n/2a-2m may communicate to the modular communication hub 203 via a number of wireless or wired communication standards or protocols, including but not limited to Wi-Fi (IEEE 802.11 family), WiMAX (IEEE 802.16 family), IEEE 802.20, long-term evolution (LTE), and Ev-DO, HSPA+, HSDPA+, HSUPA+, EDGE, GSM, GPRS, CDMA, TDMA, DECT, and Ethernet derivatives thereof, as well as any other wireless and wired protocols that are designated as 3G, 4G, 5G, and beyond. The computing module may include a plurality of communication modules. For instance, a first communication module may be dedicated to shorter-range wireless communications such as Wi-Fi and Bluetooth, and a second

communication module may be dedicated to longer-range wireless communications such as GPS, EDGE, GPRS, CDMA, WiMAX, LTE, Ev-DO, and others.

[0120] The modular communication hub 203 may serve as a central connection for one or all of the operating theater devices 1a-1n/2a-2m and handles a data type known as frames. Frames carry the data generated by the devices 1a-1n/2a-2m. When a frame is received by the modular communication hub 203, it is amplified and transmitted to the network router 211, which transfers the data to the cloud computing resources by using a number of wireless or wired communication standards or protocols, as described herein.

[0121] The modular communication hub 203 can be used as a standalone device or be connected to compatible network hubs and network switches to form a larger network. The modular communication hub 203 is generally easy to install, configure, and maintain, making it a good option for networking the operating theater devices 1a-1n/2a-2m.

[0122] FIG. 9 illustrates a computer-implemented interactive surgical system 200. The computer-implemented interactive surgical system 200 is similar in many respects to the computer-implemented interactive surgical system 100. For example, the computer-implemented interactive surgical system 200 includes one or more surgical systems 202, which are similar in many respects to the surgical systems 102. Each surgical system 202 includes at least one surgical hub 206 in communication with a cloud 204 that may include a remote server 213. In one aspect, the computer-implemented interactive surgical system 200 comprises a modular control tower 236 connected to multiple operating theater devices such as, for example, intelligent surgical instruments, robots, and other computerized devices located in the operating theater. As shown in FIG. 10, the modular control tower 236 comprises a modular communication hub 203 coupled to a computer system 210. As illustrated in the example of FIG. 9, the modular control tower 236 is coupled to an imaging module 238 that is coupled to an endoscope 239, a generator module 240 that is coupled to an energy device 241, a smoke evacuator module 226, a suction/irrigation module 228, a communication module 230, a processor module 232, a storage array 234, a smart device/instrument 235 optionally coupled to a display 237, and a non-contact sensor module 242. The operating theater devices are coupled to cloud computing resources and data storage via the modular control tower 236. A robot hub 222 also may be connected to the modular control tower 236 and to the cloud computing resources. The devices/instruments 235, visualization systems 208, among others, may be coupled to the modular control tower 236 via wired or wireless communication standards or protocols, as described herein. The modular control tower 236 may be coupled to a hub display 215 (e.g., monitor, screen) to display and overlay images received from the imaging module, device/instrument display, and/or other visualization systems 208. The hub display also may display data received from devices connected to the modular control tower in conjunction with images and overlaid images.

[0123] FIG. 10 illustrates a surgical hub 206 comprising a plurality of modules coupled to the modular control tower 236. The modular control tower 236 comprises a modular communication hub 203, e.g., a network connectivity device, and a computer system 210 to provide local processing, visualization, and imaging, for example. As shown in FIG. 10, the modular communication hub 203 may be connected in a tiered configuration to expand the number of modules (e.g., devices) that may be connected to the modular communication hub 203 and transfer data associated with the modules to the computer system 210, cloud computing resources, or both. As shown in FIG. 10, each of the network hubs/switches in the modular communication hub 203 includes three downstream ports and one upstream port. The upstream network hub/switch is connected to a processor to provide a communication connection to the cloud computing resources and a local display 217. Communication to the cloud 204 may be made either through a wired or a wireless communication channel.

[0124] The surgical hub 206 employs a non-contact sensor module 242 to measure the dimensions of the operating theater and generate a map of the surgical theater using either ultrasonic or laser-type non-contact measurement devices. An ultrasound-based non-contact sensor module scans the operating theater by transmitting a burst of ultrasound and receiving the echo when it bounces off the perimeter walls of an operating theater as described under the heading “Surgical Hub Spatial Awareness Within an Operating Room” in U.S. Provisional Patent Application Serial No. 62/611,341, titled INTERACTIVE SURGICAL PLATFORM, filed December 28, 2017, which is herein incorporated by reference in its entirety, in which the sensor module is configured to determine the size of the operating theater and to adjust Bluetooth-pairing distance limits. A laser-based non-contact sensor module scans the operating theater by transmitting laser light pulses, receiving laser light pulses that bounce off the perimeter walls of the operating theater, and comparing the phase of the transmitted pulse to the received pulse to determine the size of the operating theater and to adjust Bluetooth pairing distance limits, for example.

[0125] The computer system 210 comprises a processor 244 and a network interface 245. The processor 244 is coupled to a communication module 247, storage 248, memory 249, non-volatile memory 250, and input/output interface 251 via a system bus. The system bus can be any of several types of bus structure(s) including the memory bus or memory controller, a peripheral bus or external bus, and/or a local bus using any variety of available bus architectures including, but not limited to, 9-bit bus, Industrial Standard Architecture (ISA), Micro-Charmel Architecture (MSA), Extended ISA (EISA), Intelligent Drive Electronics (IDE), VESA Local Bus (VLB), Peripheral Component Interconnect (PCI), USB, Advanced Graphics Port (AGP), Personal Computer Memory Card International Association bus (PCMCIA), Small Computer Systems Interface (SCSI), or any other proprietary bus.

[0126] The processor 244 may be any single-core or multicore processor such as those known under the trade name ARM Cortex by Texas Instruments. In one aspect, the processor may be an LM4F230H5QR ARM Cortex-M4F Processor Core, available from Texas Instruments, for example, comprising an on-chip memory of 256 KB single-cycle flash memory, or other non-volatile memory, up to

40 MHz, a prefetch buffer to improve performance above 40 MHz, a 32 KB single-cycle serial random access memory (SRAM), an internal read-only memory (ROM) loaded with StellarisWare® software, a 2 KB electrically erasable programmable read-only memory (EEPROM), and/or one or more pulse width modulation (PWM) modules, one or more quadrature encoder inputs (QEI) analogs, one or more 12-bit analog-to-digital converters (ADCs) with 12 analog input channels, details of which are available for the product datasheet.

[0127] In one aspect, the processor 244 may comprise a safety controller comprising two controller-based families such as TMS570 and RM4x, known under the trade name Hercules ARM Cortex R4, also by Texas Instruments. The safety controller may be configured specifically for IEC 61508 and ISO 26262 safety critical applications, among others, to provide advanced integrated safety features while delivering scalable performance, connectivity, and memory options.

[0128] The system memory includes volatile memory and non-volatile memory. The basic input/output system (BIOS), containing the basic routines to transfer information between elements within the computer system, such as during start-up, is stored in non-volatile memory. For example, the non-volatile memory can include ROM, programmable ROM (PROM), electrically programmable ROM (EPROM), EEPROM, or flash memory. Volatile memory includes random-access memory (RAM), which acts as external cache memory. Moreover, RAM is available in many forms such as SRAM, dynamic RAM (DRAM), synchronous DRAM (SDRAM), double data rate SDRAM (DDR SDRAM), enhanced SDRAM (ESDRAM), Synchlink DRAM (SLDRAM), and direct Rambus RAM (DRRAM).

[0129] The computer system 210 also includes removable/non-removable, volatile/non-volatile computer storage media, such as for example disk storage. The disk storage includes, but is not limited to, devices like a magnetic disk drive, floppy disk drive, tape drive, Jaz drive, Zip drive, LS-60 drive, flash memory card, or memory stick. In addition, the disk storage can include storage media separately or in combination with other storage media including, but not limited to, an optical disc drive such as a compact disc ROM device (CD-ROM), compact disc recordable drive (CD-R Drive), compact disc rewritable drive (CD-RW Drive), or a digital versatile disc ROM drive (DVD-ROM). To facilitate the connection of the disk storage devices to the system bus, a removable or non-removable interface may be employed.

[0130] It is to be appreciated that the computer system 210 includes software that acts as an intermediary between users and the basic computer resources described in a suitable operating environment. Such software includes an operating system. The operating system, which can be stored on the disk storage, acts to control and allocate resources of the computer system. System applications take advantage of the management of resources by the operating system through program modules and program data stored either in the system memory or on the disk storage. It is to be appreciated that various components described herein can be implemented with various operating systems or combinations of operating systems.

[0131] A user enters commands or information into the computer system 210 through input device(s) coupled to the I/O interface 251. The input devices include, but are not limited to, a pointing device such as a mouse, trackball, stylus, touch pad, keyboard, microphone, joystick, game pad, satellite dish, scanner, TV tuner card, digital camera, digital video camera, web camera, and the like. These and other input devices connect to the processor through the system bus via interface port(s). The interface port(s) include, for example, a serial port, a parallel port, a game port, and a USB. The output device(s) use some of the same types of ports as input device(s). Thus, for example, a USB port may be used to provide input to the computer system and to output information from the computer system to an output device. An output adapter is provided to illustrate that there are some output devices like monitors, displays, speakers, and printers, among other output devices that require special adapters. The output adapters include, by way of illustration and not limitation, video and sound cards that provide a means of connection between the output device and the system bus. It should be noted that other devices and/or systems of devices, such as remote computer(s), provide both input and output capabilities.

[0132] The computer system 210 can operate in a networked environment using logical connections to one or more remote computers, such as cloud computer(s), or local computers. The remote cloud computer(s) can be a personal computer, server, router, network PC, workstation, microprocessor-based appliance, peer device, or other common network node, and the like, and typically includes many or all of the elements described relative to the computer system. For purposes of brevity, only a memory storage device is illustrated with the remote computer(s). The remote computer(s) is logically connected to the computer system through a network interface and then physically connected via a communication connection. The network interface encompasses communication networks such as local area networks (LANs) and wide area networks (WANs). LAN technologies include Fiber Distributed Data Interface (FDDI), Copper Distributed Data Interface (CDDI), Ethernet/IEEE 802.3, Token Ring/IEEE 802.5 and the like. WAN technologies include, but are not limited to, point-to-point links, circuit-switching networks like Integrated Services Digital Networks (ISDN) and variations thereon, packet-switching networks, and Digital Subscriber Lines (DSL).

[0133] In various aspects, the computer system 210 of FIG. 10, the imaging module 238 and/or visualization system 208, and/or the processor module 232 of FIGS. 9-10, may comprise an image processor, image-processing engine, media processor, or any specialized digital signal processor (DSP) used for the processing of digital images. The image processor may employ parallel computing with single instruction, multiple data (SIMD) or multiple instruction, multiple data (MIMD) technologies to increase speed and efficiency. The digital image-processing engine can perform a range of tasks. The image processor may be a system on a chip with multicore processor architecture.

[0134] The communication connection(s) refers to the hardware/software employed to connect the network interface to the bus. While the communication connection is shown for illustrative clarity inside the computer system, it can also be external to the computer system 210. The hardware/software

necessary for connection to the network interface includes, for illustrative purposes only, internal and external technologies such as modems, including regular telephone-grade modems, cable modems, and DSL modems, ISDN adapters, and Ethernet cards.

[0135] FIG. 11 illustrates a functional block diagram of one aspect of a USB network hub 300 device, in accordance with at least one aspect of the present disclosure. In the illustrated aspect, the USB network hub device 300 employs a TUSB2036 integrated circuit hub by Texas Instruments. The USB network hub 300 is a CMOS device that provides an upstream USB transceiver port 302 and up to three downstream USB transceiver ports 304, 306, 308 in compliance with the USB 2.0 specification. The upstream USB transceiver port 302 is a differential root data port comprising a differential data minus (DM0) input paired with a differential data plus (DP0) input. The three downstream USB transceiver ports 304, 306, 308 are differential data ports where each port includes differential data plus (DP1-DP3) outputs paired with differential data minus (DM1-DM3) outputs.

[0136] The USB network hub 300 device is implemented with a digital state machine instead of a microcontroller, and no firmware programming is required. Fully compliant USB transceivers are integrated into the circuit for the upstream USB transceiver port 302 and all downstream USB transceiver ports 304, 306, 308. The downstream USB transceiver ports 304, 306, 308 support both full-speed and low-speed devices by automatically setting the slew rate according to the speed of the device attached to the ports. The USB network hub 300 device may be configured either in bus-powered or self-powered mode and includes a hub power logic 312 to manage power.

[0137] The USB network hub 300 device includes a serial interface engine 310 (SIE). The SIE 310 is the front end of the USB network hub 300 hardware and handles most of the protocol described in chapter 8 of the USB specification. The SIE 310 typically comprehends signaling up to the transaction level. The functions that it handles could include: packet recognition, transaction sequencing, SOP, EOP, RESET, and RESUME signal detection/generation, clock/data separation, non-return-to-zero invert (NRZI) data encoding/decoding and bit-stuffing, CRC generation and checking (token and data), packet ID (PID) generation and checking/decoding, and/or serial-parallel/parallel-serial conversion. The 310 receives a clock input 314 and is coupled to a suspend/resume logic and frame timer 316 circuit and a hub repeater circuit 318 to control communication between the upstream USB transceiver port 302 and the downstream USB transceiver ports 304, 306, 308 through port logic circuits 320, 322, 324. The SIE 310 is coupled to a command decoder 326 via interface logic to control commands from a serial EEPROM via a serial EEPROM interface 330.

[0138] In various aspects, the USB network hub 300 can connect 127 functions configured in up to six logical layers (tiers) to a single computer. Further, the USB network hub 300 can connect to all peripherals using a standardized four-wire cable that provides both communication and power distribution. The power configurations are bus-powered and self-powered modes. The USB network hub 300 may be configured to support four modes of power management: a bus-powered hub, with either

individual-port power management or ganged-port power management, and the self-powered hub, with either individual-port power management or ganged-port power management. In one aspect, using a USB cable, the USB network hub 300, the upstream USB transceiver port 302 is plugged into a USB host controller, and the downstream USB transceiver ports 304, 306, 308 are exposed for connecting USB compatible devices, and so forth.

Surgical Instrument Hardware

[0139] FIG. 12 illustrates a logic diagram of a control system 470 of a surgical instrument or tool in accordance with one or more aspects of the present disclosure. The control system 470 includes a microcontroller 461 comprising a processor 462 and a memory 468. One or more of sensors 472, 474, 476, for example, provide real-time feedback to the processor 462. A motor 482, driven by a motor driver 492, operably couples a longitudinally movable displacement member to drive the I-beam knife element. A tracking system 480 is configured to determine the position of the longitudinally movable displacement member. The position information is provided to the processor 462, which can be programmed or configured to determine the position of the longitudinally movable drive member as well as the position of a firing member, firing bar, and I-beam knife element. Additional motors may be provided at the tool driver interface to control I-beam firing, closure tube travel, shaft rotation, and articulation. A display 473 displays a variety of operating conditions of the instruments and may include touch screen functionality for data input. Information displayed on the display 473 may be overlaid with images acquired via endoscopic imaging modules.

[0140] In one aspect, the microcontroller 461 may be any single-core or multicore processor such as those known under the trade name ARM Cortex by Texas Instruments. In one aspect, the main microcontroller 461 may be an LM4F230H5QR ARM Cortex-M4F Processor Core, available from Texas Instruments, for example, comprising an on-chip memory of 256 KB single-cycle flash memory, or other non-volatile memory, up to 40 MHz, a prefetch buffer to improve performance above 40 MHz, a 32 KB single-cycle SRAM, and internal ROM loaded with StellarisWare® software, a 2 KB EEPROM, one or more PWM modules, one or more QEI analogs, and/or one or more 12-bit ADCs with 12 analog input channels, details of which are available for the product datasheet.

[0141] In one aspect, the microcontroller 461 may comprise a safety controller comprising two controller-based families such as TMS570 and RM4x, known under the trade name Hercules ARM Cortex R4, also by Texas Instruments. The safety controller may be configured specifically for IEC 61508 and ISO 26262 safety critical applications, among others, to provide advanced integrated safety features while delivering scalable performance, connectivity, and memory options.

[0142] The microcontroller 461 may be programmed to perform various functions such as precise control over the speed and position of the knife and articulation systems. In one aspect, the microcontroller 461 includes a processor 462 and a memory 468. The electric motor 482 may be a

brushed direct current (DC) motor with a gearbox and mechanical links to an articulation or knife system. In one aspect, a motor driver 492 may be an A3941 available from Allegro Microsystems, Inc. Other motor drivers may be readily substituted for use in the tracking system 480 comprising an absolute positioning system. A detailed description of an absolute positioning system is described in U.S. Patent Application Publication No. 2017/0296213, titled SYSTEMS AND METHODS FOR CONTROLLING A SURGICAL STAPLING AND CUTTING INSTRUMENT, published on October 19, 2017, which is herein incorporated by reference in its entirety.

[0143] The microcontroller 461 may be programmed to provide precise control over the speed and position of displacement members and articulation systems. The microcontroller 461 may be configured to compute a response in the software of the microcontroller 461. The computed response is compared to a measured response of the actual system to obtain an "observed" response, which is used for actual feedback decisions. The observed response is a favorable, tuned value that balances the smooth, continuous nature of the simulated response with the measured response, which can detect outside influences on the system.

[0144] In one aspect, the motor 482 may be controlled by the motor driver 492 and can be employed by the firing system of the surgical instrument or tool. In various forms, the motor 482 may be a brushed DC driving motor having a maximum rotational speed of approximately 25,000 RPM. In other arrangements, the motor 482 may include a brushless motor, a cordless motor, a synchronous motor, a stepper motor, or any other suitable electric motor. The motor driver 492 may comprise an H-bridge driver comprising field-effect transistors (FETs), for example. The motor 482 can be powered by a power assembly releasably mounted to the handle assembly or tool housing for supplying control power to the surgical instrument or tool. The power assembly may comprise a battery which may include a number of battery cells connected in series that can be used as the power source to power the surgical instrument or tool. In certain circumstances, the battery cells of the power assembly may be replaceable and/or rechargeable. In at least one example, the battery cells can be lithium-ion (LI) batteries which can be couplable to and separable from the power assembly.

[0145] The motor driver 492 may be an A3941 available from Allegro Microsystems, Inc. The A3941 492 is a full-bridge controller for use with external N-channel power metal-oxide semiconductor field-effect transistors (MOSFETs) specifically designed for inductive loads, such as brush DC motors. The driver 492 comprises a unique charge pump regulator that provides full (>10V) gate drive for battery voltages down to 7V and allows the A3941 to operate with a reduced gate drive, down to 5.5V. A bootstrap capacitor may be employed to provide the above battery supply voltage required for N-channel MOSFETs. An internal charge pump for the high-side drive allows DC (100% duty cycle) operation. The full bridge can be driven in fast or slow decay modes using diode or synchronous rectification. In the slow decay mode, current recirculation can be through the high-side or the lowside FETs. The power FETs are protected from shoot-through by resistor-adjustable dead time. Integrated diagnostics provide

indications of undervoltage, overtemperature, and power bridge faults and can be configured to protect the power MOSFETs under most short circuit conditions. Other motor drivers may be readily substituted for use in the tracking system 480 comprising an absolute positioning system.

[0146] The tracking system 480 comprises a controlled motor drive circuit arrangement comprising a position sensor 472, in accordance with at least one aspect of this disclosure. The position sensor 472 for an absolute positioning system provides a unique position signal corresponding to the location of a displacement member. In one aspect, the displacement member represents a longitudinally movable drive member comprising a rack of drive teeth for meshing engagement with a corresponding drive gear of a gear reducer assembly. In other aspects, the displacement member represents the firing member, which could be adapted and configured to include a rack of drive teeth. In yet another aspect, the displacement member represents a firing bar or the I-beam, each of which can be adapted and configured to include a rack of drive teeth. Accordingly, as used herein, the term displacement member is used generically to refer to any movable member of the surgical instrument or tool such as the drive member, the firing member, the firing bar, the I-beam, or any element that can be displaced. In one aspect, the longitudinally movable drive member is coupled to the firing member, the firing bar, and the I-beam. Accordingly, the absolute positioning system can, in effect, track the linear displacement of the I-beam by tracking the linear displacement of the longitudinally movable drive member. In various other aspects, the displacement member may be coupled to any position sensor 472 suitable for measuring linear displacement. Thus, the longitudinally movable drive member, the firing member, the firing bar, or the I-beam, or combinations thereof, may be coupled to any suitable linear displacement sensor. Linear displacement sensors may include contact or non-contact displacement sensors. Linear displacement sensors may comprise linear variable differential transformers (LVDT), differential variable reluctance transducers (DVRT), a slide potentiometer, a magnetic sensing system comprising a movable magnet and a series of linearly arranged Hall-effect sensors, a magnetic sensing system comprising a fixed magnet and a series of movable, linearly arranged Hall-effect sensors, an optical sensing system comprising a movable light source and a series of linearly arranged photo diodes or photo detectors, an optical sensing system comprising a fixed light source and a series of movable linearly arranged photo diodes or photo detectors, or any combination thereof.

[0147] The electric motor 482 can include a rotatable shaft that operably interfaces with a gear assembly that is mounted in meshing engagement with a set, or rack, of drive teeth on the displacement member. A sensor element may be operably coupled to a gear assembly such that a single revolution of the position sensor 472 element corresponds to some linear longitudinal translation of the displacement member. An arrangement of gearing and sensors can be connected to the linear actuator, via a rack and pinion arrangement, or a rotary actuator, via a spur gear or other connection. A power source supplies power to the absolute positioning system and an output indicator may display the output of the absolute positioning system. The displacement member represents the longitudinally movable drive member

comprising a rack of drive teeth formed thereon for meshing engagement with a corresponding drive gear of the gear reducer assembly. The displacement member represents the longitudinally movable firing member, firing bar, I-beam, or combinations thereof.

[0148] A single revolution of the sensor element associated with the position sensor 472 is equivalent to a longitudinal linear displacement d1 of the of the displacement member, where d1 is the longitudinal linear distance that the displacement member moves from point “a” to point “b” after a single revolution of the sensor element coupled to the displacement member. The sensor arrangement may be connected via a gear reduction that results in the position sensor 472 completing one or more revolutions for the full stroke of the displacement member. The position sensor 472 may complete multiple revolutions for the full stroke of the displacement member.

[0149] A series of switches, where n is an integer greater than one, may be employed alone or in combination with a gear reduction to provide a unique position signal for more than one revolution of the position sensor 472. The state of the switches are fed back to the microcontroller 461 that applies logic to determine a unique position signal corresponding to the longitudinal linear displacement d1 + d2 + … dn of the displacement member. The output of the position sensor 472 is provided to the microcontroller 461. The position sensor 472 of the sensor arrangement may comprise a magnetic sensor, an analog rotary sensor like a potentiometer, or an array of analog Hall-effect elements, which output a unique combination of position signals or values.

[0150] The position sensor 472 may comprise any number of magnetic sensing elements, such as, for example, magnetic sensors classified according to whether they measure the total magnetic field or the vector components of the magnetic field. The techniques used to produce both types of magnetic sensors encompass many aspects of physics and electronics. The technologies used for magnetic field sensing include search coil, fluxgate, optically pumped, nuclear precession, SQUID, Hall-effect, anisotropic magnetoresistance, giant magnetoresistance, magnetic tunnel junctions, giant magnetoimpedance, magnetostrictive/piezoelectric composites, magnetodiode, magnetotransistor, fiber-optic, magneto-optic, and microelectromechanical systems-based magnetic sensors, among others.

[0151] In one aspect, the position sensor 472 for the tracking system 480 comprising an absolute positioning system comprises a magnetic rotary absolute positioning system. The position sensor 472 may be implemented as an AS5055EQFT single-chip magnetic rotary position sensor available from Austria Microsystems, AG. The position sensor 472 is interfaced with the microcontroller 461 to provide an absolute positioning system. The position sensor 472 is a low-voltage and low-power component and includes four Hall-effect elements in an area of the position sensor 472 that is located above a magnet. A high-resolution ADC and a smart power management controller are also provided on the chip. A coordinate rotation digital computer (CORDIC) processor, also known as the digit-by-digit method and Volder’s algorithm, is provided to implement a simple and efficient algorithm to calculate hyperbolic and trigonometric functions that require only addition, subtraction, bitshift, and table lookup operations. The

angle position, alarm bits, and magnetic field information are transmitted over a standard serial communication interface, such as a serial peripheral interface (SPI) interface, to the microcontroller 461. The position sensor 472 provides 12 or 14 bits of resolution. The position sensor 472 may be an AS5055 chip provided in a small QFN 16-pin 4x4x0.85mm package.

[0152] The tracking system 480 comprising an absolute positioning system may comprise and/or be programmed to implement a feedback controller, such as a PID, state feedback, and adaptive controller. A power source converts the signal from the feedback controller into a physical input to the system: in this case the voltage. Other examples include a PWM of the voltage, current, and force. Other sensor(s) may be provided to measure physical parameters of the physical system in addition to the position measured by the position sensor 472. In some aspects, the other sensor(s) can include sensor arrangements such as those described in U.S. Patent No. 9,345,481, titled STAPLE CARTRIDGE TISSUE THICKNESS SENSOR SYSTEM, which issued on May 24, 2016, which is herein incorporated by reference in its entirety; U.S. Patent Application Publication No. 2014/0263552, titled STAPLE CARTRIDGE TISSUE THICKNESS SENSOR SYSTEM, published on September 18, 2014, which is herein incorporated by reference in its entirety; and U.S. Patent Application Serial No. 15/628,175, titled TECHNIQUES FOR ADAPTIVE CONTROL OF MOTOR VELOCITY OF A SURGICAL STAPLING AND CUTTING INSTRUMENT, filed June 20, 2017, which is herein incorporated by reference in its entirety. In a digital signal processing system, an absolute positioning system is coupled to a digital data acquisition system where the output of the absolute positioning system will have a finite resolution and sampling frequency. The absolute positioning system may comprise a compare-and-combine circuit to combine a computed response with a measured response using algorithms, such as a weighted average and a theoretical control loop, that drive the computed response towards the measured response. The computed response of the physical system takes into account properties like mass, inertial, viscous friction, inductance resistance, etc., to predict what the states and outputs of the physical system will be by knowing the input.

[0153] The absolute positioning system provides an absolute position of the displacement member upon power-up of the instrument, without retracting or advancing the displacement member to a reset (zero or home) position as may be required with conventional rotary encoders that merely count the number of steps forwards or backwards that the motor 482 has taken to infer the position of a device actuator, drive bar, knife, or the like.

[0154] A sensor 474, such as, for example, a strain gauge or a micro-strain gauge, is configured to measure one or more parameters of the end effector, such as, for example, the amplitude of the strain exerted on the anvil during a clamping operation, which can be indicative of the closure forces applied to the anvil. The measured strain is converted to a digital signal and provided to the processor 462. Alternatively, or in addition to the sensor 474, a sensor 476, such as, for example, a load sensor, can measure the closure force applied by the closure drive system to the anvil. The sensor 476, such as, for

example, a load sensor, can measure the firing force applied to an I-beam in a firing stroke of the surgical instrument or tool. The I-beam is configured to engage a wedge sled, which is configured to upwardly cam staple drivers to force out staples into deforming contact with an anvil. The I-beam also includes a sharpened cutting edge that can be used to sever tissue as the I-beam is advanced distally by the firing bar. Alternatively, a current sensor 478 can be employed to measure the current drawn by the motor 482. The force required to advance the firing member can correspond to the current drawn by the motor 482, for example. The measured force is converted to a digital signal and provided to the processor 462.

[0155] In one form, the strain gauge sensor 474 can be used to measure the force applied to the tissue by the end effector. A strain gauge can be coupled to the end effector to measure the force on the tissue being treated by the end effector. A system for measuring forces applied to the tissue grasped by the end effector comprises a strain gauge sensor 474, such as, for example, a micro-strain gauge, that is configured to measure one or more parameters of the end effector, for example. In one aspect, the strain gauge sensor 474 can measure the amplitude or magnitude of the strain exerted on a jaw member of an end effector during a clamping operation, which can be indicative of the tissue compression. The measured strain is converted to a digital signal and provided to a processor 462 of the microcontroller 461. A load sensor 476 can measure the force used to operate the knife element, for example, to cut the tissue captured between the anvil and the staple cartridge. A magnetic field sensor can be employed to measure the thickness of the captured tissue. The measurement of the magnetic field sensor also may be converted to a digital signal and provided to the processor 462.

[0156] The measurements of the tissue compression, the tissue thickness, and/or the force required to close the end effector on the tissue, as respectively measured by the sensors 474, 476, can be used by the microcontroller 461 to characterize the selected position of the firing member and/or the corresponding value of the speed of the firing member. In one instance, a memory 468 may store a technique, an equation, and/or a lookup table which can be employed by the microcontroller 461 in the assessment.

[0157] The control system 470 of the surgical instrument or tool also may comprise wired or wireless communication circuits to communicate with the modular communication hub as shown in FIGS. 8-11.

[0158] FIG. 13 illustrates a control circuit 500 configured to control aspects of the surgical instrument or tool, in accordance with at least one aspect of this disclosure. The control circuit 500 can be configured to implement various processes described herein. The control circuit 500 may comprise a microcontroller comprising one or more processors 502 (e.g., microprocessor, microcontroller) coupled to at least one memory circuit 504. The memory circuit 504 stores machine-executable instructions that, when executed by the processor 502, cause the processor 502 to execute machine instructions to implement various processes described herein. The processor 502 may be any one of a number of single-core or multicore processors known in the art. The memory circuit 504 may comprise volatile and non-volatile storage

media. The processor 502 may include an instruction processing unit 506 and an arithmetic unit 508. The instruction processing unit may be configured to receive instructions from the memory circuit 504 of this disclosure.

[0159] FIG. 14 illustrates a combinational logic circuit 510 configured to control aspects of the surgical instrument or tool, in accordance with at least one aspect of this disclosure. The combinational logic circuit 510 can be configured to implement various processes described herein. The combinational logic circuit 510 may comprise a finite state machine comprising a combinational logic 512 configured to receive data associated with the surgical instrument or tool at an input 514, process the data by the combinational logic 512, and provide an output 516.

[0160] FIG. 15 illustrates a sequential logic circuit 520 configured to control aspects of the surgical instrument or tool, in accordance with at least one aspect of this disclosure. The sequential logic circuit 520 or the combinational logic 522 can be configured to implement various processes described herein. The sequential logic circuit 520 may comprise a finite state machine. The sequential logic circuit 520 may comprise a combinational logic 522, at least one memory circuit 524, and a clock 529, for example. The at least one memory circuit 524 can store a current state of the finite state machine. In certain instances, the sequential logic circuit 520 may be synchronous or asynchronous. The combinational logic 522 is configured to receive data associated with the surgical instrument or tool from an input 526, process the data by the combinational logic 522, and provide an output 528. In other aspects, the circuit may comprise a combination of a processor (e.g., processor 502, FIG. 13) 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 510, FIG. 14) and the sequential logic circuit 520.

[0161] FIG. 16 illustrates a surgical instrument or tool comprising a plurality of motors which can be activated to perform various functions. In certain instances, a first motor can be activated to perform a first function, a second motor can be activated to perform a second function, a third motor can be activated to perform a third function, a fourth motor can be activated to perform a fourth function, and so on. In certain instances, the plurality of motors of robotic surgical instrument 600 can be individually activated to cause firing, closure, and/or articulation motions in the end effector. The firing, closure, and/or articulation motions can be transmitted to the end effector through a shaft assembly, for example.

[0162] In certain instances, the surgical instrument system or tool may include a firing motor 602. The firing motor 602 may be operably coupled to a firing motor drive assembly 604, which can be configured to transmit firing motions, generated by the firing motor 602 to the end effector, in particular to displace the I-beam element. In certain instances, the firing motions generated by the firing motor 602 may cause the staples to be deployed from the staple cartridge into tissue captured by the end effector and/or the cutting edge of the I-beam element to be advanced to cut the captured tissue, for example. The I-beam element may be retracted by reversing the direction of the firing motor 602.

[0163] In certain instances, the surgical instrument or tool may include a closure motor 603. The closure motor 603 may be operably coupled to a closure motor drive assembly 605, which can be configured to transmit closure motions, generated by the closure motor 603 to the end effector, in particular to displace a closure tube to close the anvil and compress tissue between the anvil and the staple cartridge. The closure motions may cause the end effector to transition from an open configuration to an approximated configuration to capture tissue, for example. The end effector may be transitioned to an open position by reversing the direction of the closure motor 603.

[0164] In certain instances, the surgical instrument or tool may include one or more articulation motors 606a, 606b, for example. The articulation motors 606a, 606b may be operably coupled to respective articulation motor drive assemblies 608a, 608b, which can be configured to transmit articulation motions generated by the articulation motors 606a, 606b to the end effector. In certain instances, the articulation motions may cause the end effector to articulate relative to the shaft, for example.

[0165] As described above, the surgical instrument or tool may include a plurality of motors, which may be configured to perform various independent functions. In certain instances, the plurality of motors of the surgical instrument or tool can be individually or separately activated to perform one or more functions while the other motors remain inactive. For example, the articulation motors 606a, 606b can be activated to cause the end effector to be articulated while the firing motor 602 remains inactive. Alternatively, the firing motor 602 can be activated to fire the plurality of staples, and/or to advance the cutting edge, while the articulation motor 606 remains inactive. Furthermore, the closure motor 603 may be activated simultaneously with the firing motor 602 to cause the closure tube and the I-beam element to advance distally as described in more detail hereinbelow.

[0166] In certain instances, the surgical instrument or tool may include a common control module 610, which can be employed with a plurality of motors of the surgical instrument or tool. In certain instances, the common control module 610 may accommodate one of the plurality of motors at a time. For example, the common control module 610 can be couplable to and separable from the plurality of motors of the robotic surgical instrument individually. In certain instances, a plurality of the motors of the surgical instrument or tool may share one or more common control modules such as the common control module 610. In certain instances, a plurality of motors of the surgical instrument or tool can be individually and selectively engaged with the common control module 610. In certain instances, the common control module 610 can be selectively switched from interfacing with one of a plurality of motors of the surgical instrument or tool to interfacing with another one of the plurality of motors of the surgical instrument or tool.

[0167] In at least one example, the common control module 610 can be selectively switched between operable engagement with the articulation motors 606a, 606b and operable engagement with either the firing motor 602 or the closure motor 603. In at least one example, as illustrated in FIG. 16, a switch 614 can be moved or transitioned between a plurality of positions and/or states. In a first position 616, the

switch 614 may electrically couple the common control module 610 to the firing motor 602; in a second position 617, the switch 614 may electrically couple the common control module 610 to the closure motor 603; in a third position 618a, the switch 614 may electrically couple the common control module 610 to the first articulation motor 606a; and in a fourth position 618b, the switch 614 may electrically couple the common control module 610 to the second articulation motor 606b, for example. In certain instances, separate common control modules 610 can be electrically coupled to the firing motor 602, the closure motor 603, and the articulation motors 606a, 606b at the same time. In certain instances, the switch 614 may be a mechanical switch, an electromechanical switch, a solid-state switch, or any suitable switching mechanism.

[0168] Each of the motors 602, 603, 606a, 606b may comprise a torque sensor to measure the output torque on the shaft of the motor. The force on an end effector may be sensed in any conventional manner, such as by force sensors on the outer sides of the jaws or by a torque sensor for the motor actuating the jaws.

[0169] In various instances, as illustrated in FIG. 16, the common control module 610 may comprise a motor driver 626, which may comprise one or more H-bridge FETs. The motor driver 626 may modulate the power transmitted from a power source 628 to a motor coupled to the common control module 610 based on input from a microcontroller 620 (the "controller"), for example. In certain instances, the microcontroller 620 can be employed to determine the current drawn by the motor, for example, while the motor is coupled to the common control module 610, as described above.

[0170] In certain instances, the microcontroller 620 may include a microprocessor 622 (the "processor") and one or more non-transitory computer-readable mediums or memory units 624 (the "memory"). In certain instances, the memory 624 may store various program instructions, which when executed may cause the processor 622 to perform a plurality of functions and/or calculations described herein. In certain instances, one or more of the memory 624 may be coupled to the processor 622, for example.

[0171] In certain instances, the power source 628 can be employed to supply power to the microcontroller 620, for example. In certain instances, the power source 628 may comprise a battery (or "battery pack" or "power pack"), such as an LI battery, for example. In certain instances, the battery pack may be configured to be releasably mounted to a handle for supplying power to the surgical instrument 600. A number of battery cells connected in series may be used as the power source 628. In certain instances, the power source 628 may be replaceable and/or rechargeable, for example.

[0172] In various instances, the processor 622 may control the motor driver 626 to control the position, direction of rotation, and/or velocity of a motor that is coupled to the common control module 610. In certain instances, the processor 622 can signal the motor driver 626 to stop and/or disable a motor that is coupled to the common control module 610. It should be understood that the term "processor" as used herein includes any suitable microprocessor, microcontroller, or other basic computing device that

incorporates the functions of a computer's central processing unit (CPU) on an integrated circuit or, at most, a few integrated circuits. The processor is a multipurpose, programmable device that accepts digital data as input, processes it according to instructions stored in its memory, and provides results as output. It is an example of sequential digital logic, as it has internal memory. Processors operate on numbers and symbols represented in the binary numeral system.

[0173] In one instance, the processor 622 may be any single-core or multicore processor such as those known under the trade name ARM Cortex by Texas Instruments. In certain instances, the microcontroller 620 may be an LM 4F230H5QR, available from Texas Instruments, for example. In at least one example, the Texas Instruments LM4F230H5QR is an ARM Cortex-M4F Processor Core comprising an on-chip memory of 256 KB single-cycle flash memory, or other non-volatile memory, up to 40 MHz, a prefetch buffer to improve performance above 40 MHz, a 32 KB single-cycle SRAM, an internal ROM loaded with StellarisWare® software, a 2 KB EEPROM, one or more PWM modules, one or more QEI analogs, one or more 12-bit ADCs with 12 analog input channels, among other features that are readily available for the product datasheet. Other microcontrollers may be readily substituted for use with the module 4410. Accordingly, the present disclosure should not be limited in this context.

[0174] In certain instances, the memory 624 may include program instructions for controlling each of the motors of the surgical instrument 600 that are couplable to the common control module 610. For example, the memory 624 may include program instructions for controlling the firing motor 602, the closure motor 603, and the articulation motors 606a, 606b. Such program instructions may cause the processor 622 to control the firing, closure, and articulation functions in accordance with inputs from algorithms or control programs of the surgical instrument or tool.

[0175] In certain instances, one or more mechanisms and/or sensors such as, for example, sensors 630 can be employed to alert the processor 622 to the program instructions that should be used in a particular setting. For example, the sensors 630 may alert the processor 622 to use the program instructions associated with firing, closing, and articulating the end effector. In certain instances, the sensors 630 may comprise position sensors which can be employed to sense the position of the switch 614, for example. Accordingly, the processor 622 may use the program instructions associated with firing the I-beam of the end effector upon detecting, through the sensors 630 for example, that the switch 614 is in the first position 616; the processor 622 may use the program instructions associated with closing the anvil upon detecting, through the sensors 630 for example, that the switch 614 is in the second position 617; and the processor 622 may use the program instructions associated with articulating the end effector upon detecting, through the sensors 630 for example, that the switch 614 is in the third or fourth position 618a, 618b.

[0176] FIG. 17 is a schematic diagram of a robotic surgical instrument 700 configured to operate a surgical tool described herein, in accordance with at least one aspect of this disclosure. The robotic surgical instrument 700 may be programmed or configured to control distal/proximal translation of a

displacement member, distal/proximal displacement of a closure tube, shaft rotation, and articulation, either with single or multiple articulation drive links. In one aspect, the surgical instrument 700 may be programmed or configured to individually control a firing member, a closure member, a shaft member, and/or one or more articulation members. The surgical instrument 700 comprises a control circuit 710 configured to control motor-driven firing members, closure members, shaft members, and/or one or more articulation members.

[0177] In one aspect, the robotic surgical instrument 700 comprises a control circuit 710 configured to control an anvil 716 and an I-beam 714 (including a sharp cutting edge) portion of an end effector 702, a removable staple cartridge 718, a shaft 740, and one or more articulation members 742a, 742b via a plurality of motors 704a-704e. A position sensor 734 may be configured to provide position feedback of the I-beam 714 to the control circuit 710. Other sensors 738 may be configured to provide feedback to the control circuit 710. A timer/counter 731 provides timing and counting information to the control circuit 710. An energy source 712 may be provided to operate the motors 704a-704e, and a current sensor 736 provides motor current feedback to the control circuit 710. The motors 704a-704e can be operated individually by the control circuit 710 in an open-loop or closed-loop feedback control.

[0178] In one aspect, the control circuit 710 may comprise one or more microcontrollers, microprocessors, or other suitable processors for executing instructions that cause the processor or processors to perform one or more tasks. In one aspect, a timer/counter 731 provides an output signal, such as the elapsed time or a digital count, to the control circuit 710 to correlate the position of the I-beam 714 as determined by the position sensor 734 with the output of the timer/counter 731 such that the control circuit 710 can determine the position of the I-beam 714 at a specific time (t) relative to a starting position or the time (t) when the I-beam 714 is at a specific position relative to a starting position. The timer/counter 731 may be configured to measure elapsed time, count external events, or time external events.

[0179] In one aspect, the control circuit 710 may be programmed to control functions of the end effector 702 based on one or more tissue conditions. The control circuit 710 may be programmed to sense tissue conditions, such as thickness, either directly or indirectly, as described herein. The control circuit 710 may be programmed to select a firing control program or closure control program based on tissue conditions. A firing control program may describe the distal motion of the displacement member. Different firing control programs may be selected to better treat different tissue conditions. For example, when thicker tissue is present, the control circuit 710 may be programmed to translate the displacement member at a lower velocity and/or with lower power. When thinner tissue is present, the control circuit 710 may be programmed to translate the displacement member at a higher velocity and/or with higher power. A closure control program may control the closure force applied to the tissue by the anvil 716. Other control programs control the rotation of the shaft 740 and the articulation members 742a, 742b.

[0180] In one aspect, the control circuit 710 may generate motor set point signals. The motor set point signals may be provided to various motor controls 708a-708e. The motor controls 708a-708e may comprise one or more circuits configured to provide motor drive signals to the motors 704a-704e to drive the motors 704a-704e as described herein. In some examples, the motors 704a-704e may be brushed DC electric motors. For example, the velocity of the motors 704a-704e may be proportional to the respective motor drive signals. In some examples, the motors 704a-704e may be brushless DC electric motors, and the respective motor drive signals may comprise a PWM signal provided to one or more stator windings of the motors 704a-704e. Also, in some examples, the motor controls 708a-708e may be omitted and the control circuit 710 may generate the motor drive signals directly.

[0181] In one aspect, the control circuit 710 may initially operate each of the motors 704a-704e in an open-loop configuration for a first open-loop portion of a stroke of the displacement member. Based on the response of the robotic surgical instrument 700 during the open-loop portion of the stroke, the control circuit 710 may select a firing control program in a closed-loop configuration. The response of the instrument may include a translation distance of the displacement member during the open-loop portion, a time elapsed during the open-loop portion, the energy provided to one of the motors 704a-704e during the open-loop portion, a sum of pulse widths of a motor drive signal, etc. After the open-loop portion, the control circuit 710 may implement the selected firing control program for a second portion of the displacement member stroke. For example, during a closed-loop portion of the stroke, the control circuit 710 may modulate one of the motors 704a-704e based on translation data describing a position of the displacement member in a closed-loop manner to translate the displacement member at a constant velocity.

[0182] In one aspect, the motors 704a-704e may receive power from an energy source 712. The energy source 712 may be a DC power supply driven by a main alternating current power source, a battery, a super capacitor, or any other suitable energy source. The motors 704a-704e may be mechanically coupled to individual movable mechanical elements such as the I-beam 714, anvil 716, shaft 740, articulation 742a, and articulation 742b via respective transmissions 706a-706e. The transmissions 706a-706e may include one or more gears or other linkage components to couple the motors 704a-704e to movable mechanical elements. A position sensor 734 may sense a position of the I-beam 714. The position sensor 734 may be or include any type of sensor that is capable of generating position data that indicate a position of the I-beam 714. In some examples, the position sensor 734 may include an encoder configured to provide a series of pulses to the control circuit 710 as the I-beam 714 translates distally and proximally. The control circuit 710 may track the pulses to determine the position of the I-beam 714. Other suitable position sensors may be used, including, for example, a proximity sensor. Other types of position sensors may provide other signals indicating motion of the I-beam 714. Also, in some examples, the position sensor 734 may be omitted. Where any of the motors 704a-704e is a stepper motor, the control circuit 710 may track the position of the I-beam 714 by aggregating the

number and direction of steps that the motor 704 has been instructed to execute. The position sensor 734 may be located in the end effector 702 or at any other portion of the instrument. The outputs of each of the motors 704a-704e include a torque sensor 744a-744e to sense force and have an encoder to sense rotation of the drive shaft.

[0183] In one aspect, the control circuit 710 is configured to drive a firing member such as the I-beam 714 portion of the end effector 702. The control circuit 710 provides a motor set point to a motor control 708a, which provides a drive signal to the motor 704a. The output shaft of the motor 704a is coupled to a torque sensor 744a. The torque sensor 744a is coupled to a transmission 706a which is coupled to the I-beam 714. The transmission 706a comprises movable mechanical elements such as rotating elements and a firing member to control the movement of the I-beam 714 distally and proximally along a longitudinal axis of the end effector 702. In one aspect, the motor 704a may be coupled to the knife gear assembly, which includes a knife gear reduction set that includes a first knife drive gear and a second knife drive gear. A torque sensor 744a provides a firing force feedback signal to the control circuit 710. The firing force signal represents the force required to fire or displace the I-beam 714. A position sensor 734 may be configured to provide the position of the I-beam 714 along the firing stroke or the position of the firing member as a feedback signal to the control circuit 710. The end effector 702 may include additional sensors 738 configured to provide feedback signals to the control circuit 710. When ready to use, the control circuit 710 may provide a firing signal to the motor control 708a. In response to the firing signal, the motor 704a may drive the firing member distally along the longitudinal axis of the end effector 702 from a proximal stroke start position to a stroke end position distal to the stroke start position. As the firing member translates distally, an I-beam 714, with a cutting element positioned at a distal end, advances distally to cut tissue located between the staple cartridge 718 and the anvil 716.

[0184] In one aspect, the control circuit 710 is configured to drive a closure member such as the anvil 716 portion of the end effector 702. The control circuit 710 provides a motor set point to a motor control 708b, which provides a drive signal to the motor 704b. The output shaft of the motor 704b is coupled to a torque sensor 744b. The torque sensor 744b is coupled to a transmission 706b which is coupled to the anvil 716. The transmission 706b comprises movable mechanical elements such as rotating elements and a closure member to control the movement of the anvil 716 from the open and closed positions. In one aspect, the motor 704b is coupled to a closure gear assembly, which includes a closure reduction gear set that is supported in meshing engagement with the closure spur gear. The torque sensor 744b provides a closure force feedback signal to the control circuit 710. The closure force feedback signal represents the closure force applied to the anvil 716. The position sensor 734 may be configured to provide the position of the closure member as a feedback signal to the control circuit 710. Additional sensors 738 in the end effector 702 may provide the closure force feedback signal to the control circuit 710. The pivotable anvil 716 is positioned opposite the staple cartridge 718. When ready to use, the control circuit 710 may provide a closure signal to the motor control 708b. In response to the closure

signal, the motor 704b advances a closure member to grasp tissue between the anvil 716 and the staple cartridge 718.

[0185] In one aspect, the control circuit 710 is configured to rotate a shaft member such as the shaft 740 to rotate the end effector 702. The control circuit 710 provides a motor set point to a motor control 708c, which provides a drive signal to the motor 704c. The output shaft of the motor 704c is coupled to a torque sensor 744c. The torque sensor 744c is coupled to a transmission 706c which is coupled to the shaft 740. The transmission 706c comprises movable mechanical elements such as rotating elements to control the rotation of the shaft 740 clockwise or counterclockwise up to and over 360°. In one aspect, the motor 704c is coupled to the rotational transmission assembly, which includes a tube gear segment that is formed on (or attached to) the proximal end of the proximal closure tube for operable engagement by a rotational gear assembly that is operably supported on the tool mounting plate. The torque sensor 744c provides a rotation force feedback signal to the control circuit 710. The rotation force feedback signal represents the rotation force applied to the shaft 740. The position sensor 734 may be configured to provide the position of the closure member as a feedback signal to the control circuit 710. Additional sensors 738 such as a shaft encoder may provide the rotational position of the shaft 740 to the control circuit 710.

[0186] In one aspect, the control circuit 710 is configured to articulate the end effector 702. The control circuit 710 provides a motor set point to a motor control 708d, which provides a drive signal to the motor 704d. The output shaft of the motor 704d is coupled to a torque sensor 744d. The torque sensor 744d is coupled to a transmission 706d which is coupled to an articulation member 742a. The transmission 706d comprises movable mechanical elements such as articulation elements to control the articulation of the end effector 702 ±65°. In one aspect, the motor 704d is coupled to an articulation nut, which is rotatably journaled on the proximal end portion of the distal spine portion and is rotatably driven thereon by an articulation gear assembly. The torque sensor 744d provides an articulation force feedback signal to the control circuit 710. The articulation force feedback signal represents the articulation force applied to the end effector 702. Sensors 738, such as an articulation encoder, may provide the articulation position of the end effector 702 to the control circuit 710.

[0187] In another aspect, the articulation function of the robotic surgical system 700 may comprise two articulation members, or links, 742a, 742b. These articulation members 742a, 742b are driven by separate disks on the robot interface (the rack), which are driven by the two motors 708d, 708e. When the separate firing motor 704a is provided, each of the articulation links 742a, 742b can be antagonistically driven with respect to the other link in order to provide a resistive holding motion and a load to the head when it is not moving and to provide an articulation motion as the head is articulated. The articulation members 742a, 742b attach to the head at a fixed radius as the head is rotated. Accordingly, the mechanical advantage of the push-and-pull link changes as the head is rotated. This change in the mechanical advantage may be more pronounced with other articulation link drive systems.

[0188] In one aspect, the one or more motors 704a-704e may comprise a brushed DC motor with a gearbox and mechanical links to a firing member, closure member, or articulation member. Another example includes electric motors 704a-704e that operate the movable mechanical elements such as the displacement member, articulation links, closure tube, and shaft. An outside influence is an unmeasured, unpredictable influence of things like tissue, surrounding bodies, and friction on the physical system. Such outside influence can be referred to as drag, which acts in opposition to one of electric motors 704a-704e. The outside influence, such as drag, may cause the operation of the physical system to deviate from a desired operation of the physical system.

[0189] In one aspect, the position sensor 734 may be implemented as an absolute positioning system. In one aspect, the position sensor 734 may comprise a magnetic rotary absolute positioning system implemented as an AS5055EQFT single-chip magnetic rotary position sensor available from Austria Microsystems, AG. The position sensor 734 may interface with the control circuit 710 to provide an absolute positioning system. The position may include multiple Hall-effect elements located above a magnet and coupled to a CORDIC processor, also known as the digit-by-digit method and Volder's algorithm, that is provided to implement a simple and efficient algorithm to calculate hyperbolic and trigonometric functions that require only addition, subtraction, bitshift, and table lookup operations.

[0190] In one aspect, the control circuit 710 may be in communication with one or more sensors 738. The sensors 738 may be positioned on the end effector 702 and adapted to operate with the robotic surgical instrument 700 to measure the various derived parameters such as the gap distance versus time, tissue compression versus time, and anvil strain versus time. The sensors 738 may comprise a magnetic sensor, a magnetic field sensor, a strain gauge, a load cell, a pressure sensor, a force sensor, a torque sensor, an inductive sensor such as an eddy current sensor, a resistive sensor, a capacitive sensor, an optical sensor, and/or any other suitable sensor for measuring one or more parameters of the end effector 702. The sensors 738 may include one or more sensors. The sensors 738 may be located on the staple cartridge 718 deck to determine tissue location using segmented electrodes. The torque sensors 744a-744e may be configured to sense force such as firing force, closure force, and/or articulation force, among others. Accordingly, the control circuit 710 can sense (1) the closure load experienced by the distal closure tube and its position, (2) the firing member at the rack and its position, (3) what portion of the staple cartridge 718 has tissue on it, and (4) the load and position on both articulation rods.

[0191] In one aspect, the one or more sensors 738 may comprise a strain gauge, such as a micro-strain gauge, configured to measure the magnitude of the strain in the anvil 716 during a clamped condition. The strain gauge provides an electrical signal whose amplitude varies with the magnitude of the strain. The sensors 738 may comprise a pressure sensor configured to detect a pressure generated by the presence of compressed tissue between the anvil 716 and the staple cartridge 718. The sensors

738 may be configured to detect impedance of a tissue section located between the anvil 716 and the staple cartridge 718 that is indicative of the thickness and/or fullness of tissue located therebetween.

[0192] In one aspect, the sensors 738 may be implemented as one or more limit switches, electromechanical devices, solid-state switches, Hall-effect devices, magneto-resistive (MR) devices, giant magneto-resistive (GMR) devices, magnetometers, among others. In other implementations, the sensors 738 may be implemented as solid-state switches that operate under the influence of light, such as optical sensors, IR sensors, ultraviolet sensors, among others. Still, the switches may be solid-state devices such as transistors (e.g., FET, junction FET, MOSFET, bipolar, and the like). In other implementations, the sensors 738 may include electrical conductorless switches, ultrasonic switches, accelerometers, and inertial sensors, among others.

[0193] In one aspect, the sensors 738 may be configured to measure forces exerted on the anvil 716 by the closure drive system. For example, one or more sensors 738 can be at an interaction point between the closure tube and the anvil 716 to detect the closure forces applied by the closure tube to the anvil 716. The forces exerted on the anvil 716 can be representative of the tissue compression experienced by the tissue section captured between the anvil 716 and the staple cartridge 718. The one or more sensors 738 can be positioned at various interaction points along the closure drive system to detect the closure forces applied to the anvil 716 by the closure drive system. The one or more sensors 738 may be sampled in real time during a clamping operation by the processor of the control circuit 710. The control circuit 710 receives real-time sample measurements to provide and analyze time-based information and assess, in real time, closure forces applied to the anvil 716.

[0194] In one aspect, a current sensor 736 can be employed to measure the current drawn by each of the motors 704a-704e. The force required to advance any of the movable mechanical elements such as the I-beam 714 corresponds to the current drawn by one of the motors 704a-704e. The force is converted to a digital signal and provided to the control circuit 710. The control circuit 710 can be configured to simulate the response of the actual system of the instrument in the software of the controller. A displacement member can be actuated to move an I-beam 714 in the end effector 702 at or near a target velocity. The robotic surgical instrument 700 can include a feedback controller, which can be one of any feedback controllers, including, but not limited to a PID, a state feedback, a linear-quadratic (LQR), and/or an adaptive controller, for example. The robotic surgical instrument 700 can include a power source to convert the signal from the feedback controller into a physical input such as case voltage, PWM voltage, frequency modulated voltage, current, torque, and/or force, for example. Additional details are disclosed in U.S. Patent Application Serial No. 15/636,829, titled CLOSED LOOP VELOCITY CONTROL TECHNIQUES FOR ROBOTIC SURGICAL INSTRUMENT, filed June 29, 2017, which is herein incorporated by reference in its entirety.

[0195] FIG. 18 illustrates a block diagram of a surgical instrument 750 programmed to control the distal translation of a displacement member, in accordance with at least one aspect of this disclosure. In one

aspect, the surgical instrument 750 is programmed to control the distal translation of a displacement member such as the I-beam 764. The surgical instrument 750 comprises an end effector 752 that may comprise an anvil 766, an I-beam 764 (including a sharp cutting edge), and a removable staple cartridge 768.

[0196] The position, movement, displacement, and/or translation of a linear displacement member, such as the I-beam 764, can be measured by an absolute positioning system, sensor arrangement, and position sensor 784. Because the I-beam 764 is coupled to a longitudinally movable drive member, the position of the I-beam 764 can be determined by measuring the position of the longitudinally movable drive member employing the position sensor 784. Accordingly, in the following description, the position, displacement, and/or translation of the I-beam 764 can be achieved by the position sensor 784 as described herein. A control circuit 760 may be programmed to control the translation of the displacement member, such as the I-beam 764. The control circuit 760, in some examples, may comprise one or more microcontrollers, microprocessors, or other suitable processors for executing instructions that cause the processor or processors to control the displacement member, e.g., the I-beam 764, in the manner described. In one aspect, a timer/counter 781 provides an output signal, such as the elapsed time or a digital count, to the control circuit 760 to correlate the position of the I-beam 764 as determined by the position sensor 784 with the output of the timer/counter 781 such that the control circuit 760 can determine the position of the I-beam 764 at a specific time (t) relative to a starting position. The timer/counter 781 may be configured to measure elapsed time, count external events, or time external events.

[0197] The control circuit 760 may generate a motor set point signal 772. The motor set point signal 772 may be provided to a motor control 758. The motor control 758 may comprise one or more circuits configured to provide a motor drive signal 774 to the motor 754 to drive the motor 754 as described herein. In some examples, the motor 754 may be a brushed DC electric motor. For example, the velocity of the motor 754 may be proportional to the motor drive signal 774. In some examples, the motor 754 may be a brushless DC electric motor and the motor drive signal 774 may comprise a PWM signal provided to one or more stator windings of the motor 754. Also, in some examples, the motor control 758 may be omitted, and the control circuit 760 may generate the motor drive signal 774 directly.

[0198] The motor 754 may receive power from an energy source 762. The energy source 762 may be or include a battery, a super capacitor, or any other suitable energy source. The motor 754 may be mechanically coupled to the I-beam 764 via a transmission 756. The transmission 756 may include one or more gears or other linkage components to couple the motor 754 to the I-beam 764. A position sensor 784 may sense a position of the I-beam 764. The position sensor 784 may be or include any type of sensor that is capable of generating position data that indicate a position of the I-beam 764. In some examples, the position sensor 784 may include an encoder configured to provide a series of pulses to the control circuit 760 as the I-beam 764 translates distally and proximally. The control circuit 760 may

track the pulses to determine the position of the I-beam 764. Other suitable position sensors may be used, including, for example, a proximity sensor. Other types of position sensors may provide other signals indicating motion of the I-beam 764. Also, in some examples, the position sensor 784 may be omitted. Where the motor 754 is a stepper motor, the control circuit 760 may track the position of the I-beam 764 by aggregating the number and direction of steps that the motor 754 has been instructed to execute. The position sensor 784 may be located in the end effector 752 or at any other portion of the instrument.

[0199] The control circuit 760 may be in communication with one or more sensors 788. The sensors 788 may be positioned on the end effector 752 and adapted to operate with the surgical instrument 750 to measure the various derived parameters such as gap distance versus time, tissue compression versus time, and anvil strain versus time. The sensors 788 may comprise a magnetic sensor, a magnetic field sensor, a strain gauge, a pressure sensor, a force sensor, an inductive sensor such as an eddy current sensor, a resistive sensor, a capacitive sensor, an optical sensor, and/or any other suitable sensor for measuring one or more parameters of the end effector 752. The sensors 788 may include one or more sensors.

[0200] The one or more sensors 788 may comprise a strain gauge, such as a micro-strain gauge, configured to measure the magnitude of the strain in the anvil 766 during a clamped condition. The strain gauge provides an electrical signal whose amplitude varies with the magnitude of the strain. The sensors 788 may comprise a pressure sensor configured to detect a pressure generated by the presence of compressed tissue between the anvil 766 and the staple cartridge 768. The sensors 788 may be configured to detect impedance of a tissue section located between the anvil 766 and the staple cartridge 768 that is indicative of the thickness and/or fullness of tissue located therebetween.

[0201] The sensors 788 may be is configured to measure forces exerted on the anvil 766 by a closure drive system. For example, one or more sensors 788 can be at an interaction point between a closure tube and the anvil 766 to detect the closure forces applied by a closure tube to the anvil 766. The forces exerted on the anvil 766 can be representative of the tissue compression experienced by the tissue section captured between the anvil 766 and the staple cartridge 768. The one or more sensors 788 can be positioned at various interaction points along the closure drive system to detect the closure forces applied to the anvil 766 by the closure drive system. The one or more sensors 788 may be sampled in real time during a clamping operation by a processor of the control circuit 760. The control circuit 760 receives real-time sample measurements to provide and analyze time-based information and assess, in real time, closure forces applied to the anvil 766.

[0202] A current sensor 786 can be employed to measure the current drawn by the motor 754. The force required to advance the I-beam 764 corresponds to the current drawn by the motor 754. The force is converted to a digital signal and provided to the control circuit 760.

[0203] The control circuit 760 can be configured to simulate the response of the actual system of the instrument in the software of the controller. A displacement member can be actuated to move an I-beam 764 in the end effector 752 at or near a target velocity. The surgical instrument 750 can include a feedback controller, which can be one of any feedback controllers, including, but not limited to a PID, a state feedback, LQR, and/or an adaptive controller, for example. The surgical instrument 750 can include a power source to convert the signal from the feedback controller into a physical input such as case voltage, PWM voltage, frequency modulated voltage, current, torque, and/or force, for example.

[0204] The actual drive system of the surgical instrument 750 is configured to drive the displacement member, cutting member, or I-beam 764, by a brushed DC motor with gearbox and mechanical links to an articulation and/or knife system. Another example is the electric motor 754 that operates the displacement member and the articulation driver, for example, of an interchangeable shaft assembly. An outside influence is an unmeasured, unpredictable influence of things like tissue, surrounding bodies, and friction on the physical system. Such outside influence can be referred to as drag which acts in opposition to the electric motor 754. The outside influence, such as drag, may cause the operation of the physical system to deviate from a desired operation of the physical system.

[0205] Various example aspects are directed to a surgical instrument 750 comprising an end effector 752 with motor-driven surgical stapling and cutting implements. For example, a motor 754 may drive a displacement member distally and proximally along a longitudinal axis of the end effector 752. The end effector 752 may comprise a pivotable anvil 766 and, when configured for use, a staple cartridge 768 positioned opposite the anvil 766. A clinician may grasp tissue between the anvil 766 and the staple cartridge 768, as described herein. When ready to use the surgical instrument 750, the clinician may provide a firing signal, for example by depressing a trigger of the surgical instrument 750. In response to the firing signal, the motor 754 may drive the displacement member distally along the longitudinal axis of the end effector 752 from a proximal stroke begin position to a stroke end position distal of the stroke begin position. As the displacement member translates distally, an I-beam 764 with a cutting element positioned at a distal end may cut the tissue between the staple cartridge 768 and the anvil 766.

[0206] In various examples, the surgical instrument 750 may comprise a control circuit 760 programmed to control the distal translation of the displacement member, such as the I-beam 764, for example, based on one or more tissue conditions. The control circuit 760 may be programmed to sense tissue conditions, such as thickness, either directly or indirectly, as described herein. The control circuit 760 may be programmed to select a firing control program based on tissue conditions. A firing control program may describe the distal motion of the displacement member. Different firing control programs may be selected to better treat different tissue conditions. For example, when thicker tissue is present, the control circuit 760 may be programmed to translate the displacement member at a lower velocity and/or with lower power. When thinner tissue is present, the control circuit 760 may be programmed to translate the displacement member at a higher velocity and/or with higher power.

[0207] In some examples, the control circuit 760 may initially operate the motor 754 in an open loop configuration for a first open loop portion of a stroke of the displacement member. Based on a response of the surgical instrument 750 during the open loop portion of the stroke, the control circuit 760 may select a firing control program. The response of the instrument may include, a translation distance of the displacement member during the open loop portion, a time elapsed during the open loop portion, energy provided to the motor 754 during the open loop portion, a sum of pulse widths of a motor drive signal, etc. After the open loop portion, the control circuit 760 may implement the selected firing control program for a second portion of the displacement member stroke. For example, during the closed loop portion of the stroke, the control circuit 760 may modulate the motor 754 based on translation data describing a position of the displacement member in a closed loop manner to translate the displacement member at a constant velocity. Additional details are disclosed in U.S. Patent Application Serial No. 15/720,852, titled SYSTEM AND METHODS FOR CONTROLLING A DISPLAY OF A SURGICAL INSTRUMENT, filed September 29, 2017, which is herein incorporated by reference in its entirety.

[0208] FIG. 19 is a schematic diagram of a surgical instrument 790 configured to control various functions, in accordance with at least one aspect of this disclosure. In one aspect, the surgical instrument 790 is programmed to control distal translation of a displacement member such as the I-beam 764. The surgical instrument 790 comprises an end effector 792 that may comprise an anvil 766, an I-beam 764, and a removable staple cartridge 768, which may be interchanged with an RF cartridge 796 (shown in dashed line).

[0209] In one aspect, sensors 788 may be implemented as a limit switch, electromechanical device, solid-state switches, Hall-effect devices, MR devices, GMR devices, magnetometers, among others. In other implementations, the sensors 638 may be solid-state switches that operate under the influence of light, such as optical sensors, IR sensors, ultraviolet sensors, among others. Still, the switches may be solid-state devices such as transistors (e.g., FET, junction FET, MOSFET, bipolar, and the like). In other implementations, the sensors 788 may include electrical conductorless switches, ultrasonic switches, accelerometers, and inertial sensors, among others.

[0210] In one aspect, the position sensor 784 may be implemented as an absolute positioning system comprising a magnetic rotary absolute positioning system implemented as an AS5055EQFT single-chip magnetic rotary position sensor available from Austria Microsystems, AG. The position sensor 784 may interface with the control circuit 760 to provide an absolute positioning system. The position may include multiple Hall-effect elements located above a magnet and coupled to a CORDIC processor, also known as the digit-by-digit method and Volder's algorithm, that is provided to implement a simple and efficient algorithm to calculate hyperbolic and trigonometric functions that require only addition, subtraction, bitshift, and table lookup operations.

[0211] In one aspect, the I-beam 764 may be implemented as a knife member comprising a knife body that operably supports a tissue cutting blade thereon and may further include anvil engagement tabs or

features and channel engagement features or a foot. In one aspect, the staple cartridge 768 may be implemented as a standard (mechanical) surgical fastener cartridge. In one aspect, the RF cartridge 796 may be implemented as an RF cartridge. These and other sensors arrangements are described in commonly owned U.S. Patent Application Serial No. 15/628,175, titled TECHNIQUES FOR ADAPTIVE CONTROL OF MOTOR VELOCITY OF A SURGICAL STAPLING AND CUTTING INSTRUMENT, filed June 20, 2017, which is herein incorporated by reference in its entirety.

[0212] The position, movement, displacement, and/or translation of a linear displacement member, such as the I-beam 764, can be measured by an absolute positioning system, sensor arrangement, and position sensor represented as position sensor 784. Because the I-beam 764 is coupled to the longitudinally movable drive member, the position of the I-beam 764 can be determined by measuring the position of the longitudinally movable drive member employing the position sensor 784. Accordingly, in the following description, the position, displacement, and/or translation of the I-beam 764 can be achieved by the position sensor 784 as described herein. A control circuit 760 may be programmed to control the translation of the displacement member, such as the I-beam 764, as described herein. The control circuit 760, in some examples, may comprise one or more microcontrollers, microprocessors, or other suitable processors for executing instructions that cause the processor or processors to control the displacement member, e.g., the I-beam 764, in the manner described. In one aspect, a timer/counter 781 provides an output signal, such as the elapsed time or a digital count, to the control circuit 760 to correlate the position of the I-beam 764 as determined by the position sensor 784 with the output of the timer/counter 781 such that the control circuit 760 can determine the position of the I-beam 764 at a specific time (t) relative to a starting position. The timer/counter 781 may be configured to measure elapsed time, count external events, or time external events.

[0213] The control circuit 760 may generate a motor set point signal 772. The motor set point signal 772 may be provided to a motor control 758. The motor control 758 may comprise one or more circuits configured to provide a motor drive signal 774 to the motor 754 to drive the motor 754 as described herein. In some examples, the motor 754 may be a brushed DC electric motor. For example, the velocity of the motor 754 may be proportional to the motor drive signal 774. In some examples, the motor 754 may be a brushless DC electric motor and the motor drive signal 774 may comprise a PWM signal provided to one or more stator windings of the motor 754. Also, in some examples, the motor control 758 may be omitted, and the control circuit 760 may generate the motor drive signal 774 directly.

[0214] The motor 754 may receive power from an energy source 762. The energy source 762 may be or include a battery, a super capacitor, or any other suitable energy source. The motor 754 may be mechanically coupled to the I-beam 764 via a transmission 756. The transmission 756 may include one or more gears or other linkage components to couple the motor 754 to the I-beam 764. A position sensor 784 may sense a position of the I-beam 764. The position sensor 784 may be or include any type of sensor that is capable of generating position data that indicate a position of the I-beam 764. In some

examples, the position sensor 784 may include an encoder configured to provide a series of pulses to the control circuit 760 as the I-beam 764 translates distally and proximally. The control circuit 760 may track the pulses to determine the position of the I-beam 764. Other suitable position sensors may be used, including, for example, a proximity sensor. Other types of position sensors may provide other signals indicating motion of the I-beam 764. Also, in some examples, the position sensor 784 may be omitted. Where the motor 754 is a stepper motor, the control circuit 760 may track the position of the I-beam 764 by aggregating the number and direction of steps that the motor has been instructed to execute. The position sensor 784 may be located in the end effector 792 or at any other portion of the instrument.

[0215] The control circuit 760 may be in communication with one or more sensors 788. The sensors 788 may be positioned on the end effector 792 and adapted to operate with the surgical instrument 790 to measure the various derived parameters such as gap distance versus time, tissue compression versus time, and anvil strain versus time. The sensors 788 may comprise a magnetic sensor, a magnetic field sensor, a strain gauge, a pressure sensor, a force sensor, an inductive sensor such as an eddy current sensor, a resistive sensor, a capacitive sensor, an optical sensor, and/or any other suitable sensor for measuring one or more parameters of the end effector 792. The sensors 788 may include one or more sensors.

[0216] The one or more sensors 788 may comprise a strain gauge, such as a micro-strain gauge, configured to measure the magnitude of the strain in the anvil 766 during a clamped condition. The strain gauge provides an electrical signal whose amplitude varies with the magnitude of the strain. The sensors 788 may comprise a pressure sensor configured to detect a pressure generated by the presence of compressed tissue between the anvil 766 and the staple cartridge 768. The sensors 788 may be configured to detect impedance of a tissue section located between the anvil 766 and the staple cartridge 768 that is indicative of the thickness and/or fullness of tissue located therebetween.

[0217] The sensors 788 may be is configured to measure forces exerted on the anvil 766 by the closure drive system. For example, one or more sensors 788 can be at an interaction point between a closure tube and the anvil 766 to detect the closure forces applied by a closure tube to the anvil 766. The forces exerted on the anvil 766 can be representative of the tissue compression experienced by the tissue section captured between the anvil 766 and the staple cartridge 768. The one or more sensors 788 can be positioned at various interaction points along the closure drive system to detect the closure forces applied to the anvil 766 by the closure drive system. The one or more sensors 788 may be sampled in real time during a clamping operation by a processor portion of the control circuit 760. The control circuit 760 receives real-time sample measurements to provide and analyze time-based information and assess, in real time, closure forces applied to the anvil 766.

[0218] A current sensor 786 can be employed to measure the current drawn by the motor 754. The force required to advance the I-beam 764 corresponds to the current drawn by the motor 754. The force is converted to a digital signal and provided to the control circuit 760.

[0219] An RF energy source 794 is coupled to the end effector 792 and is applied to the RF cartridge 796 when the RF cartridge 796 is loaded in the end effector 792 in place of the staple cartridge 768. The control circuit 760 controls the delivery of the RF energy to the RF cartridge 796.

[0220] Additional details are disclosed in U.S. Patent Application Serial No. 15/636,096, titled SURGICAL SYSTEM COUPLABLE WITH STAPLE CARTRIDGE AND RADIO FREQUENCY CARTRIDGE, AND METHOD OF USING SAME, filed June 28, 2017, which is herein incorporated by reference in its entirety.

[0221] FIGS. 21 to 24 depict a motor-driven surgical instrument 150010 for cutting and fastening that may or may not be reused. In the illustrated examples, the surgical instrument 150010 includes a housing 150012 that comprises a handle assembly 150014 that is configured to be grasped, manipulated, and actuated by the clinician. The housing 150012 is configured for operable attachment to an interchangeable shaft assembly 150200 that has an end effector 150300 operably coupled thereto that is configured to perform one or more surgical tasks or procedures. In accordance with the present disclosure, various forms of interchangeable shaft assemblies may be effectively employed in connection with robotically controlled surgical systems. The term “housing” may encompass a housing or similar portion of a robotic system that houses or otherwise operably supports at least one drive system configured to generate and apply at least one control motion that could be used to actuate interchangeable shaft assemblies. The term “frame” may refer to a portion of a handheld surgical instrument. The term “frame” also may represent a portion of a robotically controlled surgical instrument and/or a portion of the robotic system that may be used to operably control a surgical instrument. Interchangeable shaft assemblies may be employed with various robotic systems, instruments, components, and methods disclosed in U.S. Patent No. 9,072,535, titled SURGICAL STAPLING INSTRUMENTS WITH ROTATABLE STAPLE DEPLOYMENT ARRANGEMENTS, which is herein incorporated by reference in its entirety.

[0222] FIG. 21 is a perspective view of a surgical instrument 150010 that has an interchangeable shaft assembly 150200 operably coupled thereto, in accordance with at least one aspect of this disclosure. The housing 150012 includes an end effector 150300 that comprises a surgical cutting and fastening device configured to operably support a surgical staple cartridge 150304 therein. The housing 150012 may be configured for use in connection with interchangeable shaft assemblies that include end effectors that are adapted to support different sizes and types of staple cartridges and have different shaft lengths, sizes, and types. The housing 150012 may be employed with a variety of interchangeable shaft assemblies, including assemblies configured to apply other motions and forms of energy such as, radio frequency (RF) energy, ultrasonic energy, and/or motion to end effector arrangements adapted for use in

connection with various surgical applications and procedures. The end effectors, shaft assemblies, handles, surgical instruments, and/or surgical instrument systems can utilize any suitable fastener, or fasteners, to fasten tissue. For instance, a fastener cartridge comprising a plurality of fasteners removably stored therein can be removably inserted into and/or attached to the end effector of a shaft assembly.

[0223] The handle assembly 150014 may comprise a pair of interconnectable handle housing segments 150016, 150018 interconnected by screws, snap features, adhesive, etc. The handle housing segments 150016, 150018 cooperate to form a pistol grip portion 150019 that can be gripped and manipulated by the clinician. The handle assembly 150014 operably supports a plurality of drive systems configured to generate and apply control motions to corresponding portions of the interchangeable shaft assembly that is operably attached thereto. A display may be provided below a cover 150045.

[0224] FIG. 22 is an exploded assembly view of a portion of the surgical instrument 150010 of FIG. 21, in accordance with at least one aspect of this disclosure. The handle assembly 150014 may include a frame 150020 that operably supports a plurality of drive systems. The frame 150020 can operably support a “first” or closure drive system 150030, which can apply closing and opening motions to the interchangeable shaft assembly 150200. The closure drive system 150030 may include an actuator such as a closure trigger 150032 pivotally supported by the frame 150020. The closure trigger 150032 is pivotally coupled to the handle assembly 150014 by a pivot pin 150033 to enable the closure trigger 150032 to be manipulated by a clinician. When the clinician grips the pistol grip portion 150019 of the handle assembly 150014, the closure trigger 150032 can pivot from a starting or “unactuated” position to an “actuated” position and more particularly to a fully compressed or fully actuated position.

[0225] The handle assembly 150014 and the frame 150020 may operably support a firing drive system 150080 configured to apply firing motions to corresponding portions of the interchangeable shaft assembly attached thereto. The firing drive system 150080 may employ an electric motor 150082 located in the pistol grip portion 150019 of the handle assembly 150014. The electric motor 150082 may be a DC brushed motor having a maximum rotational speed of approximately 25,000 RPM, for example. In other arrangements, the motor may include a brushless motor, a cordless motor, a synchronous motor, a stepper motor, or any other suitable electric motor. The electric motor 150082 may be powered by a power source 150090 that may comprise a removable power pack 150092. The removable power pack 150092 may comprise a proximal housing portion 150094 configured to attach to a distal housing portion 150096. The proximal housing portion 150094 and the distal housing portion 150096 are configured to operably support a plurality of batteries 150098 therein. Batteries 150098 may each comprise, for example, an LI or other suitable battery. The distal housing portion 150096 is configured for removable operable attachment to a control circuit board 150100, which is operably coupled to the electric motor 150082. Several batteries 150098 connected in series may power the surgical instrument 150010. The power source 150090 may be replaceable and/or rechargeable. A display 150043, which is located

below the cover 150045, is electrically coupled to the control circuit board 150100. The cover 150045 may be removed to expose the display 150043.

[0226] The electric motor 150082 can include a rotatable shaft (not shown) that operably interfaces with a gear reducer assembly 150084 mounted in meshing engagement with a set, or rack, of drive teeth 150122 on a longitudinally movable drive member 150120. The longitudinally movable drive member 150120 has a rack of drive teeth 150122 formed thereon for meshing engagement with a corresponding drive gear 150086 of the gear reducer assembly 150084.

[0227] In use, a voltage polarity provided by the power source 150090 can operate the electric motor 150082 in a clockwise direction wherein the voltage polarity applied to the electric motor by the battery can be reversed in order to operate the electric motor 150082 in a counter-clockwise direction. When the electric motor 150082 is rotated in one direction, the longitudinally movable drive member 150120 will be axially driven in the distal direction "DD." When the electric motor 150082 is driven in the opposite rotary direction, the longitudinally movable drive member 150120 will be axially driven in a proximal direction "PD." The handle assembly 150014 can include a switch that can be configured to reverse the polarity applied to the electric motor 150082 by the power source 150090. The handle assembly 150014 may include a sensor configured to detect the position of the longitudinally movable drive member 150120 and/or the direction in which the longitudinally movable drive member 150120 is being moved.

[0228] Actuation of the electric motor 150082 can be controlled by a firing trigger 150130 that is pivotally supported on the handle assembly 150014. The firing trigger 150130 may be pivoted between an unactuated position and an actuated position.

[0229] Turning back to FIG. 21, the interchangeable shaft assembly 150200 includes an end effector 150300 comprising an elongated channel 150302 configured to operably support a surgical staple cartridge 150304 therein. The end effector 150300 may include an anvil 150306 that is pivotally supported relative to the elongated channel 150302. The interchangeable shaft assembly 150200 may include an articulation joint 150270. Construction and operation of the end effector 150300 and the articulation joint 150270 are set forth in U.S. Patent Application Publication No. 2014/0263541, titled ARTICULATABLE SURGICAL INSTRUMENT COMPRISING AN ARTICULATION LOCK, which is herein incorporated by reference in its entirety. The interchangeable shaft assembly 150200 may include a proximal housing or nozzle 150201 comprised of nozzle portions 150202, 150203. The interchangeable shaft assembly 150200 may include a closure tube 150260 extending along a shaft axis "SA" that can be utilized to close and/or open the anvil 150306 of the end effector 150300.

[0230] Turning back to FIG. 21, the closure tube 150260 is translated distally (direction "DD") to close the anvil 150306, for example, in response to the actuation of the closure trigger 150032 in the manner described in the aforementioned reference U.S. Patent Application Publication No. 2014/0263541. The anvil 150306 is opened by proximally translating the closure tube 150260. In the anvil-open position, the closure tube 150260 is moved to its proximal position.

[0231] FIG. 23 is another exploded assembly view of portions of the interchangeable shaft assembly 150200, in accordance with at least one aspect of this disclosure. The interchangeable shaft assembly 150200 may include a firing member 150220 supported for axial travel within the spine 150210. The firing member 150220 includes an intermediate firing shaft 150222 configured to attach to a distal cutting portion or knife bar 150280. The firing member 150220 may be referred to as a "second shaft" or a "second shaft assembly." The intermediate firing shaft 150222 may include a longitudinal slot 150223 in a distal end configured to receive a tab 150284 on the proximal end 150282 of the knife bar 150280. The longitudinal slot 150223 and the proximal end 150282 may be configured to permit relative movement there between and can comprise a slip joint 150286. The slip joint 150286 can permit the intermediate firing shaft 150222 of the firing member 150220 to articulate the end effector 150300 about the articulation joint 150270 without moving, or at least substantially moving, the knife bar 150280. Once the end effector 150300 has been suitably oriented, the intermediate firing shaft 150222 can be advanced distally until a proximal sidewall of the longitudinal slot 150223 contacts the tab 150284 to advance the knife bar 150280 and fire the staple cartridge positioned within the channel 150302. The spine 150210 has an elongated opening or window 150213 therein to facilitate assembly and insertion of the intermediate firing shaft 150222 into the spine 150210. Once the intermediate firing shaft 150222 has been inserted therein, a top frame segment 150215 may be engaged with the shaft frame 150212 to enclose the intermediate firing shaft 150222 and knife bar 150280 therein. Operation of the firing member 150220 may be found in U.S. Patent Application Publication No. 2014/0263541. A spine 150210 can be configured to slidably support a firing member 150220 and the closure tube 150260 that extends around the spine 150210. The spine 150210 may slidably support an articulation driver 150230.

[0232] The interchangeable shaft assembly 150200 can include a clutch assembly 150400 configured to selectively and releasably couple the articulation driver 150230 to the firing member 150220. The clutch assembly 150400 includes a lock collar, or lock sleeve 150402, positioned around the firing member 150220 wherein the lock sleeve 150402 can be rotated between an engaged position in which the lock sleeve 150402 couples the articulation driver 150230 to the firing member 150220 and a disengaged position in which the articulation driver 150230 is not operably coupled to the firing member 150220. When the lock sleeve 150402 is in the engaged position, distal movement of the firing member 150220 can move the articulation driver 150230 distally and, correspondingly, proximal movement of the firing member 150220 can move the articulation driver 150230 proximally. When the lock sleeve 150402 is in the disengaged position, movement of the firing member 150220 is not transmitted to the articulation driver 150230 and, as a result, the firing member 150220 can move independently of the articulation driver 150230. The nozzle 150201 may be employed to operably engage and disengage the articulation drive system with the firing drive system in the various manners described in U.S. Patent Application Publication No. 2014/0263541.

[0233] The interchangeable shaft assembly 150200 can comprise a slip ring assembly 150600, which can be configured to conduct electrical power to and/or from the end effector 150300 and/or communicate signals to and/or from the end effector 150300, for example. The slip ring assembly 150600 can comprise a proximal connector flange 150604 and a distal connector flange 150601 positioned within a slot defined in the nozzle portions 150202, 150203. The proximal connector flange 150604 can comprise a first face and the distal connector flange 150601 can comprise a second face positioned adjacent to and movable relative to the first face. The distal connector flange 150601 can rotate relative to the proximal connector flange 150604 about the shaft axis "SA" (FIG. 21). The proximal connector flange 150604 can comprise a plurality of concentric, or at least substantially concentric, conductors 150602 defined in the first face thereof. A connector 150607 can be mounted on the proximal side of the distal connector flange 150601 and may have a plurality of contacts wherein each contact corresponds to and is in electrical contact with one of the conductors 150602. Such an arrangement permits relative rotation between the proximal connector flange 150604 and the distal connector flange 150601 while maintaining electrical contact there between. The proximal connector flange 150604 can include an electrical connector 150606 that can place the conductors 150602 in signal communication with a shaft circuit board, for example. In at least one instance, a wiring harness comprising a plurality of conductors can extend between the electrical connector 150606 and the shaft circuit board. The electrical connector 150606 may extend proximally through a connector opening defined in the chassis mounting flange. U.S. Patent Application Publication No. 2014/0263551, titled STAPLE CARTRIDGE TISSUE THICKNESS SENSOR SYSTEM, is incorporated herein by reference in its entirety. U.S. Patent Application Publication No. 2014/0263552, titled STAPLE CARTRIDGE TISSUE THICKNESS SENSOR SYSTEM, is incorporated by reference in its entirety. Further details regarding slip ring assembly 150600 may be found in U.S. Patent Application Publication No. 2014/0263541.

[0234] The interchangeable shaft assembly 150200 can include a proximal portion fixably mounted to the handle assembly 150014 and a distal portion that is rotatable about a longitudinal axis. The rotatable distal shaft portion can be rotated relative to the proximal portion about the slip ring assembly 150600. The distal connector flange 150601 of the slip ring assembly 150600 can be positioned within the rotatable distal shaft portion.

[0235] FIG. 24 is an exploded view of one aspect of an end effector 150300 of the surgical instrument 150010 of FIG. 21, in accordance with at least one aspect of this disclosure. The end effector 150300 may include the anvil 150306 and the surgical staple cartridge 150304. The anvil 150306 may be coupled to an elongated channel 150302. Apertures 150199 can be defined in the elongated channel 150302 to receive pins 150152 extending from the anvil 150306 to allow the anvil 150306 to pivot from an open position to a closed position relative to the elongated channel 150302 and surgical staple cartridge 150304. A firing bar 150172 is configured to longitudinally translate into the end effector 150300. The firing bar 150172 may be constructed from one solid section, or may include a laminate

material comprising a stack of steel plates. The firing bar 150172 comprises an I-beam 150178 and a cutting edge 150182 at a distal end thereof. A distally projecting end of the firing bar 150172 can be attached to the I-beam 150178 to assist in spacing the anvil 150306 from a surgical staple cartridge 150304 positioned in the elongated channel 150302 when the anvil 150306 is in a closed position. The I-beam 150178 may include a sharpened cutting edge 150182 to sever tissue as the I-beam 150178 is advanced distally by the firing bar 150172. In operation, the I-beam 150178 may, or fire, the surgical staple cartridge 150304. The surgical staple cartridge 150304 can include a molded cartridge body 150194 that holds a plurality of staples 150191 resting upon staple drivers 150192 within respective upwardly open staple cavities 150195. A wedge sled 150190 is driven distally by the I-beam 150178, sliding upon a cartridge tray 150196 of the surgical staple cartridge 150304. The wedge sled 150190 upwardly cams the staple drivers 150192 to force out the staples 150191 into deforming contact with the anvil 150306 while the cutting edge 150182 of the I-beam 150178 severs clamped tissue.

[0236] The I-beam 150178 can include upper pins 150180 that engage the anvil 150306 during firing. The I-beam 150178 may include middle pins 150184 and a bottom foot 150186 to engage portions of the cartridge body 150194, cartridge tray 150196, and elongated channel 150302. When a surgical staple cartridge 150304 is positioned within the elongated channel 150302, a slot 150193 defined in the cartridge body 150194 can be aligned with a longitudinal slot 150197 defined in the cartridge tray 150196 and a slot 150189 defined in the elongated channel 150302. In use, the I-beam 150178 can slide through the aligned longitudinal slots 150193, 150197, and 150189 wherein, as indicated in FIG. 24, the bottom foot 150186 of the I-beam 150178 can engage a groove running along the bottom surface of elongated channel 150302 along the length of slot 150189, the middle pins 150184 can engage the top surfaces of cartridge tray 150196 along the length of longitudinal slot 150197, and the upper pins 150180 can engage the anvil 150306. The I-beam 150178 can space, or limit the relative movement between, the anvil 150306 and the surgical staple cartridge 150304 as the firing bar 150172 is advanced distally to fire the staples from the surgical staple cartridge 150304 and/or incise the tissue captured between the anvil 150306 and the surgical staple cartridge 150304. The firing bar 150172 and the I-beam 150178 can be retracted proximally allowing the anvil 150306 to be opened to release the two stapled and severed tissue portions.

[0237] FIGS. 25A and 25B is a block diagram of a control circuit 150700 of the surgical instrument 150010 of FIG. 21 spanning two drawing sheets, in accordance with at least one aspect of this disclosure. Referring primarily to FIGS. 25A and 25B, a handle assembly 150702 may include a motor 150714, which can be controlled by a motor driver 150715 and can be employed by the firing system of the surgical instrument 150010. In various forms, the motor 150714 may be a DC brushed driving motor having a maximum rotational speed of approximately 25,000 RPM. In other arrangements, the motor 150714 may include a brushless motor, a cordless motor, a synchronous motor, a stepper motor, or any other suitable electric motor. The motor driver 150715 may comprise an H-bridge driver comprising FETs

150719, for example. The motor 150714 can be powered by the power assembly 150706 releasably mounted to the handle assembly 150200 for supplying control power to the surgical instrument 150010. The power assembly 150706 may comprise a battery which may include a number of battery cells connected in series that can be used as the power source to power the surgical instrument 150010. In certain circumstances, the battery cells of the power assembly 150706 may be replaceable and/or rechargeable. In at least one example, the battery cells can be LI batteries which can be separably couplable to the power assembly 150706.

[0238] The shaft assembly 150704 may include a shaft assembly controller 150722, which can communicate with a safety controller and power management controller 150716 through an interface while the shaft assembly 150704 and the power assembly 150706 are coupled to the handle assembly 150702. For example, the interface may comprise a first interface portion 150725, which may include one or more electric connectors for coupling engagement with corresponding shaft assembly electric connectors, and a second interface portion 150727, which may include one or more electric connectors for coupling engagement with corresponding power assembly electric connectors to permit electrical communication between the shaft assembly controller 150722 and the power management controller 150716 while the shaft assembly 150704 and the power assembly 150706 are coupled to the handle assembly 150702. One or more communication signals can be transmitted through the interface to communicate one or more of the power requirements of the attached interchangeable shaft assembly 150704 to the power management controller 150716. In response, the power management controller may modulate the power output of the battery of the power assembly 150706, as described below in greater detail, in accordance with the power requirements of the attached shaft assembly 150704. The connectors may comprise switches which can be activated after mechanical coupling engagement of the handle assembly 150702 to the shaft assembly 150704 and/or to the power assembly 150706 to allow electrical communication between the shaft assembly controller 150722 and the power management controller 150716.

[0239] The interface can facilitate transmission of the one or more communication signals between the power management controller 150716 and the shaft assembly controller 150722 by routing such communication signals through a main controller 150717 residing in the handle assembly 150702, for example. In other circumstances, the interface can facilitate a direct line of communication between the power management controller 150716 and the shaft assembly controller 150722 through the handle assembly 150702 while the shaft assembly 150704 and the power assembly 150706 are coupled to the handle assembly 150702.

[0240] The main controller 150717 may be any single core or multicore processor such as those known under the trade name ARM Cortex by Texas Instruments. In one aspect, the main controller 150717 may be an LM4F230H5QR ARM Cortex-M4F Processor Core, available from Texas Instruments, for example, comprising on-chip memory of 256 KB single-cycle flash memory, or other non-volatile

memory, up to 40 MHz, a prefetch buffer to improve performance above 40 MHz, a 32 KB single-cycle serial random access memory (SRAM), internal read-only memory (ROM) loaded with StellarisWare® software, 2 KB electrically erasable programmable read-only memory (EEPROM), one or more pulse width modulation (PWM) modules, one or more quadrature encoder inputs (QEI) analog, one or more 12-bit Analog-to-Digital Converters (ADC) with 12 analog input channels, details of which are available for the product datasheet.

[0241] The safety controller may be a safety controller platform comprising two controller-based families such as TMS570 and RM4x known under the trade name Hercules ARM Cortex R4, also by Texas Instruments. The safety controller may be configured specifically for IEC 61508 and ISO 26262 safety critical applications, among others, to provide advanced integrated safety features while delivering scalable performance, connectivity, and memory options.

[0242] The power assembly 150706 may include a power management circuit which may comprise the power management controller 150716, a power modulator 150738, and a current sense circuit 150736. The power management circuit can be configured to modulate power output of the battery based on the power requirements of the shaft assembly 150704 while the shaft assembly 150704 and the power assembly 150706 are coupled to the handle assembly 150702. The power management controller 150716 can be programmed to control the power modulator 150738 of the power output of the power assembly 150706 and the current sense circuit 150736 can be employed to monitor power output of the power assembly 150706 to provide feedback to the power management controller 150716 about the power output of the battery so that the power management controller 150716 may adjust the power output of the power assembly 150706 to maintain a desired output. The power management controller 150716 and/or the shaft assembly controller 150722 each may comprise one or more processors and/or memory units that may store a number of software modules.

[0243] The surgical instrument 150010 (FIGS. 21 to 24) may comprise an output device 150742, which may include devices for providing a sensory feedback to a user. Such devices may comprise, for example, visual feedback devices (e.g., a liquid-crystal display (LCD) screen, LED indicators), audio feedback devices (e.g., a speaker, a buzzer) or tactile feedback devices (e.g., haptic actuators). In certain circumstances, the output device 150742 may comprise a display 150743, which may be included in the handle assembly 150702. The shaft assembly controller 150722 and/or the power management controller 150716 can provide feedback to a user of the surgical instrument 150010 through the output device 150742. The interface can be configured to connect the shaft assembly controller 150722 and/or the power management controller 150716 to the output device 150742. The output device 150742 can instead be integrated with the power assembly 150706. In such circumstances, communication between the output device 150742 and the shaft assembly controller 150722 may be accomplished through the interface while the shaft assembly 150704 is coupled to the handle assembly 150702.

[0244] The control circuit 150700 comprises circuit segments configured to control operations of the powered surgical instrument 150010. A safety controller segment (Segment 1) comprises a safety controller and the main controller 150717 segment (Segment 2). The safety controller and/or the main controller 150717 are configured to interact with one or more additional circuit segments such as an acceleration segment, a display segment, a shaft segment, an encoder segment, a motor segment, and a power segment. Each of the circuit segments may be coupled to the safety controller and/or the main controller 150717. The main controller 150717 is also coupled to a flash memory. The main controller 150717 also comprises a serial communication interface. The main controller 150717 comprises a plurality of inputs coupled to, for example, one or more circuit segments, a battery, and/or a plurality of switches. The segmented circuit may be implemented by any suitable circuit, such as, for example, a printed circuit board assembly (PCBA) within the powered surgical instrument 150010. It should be understood that the term processor as used herein includes any microprocessor, processors, controller, controllers, or other basic computing device that incorporates the functions of a computer's central processing unit (CPU) on an integrated circuit or at most a few integrated circuits. The main controller 150717 is a multipurpose, programmable device that accepts digital data as input, processes it according to instructions stored in its memory, and provides results as output. It is an example of sequential digital logic, as it has internal memory. The control circuit 150700 can be configured to implement one or more of the processes described herein.

[0245] The acceleration segment (Segment 3) comprises an accelerometer. The accelerometer is configured to detect movement or acceleration of the powered surgical instrument 150010. Input from the accelerometer may be used to transition to and from a sleep mode, identify an orientation of the powered surgical instrument, and/or identify when the surgical instrument has been dropped. In some examples, the acceleration segment is coupled to the safety controller and/or the main controller 150717.

[0246] The display segment (Segment 4) comprises a display connector coupled to the main controller 150717. The display connector couples the main controller 150717 to a display through one or more integrated circuit drivers of the display. The integrated circuit drivers of the display may be integrated with the display and/or may be located separately from the display. The display may comprise any suitable display, such as, for example, an organic light-emitting diode (OLED) display, a liquid-crystal display (LCD), and/or any other suitable display. In some examples, the display segment is coupled to the safety controller.

[0247] The shaft segment (Segment 5) comprises controls for an interchangeable shaft assembly 150200 (FIGS. 21 and 23) coupled to the surgical instrument 150010 (FIGS. 21 to 24) and/or one or more controls for an end effector 150300 coupled to the interchangeable shaft assembly 150200. The shaft segment comprises a shaft connector configured to couple the main controller 150717 to a shaft PCBA. The shaft PCBA comprises a low-power microcontroller with a ferroelectric random access memory (FRAM), an articulation switch, a shaft release Hall effect switch, and a shaft PCBA EEPROM.

The shaft PCBA EEPROM comprises one or more parameters, routines, and/or programs specific to the interchangeable shaft assembly 150200 and/or the shaft PCBA. The shaft PCBA may be coupled to the interchangeable shaft assembly 150200 and/or integral with the surgical instrument 150010. In some examples, the shaft segment comprises a second shaft EEPROM. The second shaft EEPROM comprises a plurality of algorithms, routines, parameters, and/or other data corresponding to one or more shaft assemblies 150200 and/or end effectors 150300 that may be interfaced with the powered surgical instrument 150010.

[0248] The position encoder segment (Segment 6) comprises one or more magnetic angle rotary position encoders. The one or more magnetic angle rotary position encoders are configured to identify the rotational position of the motor 150714, an interchangeable shaft assembly 150200 (FIGS. 21 and 23), and/or an end effector 150300 of the surgical instrument 150010 (FIGS. 21 to 24). In some examples, the magnetic angle rotary position encoders may be coupled to the safety controller and/or the main controller 150717.

[0249] The motor circuit segment (Segment 7) comprises a motor 150714 configured to control movements of the powered surgical instrument 150010 (FIGS. 21 to 24). The motor 150714 is coupled to the main microcontroller processor 150717 by an H-bridge driver comprising one or more H-bridge field-effect transistors (FETs) and a motor controller. The H-bridge driver is also coupled to the safety controller. A motor current sensor is coupled in series with the motor to measure the current draw of the motor. The motor current sensor is in signal communication with the main controller 150717 and/or the safety controller. In some examples, the motor 150714 is coupled to a motor electromagnetic interference (EMI) filter.

[0250] The motor controller controls a first motor flag and a second motor flag to indicate the status and position of the motor 150714 to the main controller 150717. The main controller 150717 provides a pulse-width modulation (PWM) high signal, a PWM low signal, a direction signal, a synchronize signal, and a motor reset signal to the motor controller through a buffer. The power segment is configured to provide a segment voltage to each of the circuit segments.

[0251] The power segment (Segment 8) comprises a battery coupled to the safety controller, the main controller 150717, and additional circuit segments. The battery is coupled to the segmented circuit by a battery connector and a current sensor. The current sensor is configured to measure the total current draw of the segmented circuit. In some examples, one or more voltage converters are configured to provide predetermined voltage values to one or more circuit segments. For example, in some examples, the segmented circuit may comprise 3.3V voltage converters and/or 5V voltage converters. A boost converter is configured to provide a boost voltage up to a predetermined amount, such as, for example, up to 13V. The boost converter is configured to provide additional voltage and/or current during power intensive operations and prevent brownout or low-power conditions.

[0252] A plurality of switches are coupled to the safety controller and/or the main controller 150717. The switches may be configured to control operations of the surgical instrument 150010 (FIGS. 21 to 24), of the segmented circuit, and/or indicate a status of the surgical instrument 150010. A bail-out door switch and Hall effect switch for bailout are configured to indicate the status of a bail-out door. A plurality of articulation switches, such as, for example, a left side articulation left switch, a left side articulation right switch, a left side articulation center switch, a right side articulation left switch, a right side articulation right switch, and a right side articulation center switch are configured to control articulation of an interchangeable shaft assembly 150200 (FIGS. 21 and 23) and/or the end effector 150300 (FIGS. 21 to 24). A left side reverse switch and a right side reverse switch are coupled to the main controller 150717. The left side switches comprising the left side articulation left switch, the left side articulation right switch, the left side articulation center switch, and the left side reverse switch are coupled to the main controller 150717 by a left flex connector. The right side switches comprising the right side articulation left switch, the right side articulation right switch, the right side articulation center switch, and the right side reverse switch are coupled to the main controller 150717 by a right flex connector. A firing switch, a clamp release switch, and a shaft engaged switch are coupled to the main controller 150717.

[0253] Any suitable mechanical, electromechanical, or solid state switches may be employed to implement the plurality of switches, in any combination. For example, the switches may be limit switches operated by the motion of components associated with the surgical instrument 150010 (FIGS. 21 to 24) or the presence of an object. Such switches may be employed to control various functions associated with the surgical instrument 150010. A limit switch is an electromechanical device that consists of an actuator mechanically linked to a set of contacts. When an object comes into contact with the actuator, the device operates the contacts to make or break an electrical connection. Limit switches are used in a variety of applications and environments because of their ruggedness, ease of installation, and reliability of operation. They can determine the presence or absence, passing, positioning, and end of travel of an object. In other implementations, the switches may be solid state switches that operate under the influence of a magnetic field such as Hall-effect devices, magneto-resistive (MR) devices, giant magneto-resistive (GMR) devices, magnetometers, among others. In other implementations, the switches may be solid state switches that operate under the influence of light, such as optical sensors, infrared sensors, ultraviolet sensors, among others. Still, the switches may be solid state devices such as transistors (e.g., FET, Junction-FET, metal-oxide semiconductor-FET (MOSFET), bipolar, and the like). Other switches may include wireless switches, ultrasonic switches, accelerometers, inertial sensors, among others.

[0254] FIG. 26 is another block diagram of the control circuit 150700 of the surgical instrument of FIG. 21 illustrating interfaces between the handle assembly 150702 and the power assembly 150706 and between the handle assembly 150702 and the interchangeable shaft assembly 150704, in accordance with at least one aspect of this disclosure. The handle assembly 150702 may comprise a main controller 150717, a shaft assembly connector 150726, and a power assembly connector 150730. The power

assembly 150706 may include a power assembly connector 150732, a power management circuit 150734 that may comprise the power management controller 150716, a power modulator 150738, and a current sense circuit 150736. The shaft assembly connectors 150726, 150728 form an interface 150727. The power management circuit 150734 can be configured to modulate power output of the battery 150707 based on the power requirements of the interchangeable shaft assembly 150704 while the interchangeable shaft assembly 150704 and the power assembly 150706 are coupled to the handle assembly 150702. The power management controller 150716 can be programmed to control the power modulator 150738 of the power output of the power assembly 150706 and the current sense circuit 150736 can be employed to monitor power output of the power assembly 150706 to provide feedback to the power management controller 150716 about the power output of the battery 150707 so that the power management controller 150716 may adjust the power output of the power assembly 150706 to maintain a desired output. The shaft assembly 150704 comprises a shaft processor 150720 coupled to a non-volatile memory 150721 and shaft assembly connector 150728 to electrically couple the shaft assembly 150704 to the handle assembly 150702. The shaft assembly connectors 150726, 150728 form interface 150725. The main controller 150717, the shaft processor 150720, and/or the power management controller 150716 can be configured to implement one or more of the processes described herein.

[0255] The surgical instrument 150010 (FIGS. 21 to 24) may comprise an output device 150742 to a sensory feedback to a user. Such devices may comprise visual feedback devices (e.g., an LCD display screen, LED indicators), audio feedback devices (e.g., a speaker, a buzzer), or tactile feedback devices (e.g., haptic actuators). In certain circumstances, the output device 150742 may comprise a display 150743 that may be included in the handle assembly 150702. The shaft assembly controller 150722 and/or the power management controller 150716 can provide feedback to a user of the surgical instrument 150010 through the output device 150742. The interface 150727 can be configured to connect the shaft assembly controller 150722 and/or the power management controller 150716 to the output device 150742. The output device 150742 can be integrated with the power assembly 150706. Communication between the output device 150742 and the shaft assembly controller 150722 may be accomplished through the interface 150725 while the interchangeable shaft assembly 150704 is coupled to the handle assembly 150702.

Cancerous Tissue Proximity Detection

[0256] Cancer is a disease at the cellular level involving disorders in cellular control mechanisms. Tumor cells alter their metabolism to maintain unregulated cellular proliferation and survival, but this transformation leaves them reliant on constant supply of nutrients and energy. Cancer cells are shown to experience characteristic changes in their metabolic programs, including increased uptake of glucose. Many cancer cells have shown an increase in glycolysis (anaerobic metabolism) leading to decreased

glucose and increased lactic acid in the interstitial fluid environment. Accordingly, glucose levels in normal tissue are higher than cancerous tissue. Also, due to the increase in lactic acid levels in cancerous tissue, cancerous tissue pH (potential of hydrogen) is lower than normal tissue pH.

[0257] One of the popular treatments of cancer is to excise the cancerous tissue. As illustrated in FIG. 27, a surgical instrument can be employed to seal and cut tissue along a perimeter defined in healthy tissue around the cancerous tissue. The sealing of the tissue can be achieved by application of energy (e.g., RF or ultrasonic) or by deployment of staples into the tissue. In a successful procedure, no cancer cells are detected at the outer edge of the tissue that was removed, which is referred to as a clear surgical margin.

[0258] Using various existing techniques, a surgeon may attempt to visually determine where tissue grasped by a surgical end effector is located relative to a desired clear surgical margin. Needless to say, such visual determination may be inefficient. Furthermore, unintentionally disturbing the cancerous tissue by cutting through the cancerous tissue may have undesirable consequences. For example, cancerous cells dislodged by this process may migrate into other healthy tissue through the blood stream, for example, causing the cancer to spread to other healthy tissue.

[0259] Aspects of the present disclosure present various surgical instruments utilized in cancer treatment, which employ various sensors and algorithms for assessing proximity to cancerous tissue and/or assisting a user in navigating a safe distance away from cancerous tissue before application of a cancer treatment by the end effector.

[0260] FIG. 29 is a logic flow diagram of a process 26120 depicting a control program or a logic configuration for assessing proximity of an end effector 26000 of a surgical instrument 26010 to cancerous tissue, in accordance with at least one aspect of the present disclosure. In one aspect, as described in greater detail below, the process 26120 is executed by a control circuit 500 (FIG. 13). In another aspect, the process 26120 can be executed by a combinational logic circuit 510 (FIG. 14). In yet another aspect, the process 26120 can be executed by a sequential logic circuit 520 (FIG. 15).

[0261] The process 26120 measures 26123 a physiological parameter of tissue in contact with the end effector 26000, the measured physiological parameter being one that indicates proximity of the end effector 26000 to cancerous tissue. The process 26120 further alerts 26125 a user and/or overrides 26126 a tissue treatment, if it is determined that the physiological parameter reaches or crosses a predetermined threshold.

[0262] FIG. 30 is a logic flow diagram of a process 26020 depicting a control program or a logic configuration for assessing proximity of an end effector 26000 of a surgical instrument 26010 to cancerous tissue, in accordance with at least one aspect of the present disclosure. In one aspect, as described in greater detail below, the process 26020 is executed by a control circuit 500 (FIG. 13). In another aspect, the process 26020 can be executed by a combinational logic circuit 510 (FIG. 14). In yet another aspect, the process 26020 can be executed by a sequential logic circuit 520 (FIG. 15).

[0263] The end effector 26000, as illustrated in FIGS. 31 and 32, includes a sensor array 26471 configured to generate or provide sensor signals indicative of a physiological parameter of the tissue that represents proximity of the end effector to cancerous tissue. FIG. 32 illustrates a control system 26470 including a control circuit coupled to the sensor array 26471. The control system 26470 is configured to assess proximity of the end effector 26000 to cancerous tissue based on the sensor signals of the sensor array 26471.

[0264] In one aspect, the physiological parameter is glucose level within the tissue. A low glucose level indicates a close proximity of the end effector to cancerous tissue.

[0265] In another aspect, the physiological parameter is a pH level. A low pH level indicates a close proximity of the end effector to cancerous tissue.

[0266] FIG. 28 is a graph illustrating a physiological parameter of tissue (Y-axis) plotted against distance from a tumor (x-axis). In the example of FIG. 28, the physiological parameter decreases with an increase in proximity to the tumor. Examples of physiological parameters that exhibit such characteristic include glucose, and pH, as described below in greater detail. Other examples may involve a physiological parameter that increases with an increase in proximity to the tumor.

[0267] In the example of FIG. 28, the physiological parameter of the tissue reaches a normal level (N) at a distance (d) from the tumor, which defines a clear margin, as illustrated in FIG. 27. The normal level (N) represents a typical level of the physiological parameter in normal tissue.

[0268] The surgical instrument 26010 is similar in many respects to the surgical instrument 150010. For example, the end effector 26000 and control system 26470 are similar in many respects to the end effector 150300 and the control system 470 (FIG. 12), respectively. For conciseness, components of the surgical instrument 26010 that are similar to above-described components of the surgical instrument 150010 are not repeated herein in detail.

[0269] The end effector 26000 includes a first jaw 26001 and a second jaw 26002 extending from an interchangeable shaft assembly 150200. The end effector 26000 further includes an anvil 26009 (FIG. 32) defined in the first jaw 26001 and a staple cartridge 26005 defined in the second jaw 26002. At least one of the first jaw 26001 and the second jaw 26002 is movable relative to the other to transition the end effector 26000 between an open configuration and a closed configuration to grasp tissue between the anvil 26009 and the staple cartridge 26005. In operation, a tissue treatment by the surgical instrument 26010 involves deploying staples from the staple cartridge 26005 by a firing member 26011 into the grasped tissue. The deployed staples are deformed by the anvil 26009.

[0270] In various aspects, a surgical instrument, in accordance with the present disclosure, may include an end effector that treats tissue by application of RF or ultrasonic energy to tissue. In various aspects, the surgical instrument 26010 can be a handheld surgical instrument. Alternatively, the surgical instrument 26010 can be incorporated into a robotic system as a component of a robotic arm. Additional

details on robotic systems are disclosed in U.S. Provisional Patent Application No. 62/611,339, filed December 28, 2017, which is incorporated herein by reference in its entirety.

[0271] Measuring the physiological parameter and assessing proximity of the end effector 26000 to cancerous tissue may begin with activation of the surgical instrument 26010 and can be continually performed as long as the surgical instrument 26010 remains operational. Alternatively, as described in connection with the process 26020, such activities can be triggered by, for example, detecting a tissue grasped by the end effector 26000. In certain instances, such activities can be triggered reaching or approaching a closed configuration.

[0272] The process 26020 detects 26021 whether tissue is grasped by a surgical end effector 26000. FIG. 20 illustrates an example of a tissue contact circuit that includes tissue contact or pressure sensors that determine when the jaws of an end effector initially come into contact with the tissue "T." Contact of the jaws with tissue "T" closes a sensing circuit "SC" that is otherwise open, by establishing contacting with a pair of opposed plates "P1, P2" provided on the jaw members.

[0273] The contact sensors may also include sensitive force transducers that determine the amount of force being applied to the sensor, which may be assumed to be the same amount of force being applied to the tissue "T." Such force being applied to the tissue may then be translated into an amount of tissue compression. In certain instances, measuring the physiological parameter and assessing proximity of the end effector 26000 to cancerous tissue can be triggered by reaching a predetermined tissue compression threshold.

[0274] Force transducers may include, and are not limited to, piezoelectric elements, piezoresistive elements, metal film or semiconductor strain gauges, inductive pressure sensors, capacitive pressure sensors, and potentiometric pressure transducers that use bourbon tubes, capsules, or bellows to drive a wiper arm on a resistive element. FIG. 20 and additional exemplifications are further described in U.S. Patent No. 8,181,839, filed June 27, 2011, titled SURGICAL INSTRUMENT EMPLOYING SENSORS, which issued May 5, 2012, the entire disclosure of which is incorporated by reference herein.

[0275] In certain instances, transition of the end effector 26000 to a closed configuration can trigger measuring the physiological parameter and assessing proximity of the end effector 26000 to cancerous tissue. A tracking system 480 (FIGS. 12 and 32), which is configured to determine the position of a longitudinally movable displacement member that transmits closure motions to the end effector 26000, can be employed in detecting the closed configuration.

[0276] The microcontroller 461 may consult one or more readings from one or more of the sensors 472, 474, 476 in performing the detection 26021. For example, readings from the strain gauge sensor 474, which can be used to measure the force applied to tissue grasped by the end effector 26000, can reflect whether tissue is grasped by the end effector 26000.

[0277] In any event, if it is determined 26021 that tissue is grasped by the end effector 26000, or that a closed configuration is reached, proximity of the end effector 26000 from cancerous tissue can be

ascertained 26023 based upon a physiological parameter of grasped tissue. A sensor array 26471 including "n" sensors, wherein "n" is an integer greater than or equal to one, can be configured to provide the microcontroller 461 sensor signals according to a physiological parameter of the tissue that indicates proximity of the end effector 26000 to cancerous tissue.

[0278] If it is determined 26024 that the proximity of the end effector to cancerous tissue reaches or crosses a predetermined threshold, steps can be taken to alert 26025 a surgical operator and/or override 26026 a tissue treatment.

[0279] The microcontroller 461 may alert the surgical operator through the display 473, for example. Other audio, haptic, and/or visual means can also be employed. The microcontroller 461 may also take steps to prevent the tissue sealing. For example, the microcontroller 461 may signal the motor driver 492 to deactivate the motor 482.

[0280] In various aspects, one or more the processes 26020 and 26120 are implemented by program instructions stored in the memory 468, which can be executed by the processor 462 to perform one or more of the steps of the processes 26020 and 26120. The microcontroller 461 may also employ neural networks, look-up tables, defined functions, and/or real-time input from a cloud-based system 104 (FIG. 1) in performing one or more of the steps of the processes 26020 and 26120.

[0281] In one example, the microcontroller 461 may employ a look-up table or a defined function, which can be stored in the memory 468, in correlating sensor signals from the sensor array 26471 with values of the physiological parameter of the grasped tissue. Look-up tables can also define a proximity index for assessing proximity of the end effector 26000 to cancerous tissue based upon the determined values of the physiological parameter or, more directly, based on the received sensor signals. FIG. 33 illustrates an example proximity index 26030, which correlates sensor signal readings (R_{1-n}) received by the microcontroller 461 from the sensor array 26471 with corresponding distances (D_{1-n}) between the end effector and cancerous tissue.

[0282] In various instances, measuring the physiological parameter of the tissue and/or assessing proximity of an end effector 26000 to cancerous tissue is triggered by a user input. A user interface such as, for example, the display 473 can be employed to receive and transmit the user input to the microcontroller 461, for example.

[0283] In addition to detecting proximity of an end effector to cancerous tissue, it is desirable to provide a direction for navigating the end effector sufficiently away from the cancerous tissue. FIG. 34 is a logic flow diagram of a process 26040 depicting a control program or a logic configuration for navigating an end effector 26050 away from cancerous tissue. The end effector 26050 is similar in many respects to the end effector 26000. For example, the surgical instrument 26010 can be equipped with an end effector 26050 in lieu of the end effector 26000.

[0284] The process 26040 can be executed alone or in combination with the process 26020, or at least a portion thereof. In various aspects, the process 26040 is executed by a control circuit of a control

system 26470 in communication with sensors 26055, 26056 on opposite sides 26053, 26054 of an end effector 26050. The sensors 26055, 26056 are spaced apart and separated by a transection path defined by a longitudinal axis "L" extending along an elongated channel configured to accommodate a transection member movable there through. The sensors 26055, 26056 are configured to provide sensor signals corresponding to a physiological parameter indicative of proximity of the end effector 26050 to cancerous tissue.

[0285] The process 26040 can be executed by program instructions stored in the memory 468, which can be executed by the processor 462 to perform the process 26040. The microcontroller 461 may also employ neural networks, look-up tables, defined functions, and/or real-time input from a cloud-based system 104 (FIG. 1) in performing the process 26040.

[0286] The process 26040 includes receiving 26041 the sensor signals from sensors 26055, 26056. If it is determined 26042 that the sensor signals represent values of the physiological parameter greater than or equal to a predetermined threshold, the process 26040 allows 26043 a treatment application to the tissue by the end effector 26050. Conversely, If it is determined 26044 that the sensor signals represent values of the physiological parameter less than or equal to the predetermined threshold, the process 26040 instructs 26045 the user to move the end effector in any suitable direction.

[0287] Further to the above, if it is determined 26046 that a first sensor signal represents a value of the physiological parameter greater than or equal to the predetermined threshold, while a second sensor signal represents a value less than the predetermined threshold, the process 26040 instructs the user to move the end effector 26050 in a first direction 26061. Conversely, if it is determined 26048 that the second sensor signal represents a value of the physiological parameter greater than or equal to the predetermined threshold, while the first sensor signal represents a value less than the predetermined threshold, the process 26040 instructs the user to move the end effector 26050 in a second direction 26062, opposite the first direction 26061.

[0288] As illustrated in FIG. 35, the longitudinal axis "L" defines a first side 26053 and a second side 26054. The first direction 26061 extends away from the longitudinal axis "L" on the first side 26053, while the second direction 26062 extends away from the longitudinal axis "L" on the second side 26054.

[0289] FIG. 36 is a graph illustrating sensor signals from sensors 26055, 26056 representing values of a physiological parameter of tissue (Y-axis) plotted against time (x-axis) for three different positions (Position A, Position B, Position C) of the end effector 26050 relative to cancerous tissue. The physiological parameter is glucose level within the tissue. As described above, a low glucose level indicates a close proximity to cancerous tissue. Alternatively, the physiological parameter can be pH level. A low pH level indicates a close proximity to cancerous tissue.

[0290] In various examples, an end effector, in accordance with at least one aspect of the present disclosure, may include sensors that measure two or more physiological parameters indicative of proximity to cancerous tissue. For example, an end effector may include one or more glucose sensors

and one or more pH sensors. Sensor signals from sensor of different types can be received analyzed by the microcontroller 461 to assess proximity to cancerous tissue.

[0291] In Position A, sensor signals 26057, 26058 of the sensors 26055, 26056 are greater than or equal to the predetermined threshold "N." Accordingly, it can be concluded that the cancerous tissue is sufficiently far away from the end effector 26050. Accordingly, the microcontroller 461 may inform the surgical operator that is safe to treat tissue grasped by the end effector 26050.

[0292] In position C, the signals 26057, 26058 of the sensors 26055, 26056 are less than the predetermined threshold "N." Accordingly, it can be concluded that the tumor is on, or at least near, the transection path 26052 between the sensors 26055, 26056. Accordingly, the microcontroller 461 may instruct the surgical operator to release the grasped tissue, and reposition the end effector 26050 by moving it to the side in either direction, before application of a treatment to the tissue.

[0293] In position B, the sensor signal 26057 of the sensor 26055 is below the predetermined threshold "N," while the sensor signal 26058 of the sensor 26056 is greater than the predetermined threshold "N." Accordingly, it can be concluded that the tumor extends on the first side 56053 of the end effector 26050. Accordingly, the microcontroller 461 may instruct the surgical operator to release the grasped tissue, and reposition the end effector 26050 by moving it in the second direction 26062 away from the cancerous tissue, before treating the tissue.

[0294] In various examples, the sensor signals are directly proportional to the physiological parameter detected by the sensors. In other equivalent examples, however, the sensor signals can be inversely proportional to the physiological parameter detected by the sensors. In such other examples, the sensor signals decrease as the proximity to cancerous tissue increases. Nonetheless, an inverter can be utilized to invert the received sensor signals.

[0295] In various aspects, referring to FIGS. 32, 35, and 36, the microcontroller 461 further processes the sensor signals of the sensors 26055, 26056 by subtracting one sensor signal from the other sensor signal. The resulting delta can be further analyzed to determine the direction in which the end effector 26050 is to be moved. As illustrated in FIG. 36, in position A and position C, the sensor signals mostly cancel each other out. However, in position B of FIG. 36, a positive in the delta 26059 is detected. The delta positive transition indicates that the cancerous tissue extends on the first side 26053 of the end effector 26050 but not the second side 26054. In addition, whether the delta 26059 is above or below zero can give an indication as to the desired direction of motion for the end effector 26050.

[0296] With sensors 26055, 26056, as illustrated in the example of FIG. 35, the microcontroller 461 is able to assess relevant proximity to cancerous and determine how to navigate away from the cancerous tissue direction. In other example, a sensor array may include more than two sensors. In one example, a sensor array may include, in addition to the sensors 26055, 26056, a third sensor at a distal portion of the end effector.

[0297] In various aspects, as illustrated in FIG. 37, an end effector 26070 may be equipped with a sensor array 26080 that includes six sensors (Sen_1-Sen_6): two proximal sensors (Sen_1 and Sen_6), two medial sensors (Sen_2 and Sen_5), and two distal sensors (Sen_3 and Sen_4). The added sensors allow the microcontroller 461, among other things, to more accurately predict the position of the end effector 26070 with respect to cancerous tissue.

[0298] The end effector 26070 is similar in many respects to the end effectors 26000, 26050. For example, the end effector 26070 includes a first jaw 26071 and a second jaw 26072. At least one of the first jaw 26071 and the second jaw 26072 is movable relative to the other to grasp tissue therebetween.

[0299] Further to the above, the end effector 26070 includes an anvil defined in the second jaw 26072 and a staple cartridge 26075 defined in the first jaw 26071. To treat tissue grasped by the end effector 26070, staples are deployed from the staple cartridge 26075 into the grasped tissue, and are deformed by the anvil. To cut the tissue, a transection member is moved relative to an elongated slot that defines a transection path 26073 for the transection member. The transection path 26073 defines two opposite sides 26076, 26077 of the end effector 26070.

[0300] Further to the above, the sensor array 26080 is similar in many respects to the sensor array 26471. For example, the sensor array 26080 can also be coupled to the microcontroller 461. The sensor array 26080 includes six sensors (Sen_1-Sen_6) configured to provide the microcontroller 461 with sensor signals according to a physiological parameter of the tissue that indicates proximity of the end effector 26070 to cancerous tissue. In other examples, the sensor array 26080, like the sensor array 26471, may include more or less than six sensors.

[0301] The sensors of the sensor array 26080 are spaced apart and arranged on outer edges 26078, 26079 of the staple cartridge 26075. In the example of FIG. 37, Sen_1, Sen_2, and Sen_3 are arranged on the side 26076 while Sen_4, Sen_5, and Sen_6 are arranged on the side 26077. In other words, the transection path 26052 extends between the sensors of the sensor array 26080.

[0302] In various examples, the differential between the sensor signals and the mean of the signals can give insight into tumor proximity. If a signal indicates a sensor is on a tumor, the differential between that sensor and the other sensors will give insight if the tumor is along one side (not transected) or across the transection path (transected). If the differential between the signals and mean is small but the mean is high, the entire end effector is on the tumor.

[0303] FIGS. 38 and 41 are graphs illustrating sensor signals of sensors Sen_1-Sen_6 plotted on the Y-axis against time on the x-axis. The sensor signals of sensors Sen_1-Sen_6 measure a physiological parameter that changes with a change in distance from cancerous tissue. Accordingly, the sensor signals of Sen_1-Sen_6 represent a physiological parameter of tissue indicative of the position of the end effector 26070 with respect to cancerous tissue.

Error! No sequence specified. The physiological parameter of FIGS. 38 and 41 is one that decreases with an increase in proximity to cancerous tissue, but the sensor signals of sensors Sen_1-Sen_6 were

passed through an inverter. Each of the positions A-C of FIG. 38 and the positions A-E of FIG. 40 represents a distinct position of the end effector 26070 with respect to the cancerous tissue.

[0304] In the examples of FIGS. 38 and 41, an average (AVG) of the sensor signals may calculate microcontroller 461 from the formula:

$$AVG = \frac{Sen_1 + Sen_2 + Sen_3 \ldots Sen_n}{n}$$

, wherein $Sen_{1\text{-}n}$ represent sensor signal values at time (t), and wherein (n) represent the number of sensors.

Then, the microcontroller 461 may employ a formula:

$$\sum |Sen_n - AVG| < X$$

, wherein (n) is an integer greater than zero, wherein (AVG) is the average of the sensor signals, and wherein (x) is a predetermined threshold, to determine proximity of the end effector 26070 to cancerous tissue. If the formula yields an outcome below the predetermined threshold (x), as illustrated in Positions A of FIGS. 38 and 41, the microcontroller 461 authorizes a tissue treatment by the end effector 26070. In positions B-D of FIG. 38 and positions B-E of FIG. 41, the formula yields an outcome that is greater than the predetermined threshold (x) indicating that one or more of the sensors are within a close proximity to the cancerous tissue.

[0305] The microcontroller 461 may compare the sensor signal of each of the sensors Sen_1-Sen_6 to the average of the sensor signals (AVG) to assess proximity of the sensors Sen_1-Sen_6 to cancerous tissue. The proximity of the end effector 26070 to tissue can be inferred from the assessed proximity of the sensors Sen_1-Sen_6 to cancerous tissue. The sensors providing sensor signals greater than (AVG) can be identified as sensors positioned within close proximity to the cancerous tissue. Other mathematical formulas can be applied to the sensor signals of the sensors Sen_1-Sen_6 to ascertain proximity of the sensors Sen_1-Sen_6 to cancerous tissue.

[0306] Further to the above, additional information can also be inferred from the spatial relation of the sensors Sen_1-Sen_6 on the end effector 26070. FIG. 39 is a logic flow diagram of a process 26090 depicting a control program or a logic configuration that provides instructions for navigating an end effector with respect to cancerous tissue, wherein the instructions are based on the spatial relation of sensors on the end effector that report readings indicative of close proximity of the sensors to cancerous tissue. The process 26090 can be executed by the microcontroller 461 based on sensor readings from the sensors Sen_1-Sen_6. The process 26090 includes receiving 26091 sensor signals from sensors Sen_1-Sen_6., and determining 26092, based on the above-described formulas, the sensors with close proximity to cancerous tissue. Furthermore, the process 26090 includes providing 26092 instructions for navigating an end effector 26050 away from the cancerous tissue based on the relative location of the sensors with close proximity to cancerous tissue on the end effector 26050.

[0307] Position C of FIG. 38 and Position B of FIG. 41 illustrate an example that implements the process 26090 of FIG. 39. In Position C of FIG. 38 and Position B of FIG. 41, the readings of Sen_3 and Sen_4 are greater than (AVG) while the remaining sensors report readings below (AVG). In addition, the Sen_3 and Sen_4 are located at a distal portion of the end effector 26070 on opposite sides 26076 and 26077. Accordingly, it can be concluded that the cancerous tissue extends over the transection path 26073, and is mainly located in front of the end effector 26070. In response, the microcontroller 461 may instruct the surgical operator to release the grasped tissue, and move the end effector 26070 backward to reach a clear margin before re-grasping the tissue.

[0308] Position D of FIG. 38 illustrates another example that implements the process 26090 of FIG. 39. In Position D of FIG. 38, the readings of Sen_3 and Sen_2 are greater than (AVG) while the remaining sensors report readings below (AVG). In addition, Sen_2 and Sen_3 are positioned on the same side 26076 of the end effector 26070. Accordingly, it can be concluded the cancerous tissue extends on the side 26076 of the end effector 26070. Since the readings of Sensors Sen_4, Sen_5, and Sen_6, which are located on the side 26077, indicate that these sensors are not in close proximity to cancerous tissue, the microcontroller 461 may instruct the surgical operator to release the grasped tissue, and move the end effector 26070 in a direction away from the transection path 26073 on the side 26077 in order to reach a clear margin on the side 26076.

[0309] FIG. 40 is a logic flow diagram of a process 26190 depicting a control program or a logic configuration that provides instructions for navigating an end effector with respect to cancerous tissue, wherein the instructions are based on the spatial relation and comparison of values of readings of sensors on the end effector that report readings indicative of close proximity of the sensors to cancerous tissue. The process 26190 can be executed by the microcontroller 461 based on sensor readings from the sensors Sen_1-Sen_6. The process 26190 includes receiving 26191 sensor signals from sensors Sen_1-Sen_6., and determining 26192, based on the above-described formulas, the sensors with close proximity to cancerous tissue. Furthermore, the process 26190 includes providing 26193 instructions for navigating an end effector 26070 away from the cancerous tissue based on the relative location and relative values of the readings of the sensors with close proximity to cancerous tissue on the end effector 26070.

[0310] Position E of FIG. 41 provides an example that implements the process 26190. In Position E of FIG. 41, the readings of Sen_1, Sen_2, and Sen_3 are all greater than or equal to (AVG) while the remaining sensors report readings below (AVG). In addition, Sen_1, Sen_2, and Sen_3 are all positioned on the side 26076 of the end effector 26070. Accordingly, it can be concluded that the cancerous tissue extends on the side 26076 of the end effector 26070. In addition, the reading of Sen_2 is greater than the reading of Sen_1. Also, the reading of Sen_2 is greater than the reading of Sen_3. Since Sen_2 is positioned between Sen_1 and Sen_3 on the same side 26076, I can be concluded that the cancerous tissue extends on the side 26076 of the end effector 26070 at a position closer to Sen_2 than Sen_1 and Sen_3.

[0311] In various examples the sensors of a sensor array such as the sensor array 26471 and/or the sensor array 26080 can be integrated into a staple cartridge and conducted through metallic portions of the staple cartridge that, when assembled with an end effector, engage contactor plates that transmit power and/or data.

[0312] In various examples, the physiological parameter of the tissue that is measured by the sensors of a sensor array, in accordance with the present disclosure, is pH. As discussed above, lactic acid is a byproduct of the glycolysis (anaerobic metabolism) process that is performed by cancerous tissue leading to decreased glucose and increased lactic acid in the interstitial fluid environment.

[0313] In various examples, the physiological parameter of the tissue that is measured by the sensors of a sensor array, in accordance with the present disclosure, is glucose. As described above, glucose levels have been measured to be very low in tumor microenvironments (0.1-0.4mM). In normal tissue, glucose levels can be in the range of about 3.3-5.5 mM.

[0314] In various examples, the sensors of a sensor array, in accordance with the present disclosure, are Clark-type sensors, which can be used to measure glucose levels based on oxygen reaction with an enzyme. Clark-type sensors use an immobilized glucose oxidase embedded surface to catalyze the oxidation of beta-D-glucose to produce gluconic acid and hydrogen peroxide. Hydrogen peroxide is oxidized at a catalytic (usually platinum) anode which induces an electron transfer proportional to the number of glucose molecules present.

[0315] FIGS. 42 and 43 illustrate an example thick-film printed glucose sensor 26200, which can be employed with a sensor array of the present disclosure. This configuration uses iridium doped carbon ink, which has high specificity towards glucose detection that is not obscured by other common interference chemicals (e.g., ascorbic acid). The sensor 26200 comprises an electrode diameter of ~1mm. In one example, as illustrated in FIG. 43, the sensor 26200 includes an Ir-Carbon counter electrode 26202, and Ir-Carbon working electrode 26203, an Ag/AgCl reference electrode 26204, and a silver conducting pad 26205. In addition, the sensor 26200 further includes an insulating layer 26206. Additional details of the sensor 26200 are described in a journal publication to Shen J et al., titled Sensors and Actuators B: Chemical, 2007, V125(1), pp. 16-113, which is incorporated by reference herein in its entirety. As illustrated in FIGS. 44-45, with an applied potential of 0.2-0.3V, a response current of ~15-20 uA can be observed with an increase of 5mM of glucose.

[0316] In various aspects, the sensors of a sensor array, in accordance with the present disclosure, can be placed on a staple cartridge. An adhesive mask can be embedded with the sensors at predetermined locations. In various aspects, the sensors are attached to bumps on the staple cartridge so that the sensors are positioned higher than a cartridge deck of the staple cartridge to ensure contact with the tissue. The adhesive mask could be created in bulk using screen-printing technology on a polyester substrate, for example. Conducting pads can be printed to a common location.

[0317] In various examples, in addition to detection of proximity to cancerous tissue, an end effector of the present disclosure can also be configured to target specific cancer types in specific tissues. As indicated in the journal publication to Altenberg B and Greulich KO, Genomics 84(2004) pp. 1014-1020, which is incorporated herein by reference in its entirety, certain cancers are characterized by an overexpression of glycolysis genes while other cancers are not characterized by an overexpression of glycolysis genes. Accordingly, an end effector of the present disclosure can be equipped with a sensor array with a high specificity for cancerous tissue characterized by an overexpression of glycolysis genes such as lung cancer or liver cancer.

[0318] In various aspects, the sensor readings of a sensor array, in accordance with the present disclosure, are communicated by the surgical instrument to a surgical hub (e.g., surgical hub 106, 206) for additional analysis and/or for situational awareness.

Situational Awareness

[0319] Situational awareness is the ability of some aspects of a surgical system to determine or infer information related to a surgical procedure from data received from databases and/or instruments. The information can include the type of procedure being undertaken, the type of tissue being operated on, or the body cavity that is the subject of the procedure. With the contextual information related to the surgical procedure, the surgical system can, for example, improve the manner in which it controls the modular devices (e.g., a robotic arm and/or robotic surgical tool) that are connected to it and provide contextualized information or suggestions to the surgeon during the course of the surgical procedure.

[0320] Referring now to FIG. 46, a timeline 5200 depicting situational awareness of a hub, such as the surgical hub 106 or 206, for example, is depicted. The timeline 5200 is an illustrative surgical procedure and the contextual information that the surgical hub 106, 206 can derive from the data received from the data sources at each step in the surgical procedure. The timeline 5200 depicts the typical steps that would be taken by the nurses, surgeons, and other medical personnel during the course of a lung segmentectomy procedure, beginning with setting up the operating theater and ending with transferring the patient to a post-operative recovery room.

[0321] The situationally aware surgical hub 106, 206 receives data from the data sources throughout the course of the surgical procedure, including data generated each time medical personnel utilize a modular device that is paired with the surgical hub 106, 206. The surgical hub 106, 206 can receive this data from the paired modular devices and other data sources and continually derive inferences (i.e., contextual information) about the ongoing procedure as new data is received, such as which step of the procedure is being performed at any given time. The situational awareness system of the surgical hub 106, 206 is able to, for example, record data pertaining to the procedure for generating reports, verify the steps being taken by the medical personnel, provide data or prompts (e.g., via a display screen) that may be pertinent for the particular procedural step, adjust modular devices based on the context (e.g.,

activate monitors, adjust the field of view (FOV) of the medical imaging device, or change the energy level of an ultrasonic surgical instrument or RF electrosurgical instrument), and take any other such action described above.

[0322] At the first step 5202 in this illustrative procedure, the hospital staff members retrieve the patient's EMR from the hospital's EMR database. Based on select patient data in the EMR, the surgical hub 106, 206 determines that the procedure to be performed is a thoracic procedure.

[0323] Second step 5204, the staff members scan the incoming medical supplies for the procedure. The surgical hub 106, 206 cross-references the scanned supplies with a list of supplies that are utilized in various types of procedures and confirms that the mix of supplies corresponds to a thoracic procedure. Further, the surgical hub 106, 206 is also able to determine that the procedure is not a wedge procedure (because the incoming supplies either lack certain supplies that are necessary for a thoracic wedge procedure or do not otherwise correspond to a thoracic wedge procedure).

[0324] Third step 5206, the medical personnel scan the patient band via a scanner that is communicably connected to the surgical hub 106, 206. The surgical hub 106, 206 can then confirm the patient's identity based on the scanned data.

[0325] Fourth step 5208, the medical staff turns on the auxiliary equipment. The auxiliary equipment being utilized can vary according to the type of surgical procedure and the techniques to be used by the surgeon, but in this illustrative case they include a smoke evacuator, insufflator, and medical imaging device. When activated, the auxiliary equipment that are modular devices can automatically pair with the surgical hub 106, 206 that is located within a particular vicinity of the modular devices as part of their initialization process. The surgical hub 106, 206 can then derive contextual information about the surgical procedure by detecting the types of modular devices that pair with it during this pre-operative or initialization phase. In this particular example, the surgical hub 106, 206 determines that the surgical procedure is a VATS procedure based on this particular combination of paired modular devices. Based on the combination of the data from the patient's EMR, the list of medical supplies to be used in the procedure, and the type of modular devices that connect to the hub, the surgical hub 106, 206 can generally infer the specific procedure that the surgical team will be performing. Once the surgical hub 106, 206 knows what specific procedure is being performed, the surgical hub 106, 206 can then retrieve the steps of that procedure from a memory or from the cloud and then cross-reference the data it subsequently receives from the connected data sources (e.g., modular devices and patient monitoring devices) to infer what step of the surgical procedure the surgical team is performing.

[0326] Fifth step 5210, the staff members attach the electrocardiography (EKG) electrodes and other patient monitoring devices to the patient. The EKG electrodes and other patient monitoring devices are able to pair with the surgical hub 106, 206. As the surgical hub 106, 206 begins receiving data from the patient monitoring devices, the surgical hub 106, 206 thus confirms that the patient is in the operating theater.

[0327] Sixth step 5212, the medical personnel induce anesthesia in the patient. The surgical hub 106, 206 can infer that the patient is under anesthesia based on data from the modular devices and/or patient monitoring devices, including EKG data, blood pressure data, ventilator data, or combinations thereof, for example. Upon completion of the sixth step 5212, the pre-operative portion of the lung segmentectomy procedure is completed and the operative portion begins.

[0328] Seventh step 5214, the patient's lung that is being operated on is collapsed (while ventilation is switched to the contralateral lung). The surgical hub 106, 206 can infer from the ventilator data that the patient's lung has been collapsed, for example. The surgical hub 106, 206 can infer that the operative portion of the procedure has commenced as it can compare the detection of the patient's lung collapsing to the expected steps of the procedure (which can be accessed or retrieved previously) and thereby determine that collapsing the lung is the first operative step in this particular procedure.

[0329] Eighth step 5216, the medical imaging device (e.g., a scope) is inserted and video from the medical imaging device is initiated. The surgical hub 106, 206 receives the medical imaging device data (i.e., video or image data) through its connection to the medical imaging device. Upon receipt of the medical imaging device data, the surgical hub 106, 206 can determine that the laparoscopic portion of the surgical procedure has commenced. Further, the surgical hub 106, 206 can determine that the particular procedure being performed is a segmentectomy, as opposed to a lobectomy (note that a wedge procedure has already been discounted by the surgical hub 106, 206 based on data received at the second step 5204 of the procedure). The data from the medical imaging device 124 (FIG. 2) can be utilized to determine contextual information regarding the type of procedure being performed in a number of different ways, including by determining the angle at which the medical imaging device is oriented with respect to the visualization of the patient's anatomy, monitoring the number or medical imaging devices being utilized (i.e., that are activated and paired with the surgical hub 106, 206), and monitoring the types of visualization devices utilized. For example, one technique for performing a VATS lobectomy places the camera in the lower anterior corner of the patient's chest cavity above the diaphragm, whereas one technique for performing a VATS segmentectomy places the camera in an anterior intercostal position relative to the segmental fissure. Using pattern recognition or machine learning techniques, for example, the situational awareness system can be trained to recognize the positioning of the medical imaging device according to the visualization of the patient's anatomy. As another example, one technique for performing a VATS lobectomy utilizes a single medical imaging device, whereas another technique for performing a VATS segmentectomy utilizes multiple cameras. As yet another example, one technique for performing a VATS segmentectomy utilizes an infrared light source (which can be communicably coupled to the surgical hub as part of the visualization system) to visualize the segmental fissure, which is not utilized in a VATS lobectomy. By tracking any or all of this data from the medical imaging device, the surgical hub 106, 206 can thereby determine the specific type of surgical procedure being performed and/or the technique being used for a particular type of surgical procedure.

[0330] Ninth step 5218, the surgical team begins the dissection step of the procedure. The surgical hub 106, 206 can infer that the surgeon is in the process of dissecting to mobilize the patient's lung because it receives data from the RF or ultrasonic generator indicating that an energy instrument is being fired. The surgical hub 106, 206 can cross-reference the received data with the retrieved steps of the surgical procedure to determine that an energy instrument being fired at this point in the process (i.e., after the completion of the previously discussed steps of the procedure) corresponds to the dissection step. In certain instances, the energy instrument can be an energy tool mounted to a robotic arm of a robotic surgical system.

[0331] Tenth step 5220, the surgical team proceeds to the ligation step of the procedure. The surgical hub 106, 206 can infer that the surgeon is ligating arteries and veins because it receives data from the surgical stapling and cutting instrument indicating that the instrument is being fired. Similarly to the prior step, the surgical hub 106, 206 can derive this inference by cross-referencing the receipt of data from the surgical stapling and cutting instrument with the retrieved steps in the process. In certain instances, the surgical instrument can be a surgical tool mounted to a robotic arm of a robotic surgical system.

[0332] Eleventh step 5222, the segmentectomy portion of the procedure is performed. The surgical hub 106, 206 can infer that the surgeon is transecting the parenchyma based on data from the surgical stapling and cutting instrument, including data from its cartridge. The cartridge data can correspond to the size or type of staple being fired by the instrument, for example. As different types of staples are utilized for different types of tissues, the cartridge data can thus indicate the type of tissue being stapled and/or transected. In this case, the type of staple being fired is utilized for parenchyma (or other similar tissue types), which allows the surgical hub 106, 206 to infer that the segmentectomy portion of the procedure is being performed.

[0333] Twelfth step 5224, the node dissection step is then performed. The surgical hub 106, 206 can infer that the surgical team is dissecting the node and performing a leak test based on data received from the generator indicating that an RF or ultrasonic instrument is being fired. For this particular procedure, an RF or ultrasonic instrument being utilized after parenchyma was transected corresponds to the node dissection step, which allows the surgical hub 106, 206 to make this inference. It should be noted that surgeons regularly switch back and forth between surgical stapling/cutting instruments and surgical energy (i.e., RF or ultrasonic) instruments depending upon the particular step in the procedure because different instruments are better adapted for particular tasks. Therefore, the particular sequence in which the stapling/cutting instruments and surgical energy instruments are used can indicate what step of the procedure the surgeon is performing. Moreover, in certain instances, robotic tools can be utilized for one or more steps in a surgical procedure and/or handheld surgical instruments can be utilized for one or more steps in the surgical procedure. The surgeon(s) can alternate between robotic tools and handheld surgical instruments and/or can use the devices concurrently, for example. Upon completion of the twelfth step 5224, the incisions are closed up and the post-operative portion of the procedure begins.

[0334] Thirteenth step 5226, the patient's anesthesia is reversed. The surgical hub 106, 206 can infer that the patient is emerging from the anesthesia based on the ventilator data (i.e., the patient's breathing rate begins increasing), for example.

[0335] Lastly, the fourteenth step 5228 is that the medical personnel remove the various patient monitoring devices from the patient. The surgical hub 106, 206 can thus infer that the patient is being transferred to a recovery room when the hub loses EKG, blood pressure, and other data from the patient monitoring devices. As can be seen from the description of this illustrative procedure, the surgical hub 106, 206 can determine or infer when each step of a given surgical procedure is taking place according to data received from the various data sources that are communicably coupled to the surgical hub 106, 206.

[0336] Situational awareness is further described in U.S. Provisional Patent Application Serial No. 62/611,341, titled INTERACTIVE SURGICAL PLATFORM, filed December 28, 2017, which is incorporated by reference herein in its entirety. In certain instances, operation of a robotic surgical system, including the various robotic surgical systems disclosed herein, for example, can be controlled by the hub 106, 206 based on its situational awareness and/or feedback from the components thereof and/or based on information from the cloud 104.

EXAMPLES

[0337] Various aspects of the subject matter described herein are set out in the following numbered examples.

[0338] Example 1 - A surgical instrument is disclosed. The surgical instrument comprises an end effector and a control circuit. The end effector comprises a first jaw, a second jaw movable relative to the first jaw to grasp tissue therebetween, an anvil, a staple cartridge comprising staples deployable into the tissue, wherein the staples are deformable by the anvil, and a sensor configured to provide a sensor signal according to a physiological parameter of the tissue. The control circuit is coupled to the sensor, wherein the control circuit is configured to receive the sensor signal, and assess proximity of the sensory to cancerous tissue based on the sensor signal.

[0339] Example 2 - The surgical instrument of Example 1, wherein the control circuit is further configured to generate an alert in the event the proximity of the sensor to cancerous tissue reaches or crosses a predetermined threshold.

[0340] Example 3 - The surgical instrument of any one of Examples 1 and 2, wherein the control circuit is further configured to prevent deployment of the staples in the event the proximity of the sensor to cancerous tissue reaches or crosses a predetermined threshold.

[0341] Example 4 - The surgical instrument of any one of Examples 1-3, further comprising a motor configured to cause deployment of the staples, wherein the control circuit is further configured to prevent activation of the motor in the event the value of the physiological parameter reaches or crosses a predetermined threshold.

[0342] Example 5 - The surgical instrument of any one of Examples 1-4, wherein the physiological parameter is tissue glucose level.

[0343] Example 6 - The surgical instrument of any one of Examples 1-4, wherein the physiological parameter is tissue pH level.

[0344] Example 7 - The surgical instrument of any one of Examples 1-6, wherein the sensor is a Clark-type sensor.

[0345] Example 8 - The surgical instrument of any one of Examples 1-7, wherein the control circuit is further configured to provide instructions to move the end effector in a predetermined direction away from the cancerous tissue.

[0346] Example 9 - A surgical stapling instrument is disclosed. The surgical stapling instrument comprises an end effector and a control circuit. The end effector comprises a first jaw, a second jaw movable relative to the first jaw to grasp tissue therebetween, an anvil, a staple cartridge comprising staples deployable into the tissue, wherein the staples are deformable by the anvil, and a sensor configured to provide a sensory signal according to a physiological parameter indicative of proximity of the sensor to cancerous tissue. The control circuit is coupled to the sensor, wherein the control circuit is configured to receive the sensor signal, determine a value of the physiological parameter based on the sensor signal, and compare the value of the physiological parameter to a predetermined threshold.

[0347] Example 10 - The surgical stapling instrument of Example 9, wherein the control circuit is further configured to generate an alert based on comparing the value of the physiological parameter to a predetermined threshold.

[0348] Example 11 - The surgical stapling instrument of any one of Examples 9 and 10, wherein the control circuit is further configured to prevent deployment of the staples in the event the value of the physiological parameter reaches or crosses the predetermined threshold.

[0349] Example 12 - The surgical stapling instrument of any one of Examples 9-11, further comprising a motor configured to cause deployment of the staples, wherein the control circuit is further configured to prevent activation of the motor in the event the value of the physiological parameter reaches or crosses the predetermined threshold.

[0350] Example 13 - The surgical stapling instrument of any one of Examples 9-12, wherein the physiological parameter is tissue glucose level.

[0351] Example 14 - The surgical stapling instrument of any one of Examples 9-12, wherein the physiological parameter is tissue pH level.

[0352] Example 15 - The surgical stapling instrument of any one of Examples 9-14, wherein the sensor is a Clark-type sensor.

[0353] Example 16 - The surgical stapling instrument of any one of Examples 9-15, wherein the control circuit is further configured to provide instructions to move the end effector in a predetermined direction away from the cancerous tissue.

[0354] Example 17 - A surgical instrument is disclosed. The surgical instrument comprises an end effector and a control circuit. The end effector comprises a first jaw, a second jaw movable relative to the first jaw to grasp tissue therebetween, an anvil, a staple cartridge comprising staples deployable into the tissue, wherein the staples are deformable by the anvil, and a sensor assembly configured to provide sensor signals according to a physiological parameter indicative of proximity of the sensors to cancerous tissue. The sensor assembly comprises a first sensor on a first side of a longitudinal axis extending through the staple cartridge and a second sensor on a second side of the longitudinal axis. The control circuit is coupled to the sensor assembly, wherein the control circuit is configured to receive a first sensor signal from the first sensor, receive a second sensor signal from the second sensor, determine a first value of the physiological parameter based on the first sensor signal, determine a second value of the physiological parameter based on the second sensor signal, and compare the first value and the second value to a predetermined threshold.

[0355] Example 18 - The surgical instrument of Example 17, wherein the control circuit is further configured to provide instructions to move the end effector in a first direction in the event the first value but not the second value reaches or crosses the predetermined threshold, and wherein the first direction extends away from the longitudinal axis on the first side.

[0356] Example 19 - The surgical instrument of Example 18, wherein the control circuit is further configured to provide instructions to move the end effector in a second direction in the event the second value but not the first value reaches or crosses the predetermined threshold, and wherein the second directions extends away from the longitudinal axis on the second side.

[0357] Example 20 - The surgical instrument of Example 19, wherein the control circuit is further configured to approve position of the end effector in the event the first value and the second value are below the predetermined threshold.

[0358] 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.

[0359] 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).

[0360] As used in any aspect herein, the term “control circuit” may refer to, for example, hardwired circuitry, programmable circuitry (e.g., a computer processor comprising 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.

[0361] 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.

[0362] 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.

[0363] 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.

[0364] 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.

[0365] 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.

[0366] 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.

[0367] 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.

[0368] 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.

[0369] 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."

[0370] 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.

[0371] 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.

[0372] 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.

[0373] In summary, numerous benefits have been described which that 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.

CLAIMS

WHAT IS CLAIMED IS:

1. A surgical instrument, comprising:

an end effector, comprising:

a first jaw;

a second jaw movable relative to the first jaw to grasp tissue therebetween;

an anvil;

a staple cartridge comprising staples deployable into the tissue, wherein the staples are deformable by the anvil; and

a sensor configured to provide a sensor signal according to a physiological parameter of the tissue;

a control circuit coupled to the sensor, wherein the control circuit is configured to:

receive the sensor signal; and

assess proximity of the sensor to cancerous tissue based on the sensor signal.

2. The surgical instrument of Claim 1, wherein the control circuit is further configured to generate an alert in the event the proximity of the sensor to cancerous tissue reaches or crosses a predetermined threshold.

3. The surgical instrument of Claim 1, wherein the control circuit is further configured to prevent deployment of the staples in the event the proximity of the sensor to cancerous tissue reaches or crosses a predetermined threshold.

4. The surgical instrument of Claim 1, further comprising a motor configured to cause deployment of the staples, wherein the control circuit is further configured to prevent activation of the motor in the event the value of the physiological parameter reaches or crosses a predetermined threshold.

5. The surgical instrument of Claim 1, wherein the physiological parameter is tissue glucose level.

6. The surgical instrument of Claim 1, wherein the physiological parameter is tissue pH level.

7. The surgical instrument of Claim 1, wherein the sensor is a Clark-type sensor.

8. The surgical instrument of Claim 1, wherein the control circuit is further configured to provide instructions to move the end effector in a predetermined direction away from the cancerous tissue.

9. A surgical stapling instrument, comprising:

an end effector, comprising:

a first jaw;

a second jaw movable relative to the first jaw to grasp tissue therebetween;

an anvil;

a staple cartridge comprising staples deployable into the tissue, wherein the staples are deformable by the anvil; and

a sensor configured to provide a sensor signal according to a physiological parameter indicative of proximity of the sensor to cancerous tissue;

a control circuit coupled to the sensor, wherein the control circuit is configured to:

receive the sensor signal;

determine a value of the physiological parameter based on the sensor signal; and

compare the value of the physiological parameter to a predetermined threshold.

10. The surgical instrument of Claim 9, wherein the control circuit is further configured to generate an alert based on comparing the value of the physiological parameter to a predetermined threshold.

11. The surgical instrument of Claim 9, wherein the control circuit is further configured to prevent deployment of the staples in the event the value of the physiological parameter reaches or crosses the predetermined threshold.

12. The surgical instrument of Claim 9, further comprising a motor configured to cause deployment of the staples, wherein the control circuit is further configured to prevent activation of the motor in the event the value of the physiological parameter reaches or crosses the predetermined threshold.

13. The surgical instrument of Claim 9, wherein the physiological parameter is tissue glucose level.

14. The surgical instrument of Claim 9, wherein the physiological parameter is tissue pH level.

15. The surgical instrument of Claim 9, wherein the sensor is a Clark-type sensor.

16. The surgical instrument of Claim 9, wherein the control circuit is further configured to provide instructions to move the end effector in a predetermined direction away from the cancerous tissue.

17. A surgical instrument, comprising:

an end effector, comprising:

a first jaw;

a second jaw movable relative to the first jaw to grasp tissue therebetween;

an anvil;

a staple cartridge comprising staples deployable into the tissue, wherein the staples are deformable by the anvil; and

a sensor assembly configured to provide sensor signals according to a physiological parameter indicative of proximity of the sensors to cancerous tissue, wherein the sensor assembly comprises:

a first sensor on a first side of a longitudinal axis extending through the staple cartridge; and

a second sensor on a second side of the longitudinal axis;

a control circuit coupled to the sensor assembly, wherein the control circuit is configured to:

receive a first sensor signal from the first sensor;

receive a second sensor signal from the second sensor;

determine a first value of the physiological parameter based on the first sensor signal;

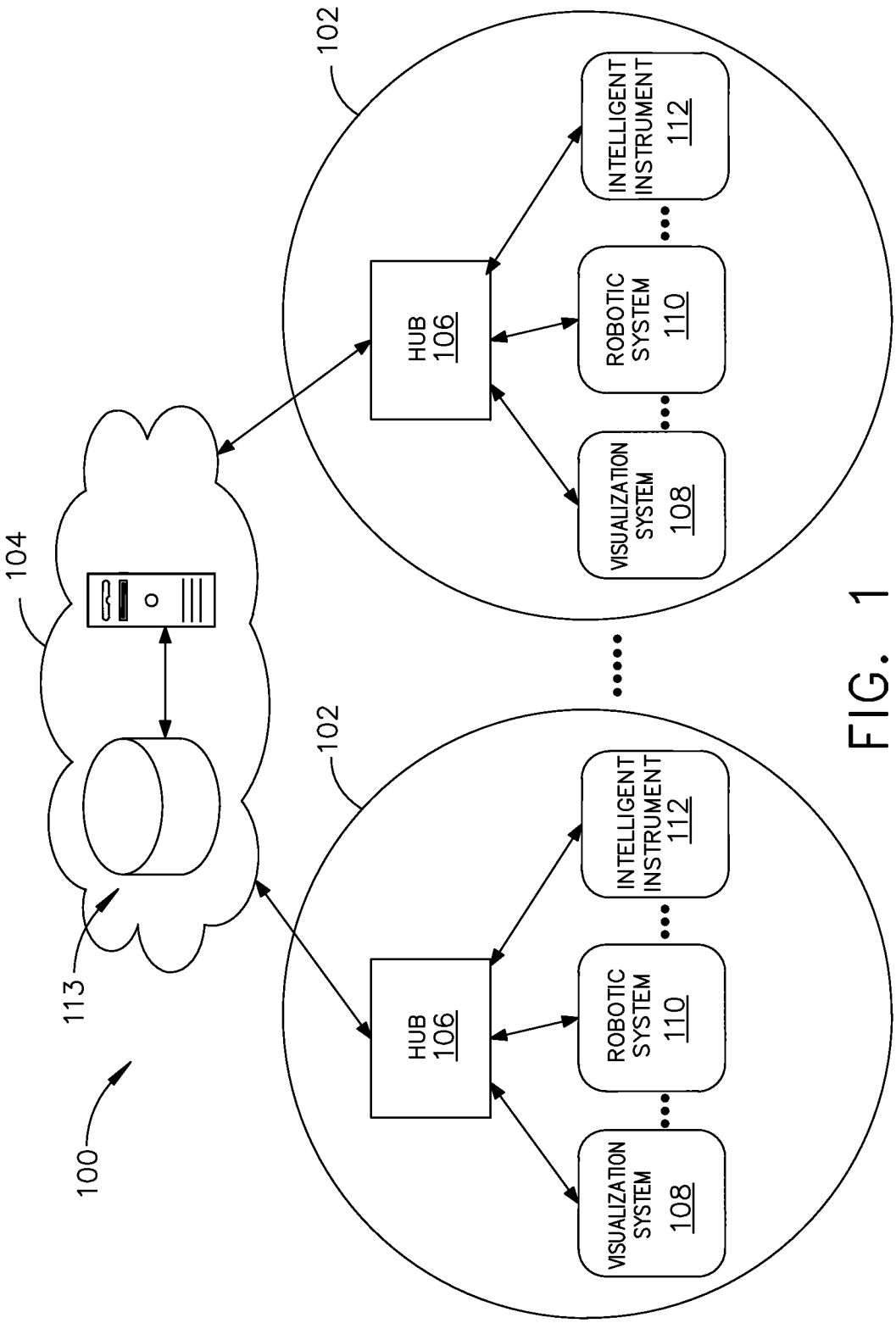
determine a second value of the physiological parameter based on the second sensor signal; and

compare the first value and the second value to a predetermined threshold.

18. The surgical instrument of Claim 17, wherein the control circuit is further configured to provide instructions to move the end effector in a first direction in the event the first value but not the second value reaches or crosses the predetermined threshold, and wherein the first direction extends away from the longitudinal axis on the first side.

19. The surgical instrument of Claim 18, wherein the control circuit is further configured to provide instructions to move the end effector in a second direction in the event the second value but not the first value reaches or crosses the predetermined threshold, and wherein the second direction extends away from the longitudinal axis on the second side.

20. The surgical instrument of Claim 19, wherein the control circuit is further configured to approve position of the end effector in the event the first value and the second value are below the predetermined threshold.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104
113
102
HUB 106
VISUALIZATION SYSTEM 108
ROBOTIC SYSTEM 110
INTELLIGENT INSTRUMENT 112
102
HUB 106
VISUALIZATION SYSTEM 108
ROBOTIC SYSTEM 110
INTELLIGENT INSTRUMENT 112

FIG. 1

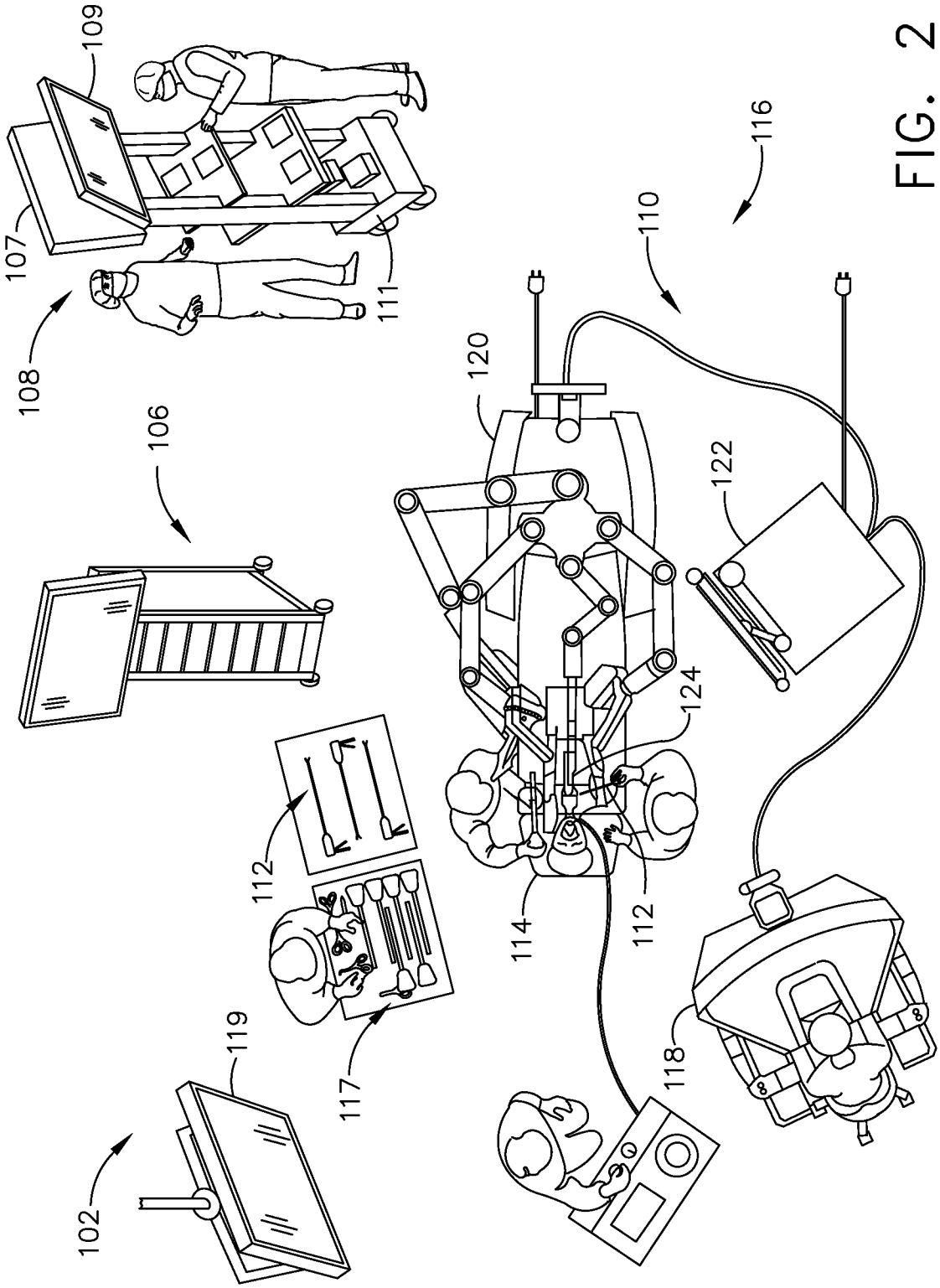
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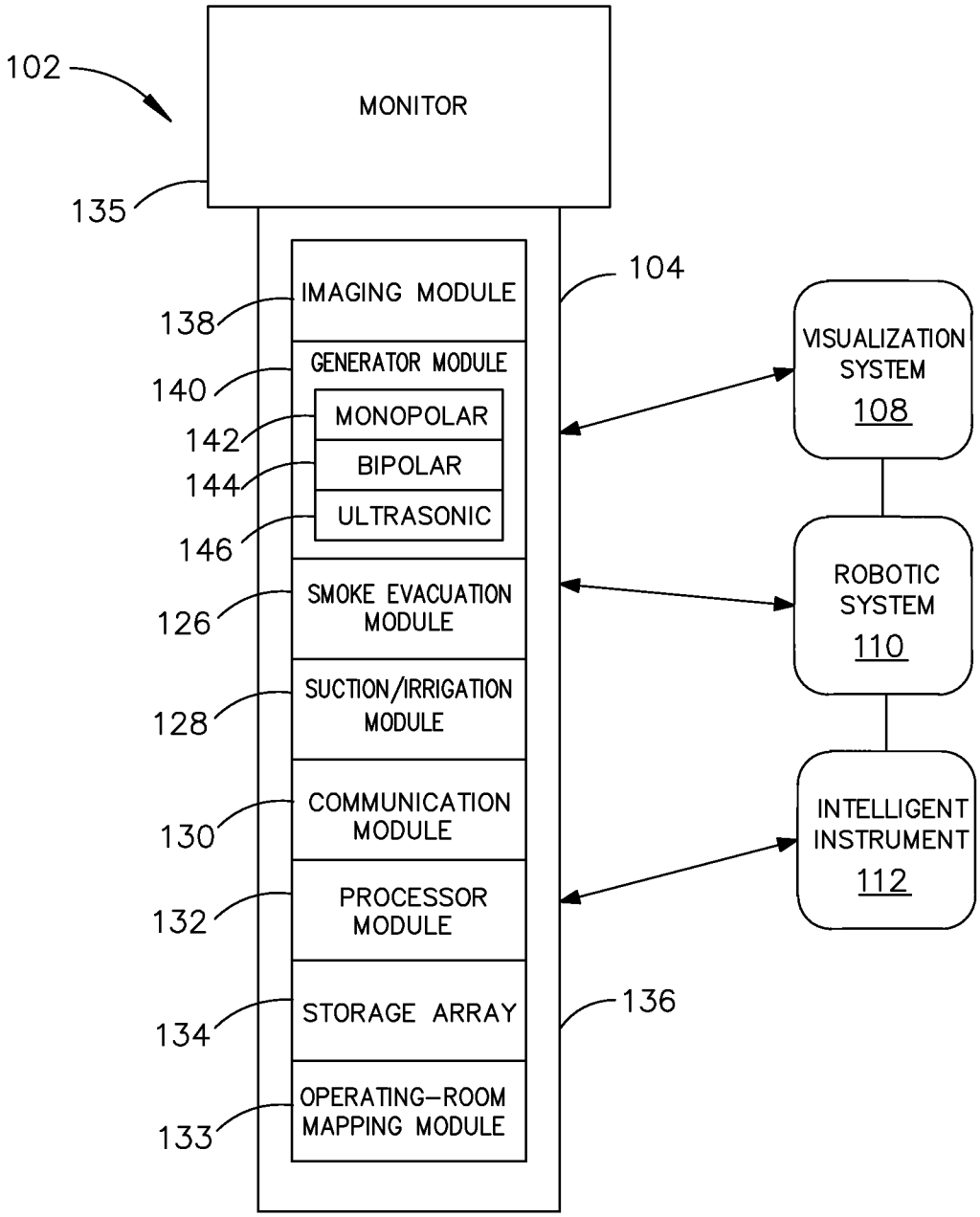
FIG. 2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IMAGING MODULE
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GENERATOR MODULE
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MONOPOLAR
142
BIPOLAR
144
ULTRASONIC
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SMOKE EVACUATION MODULE
126
SUCTION/IRRIGATION MODULE
128
COMMUNICATION MODULE
130
PROCESSOR MODULE
132
STORAGE ARRAY
134
136
OPERATING-ROOM MAPPING MODULE
133
VISUALIZATION SYSTEM
108
ROBOTIC SYSTEM
110
INTELLIGENT INSTRUMENT
112

FIG. 3

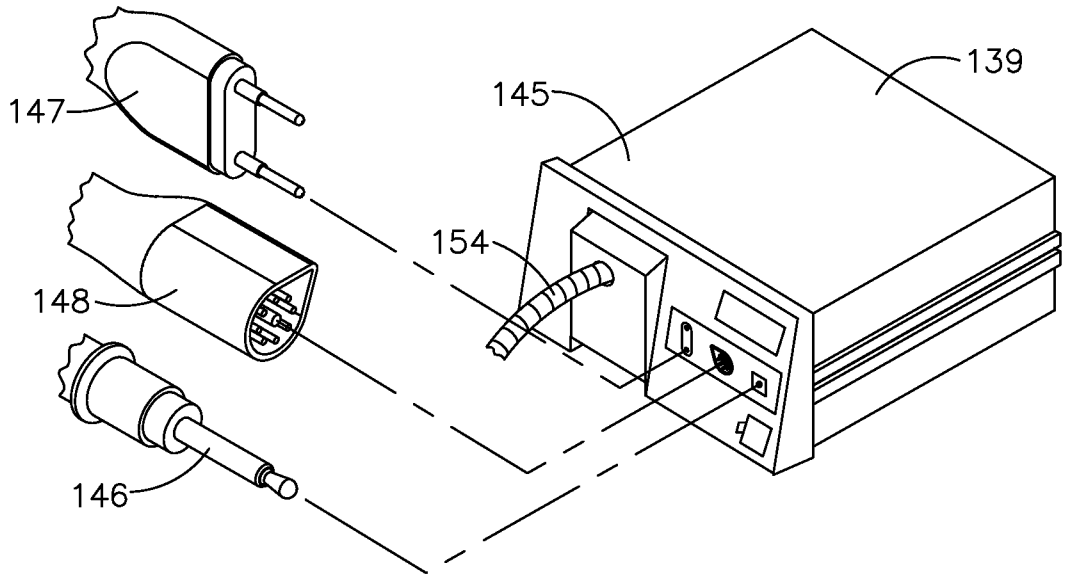
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FIG. 5

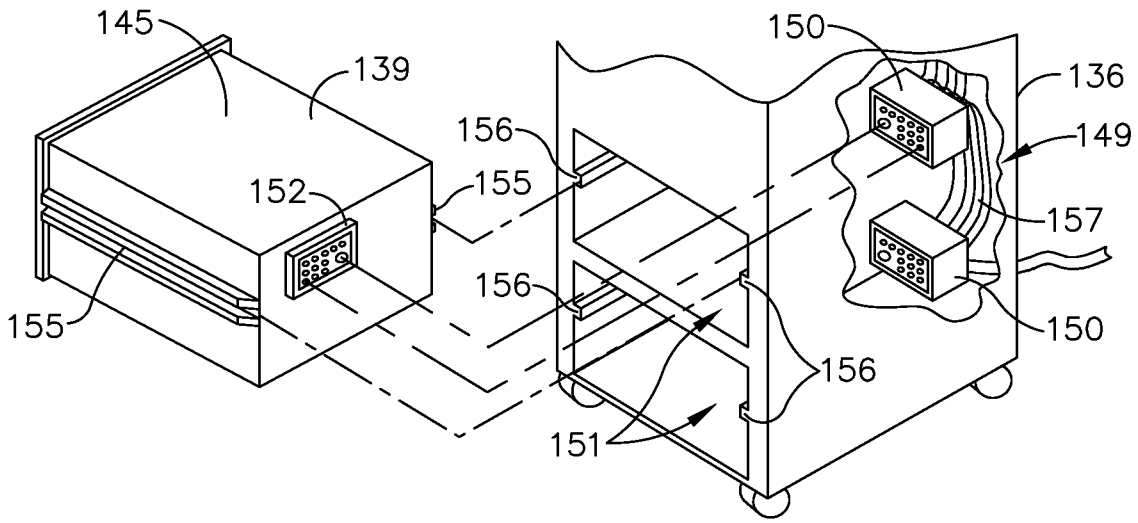
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FIG. 4

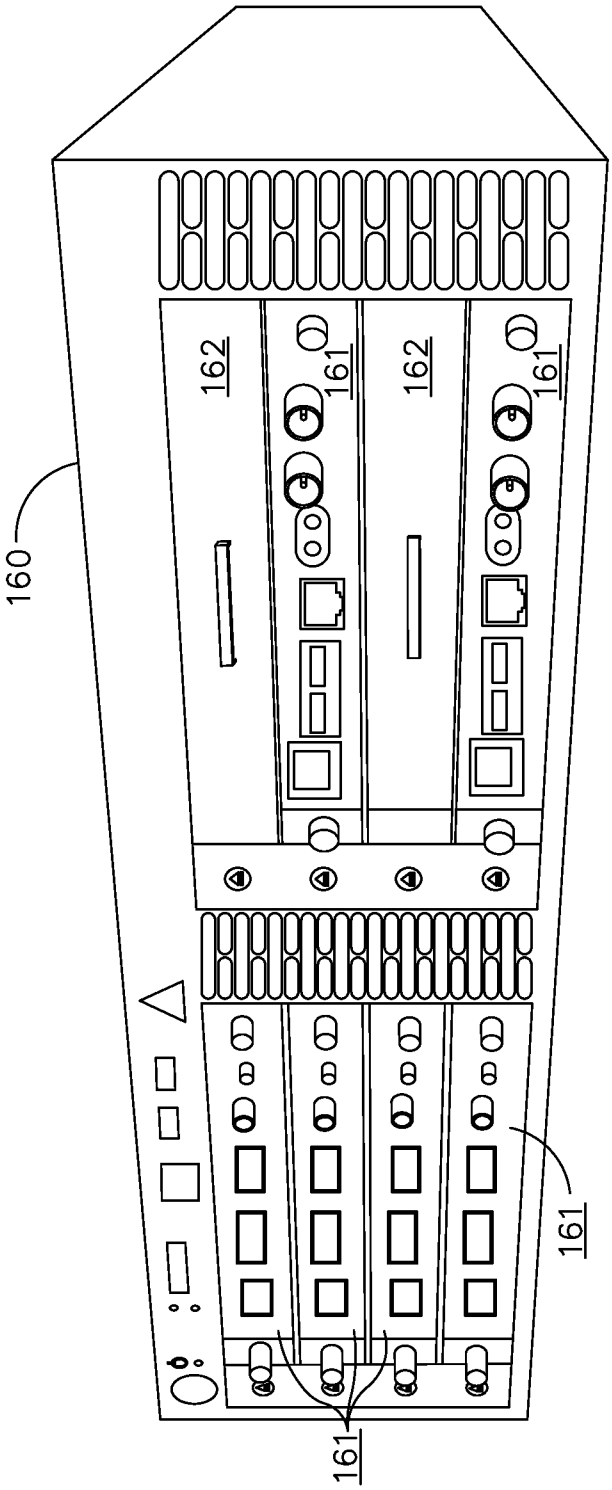


FIG. 6

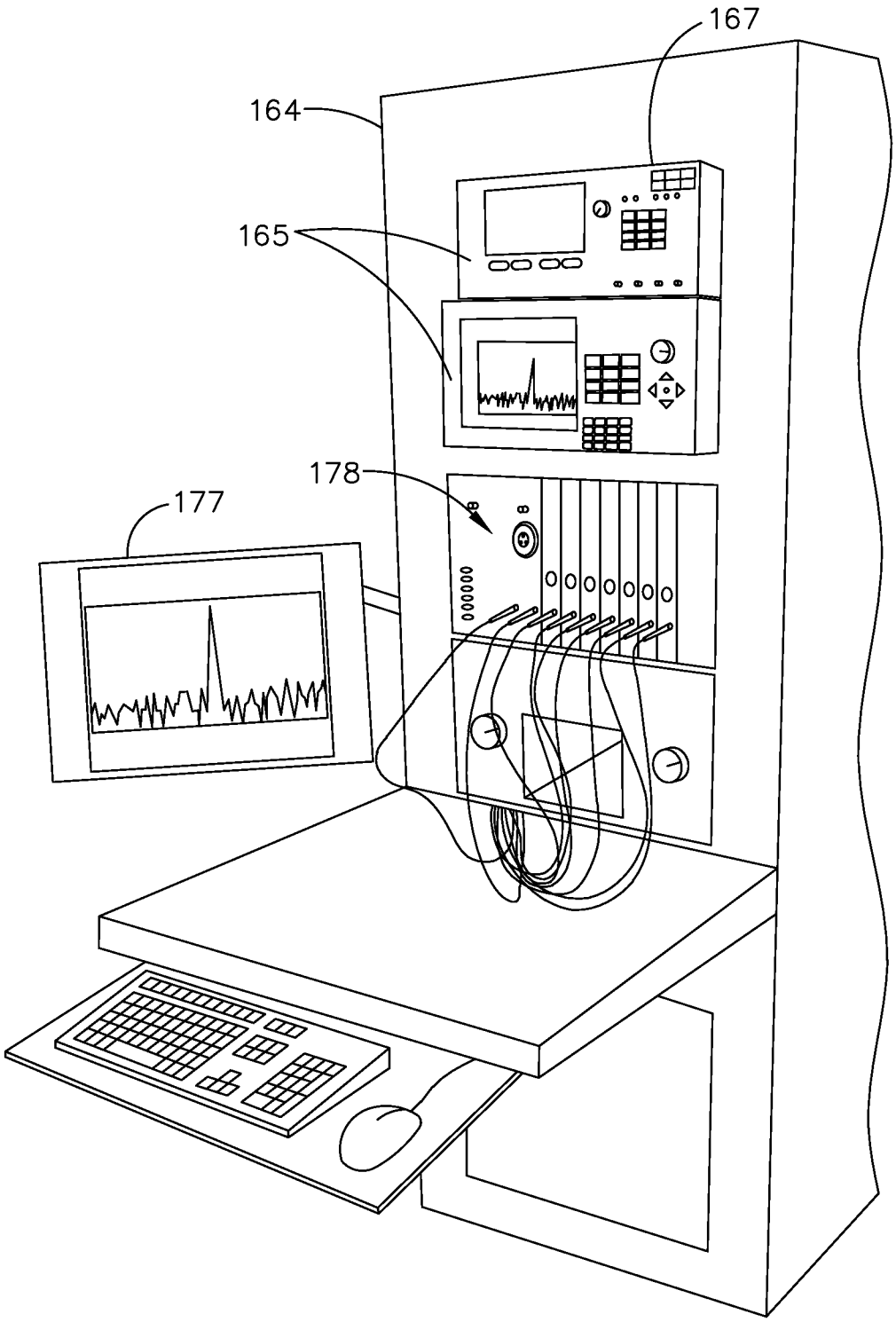
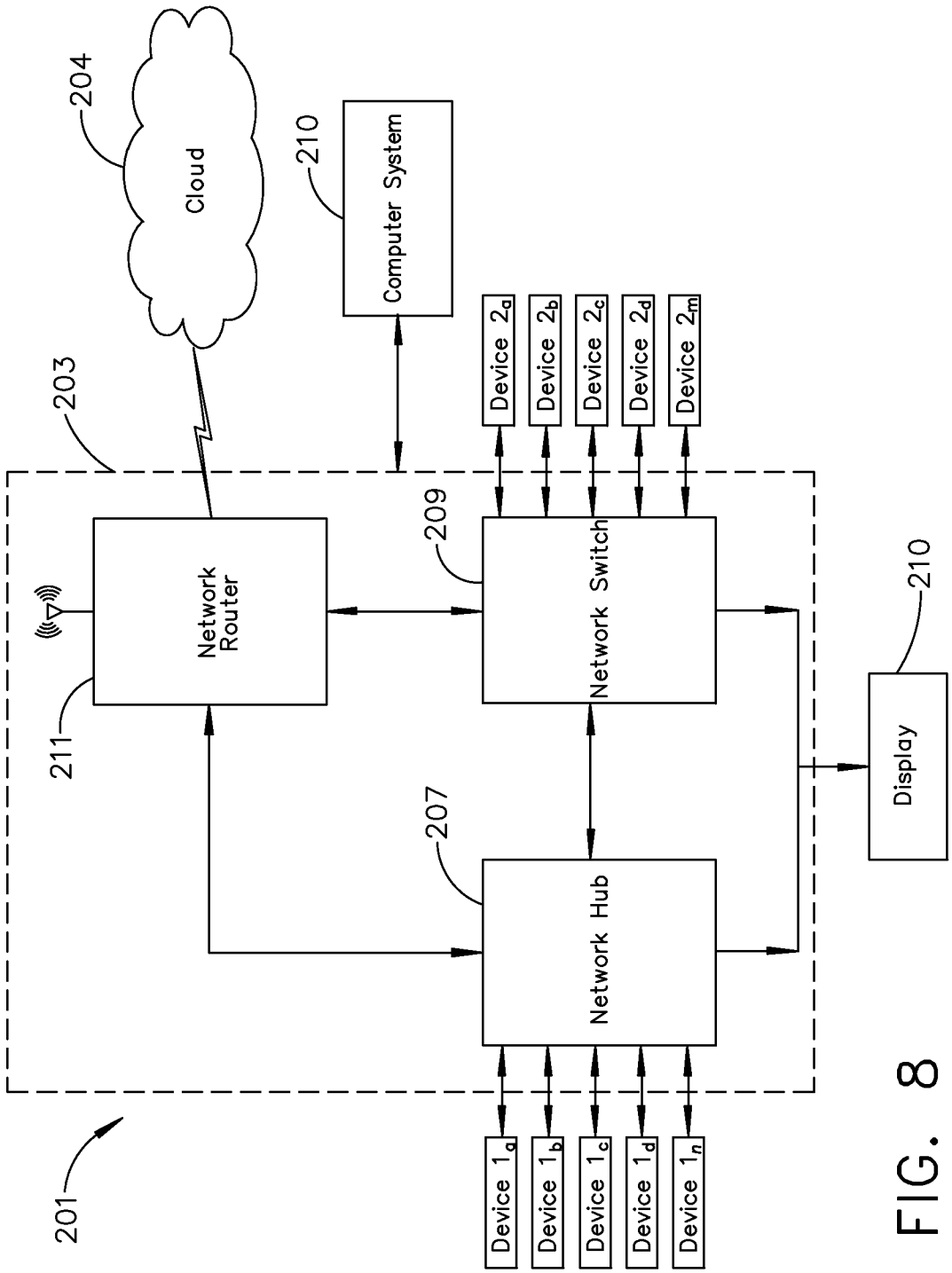


FIG. 7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Cloud
210
Computer System
Device 2a
Device 2b
Device 2c
Device 2d
Device 2m
203
209
Network Switch
Network Router
211
210
Display
207
Network Hub
201
Device 1a
Device 1b
Device 1c
Device 1d
Device 1n

FIG. 8

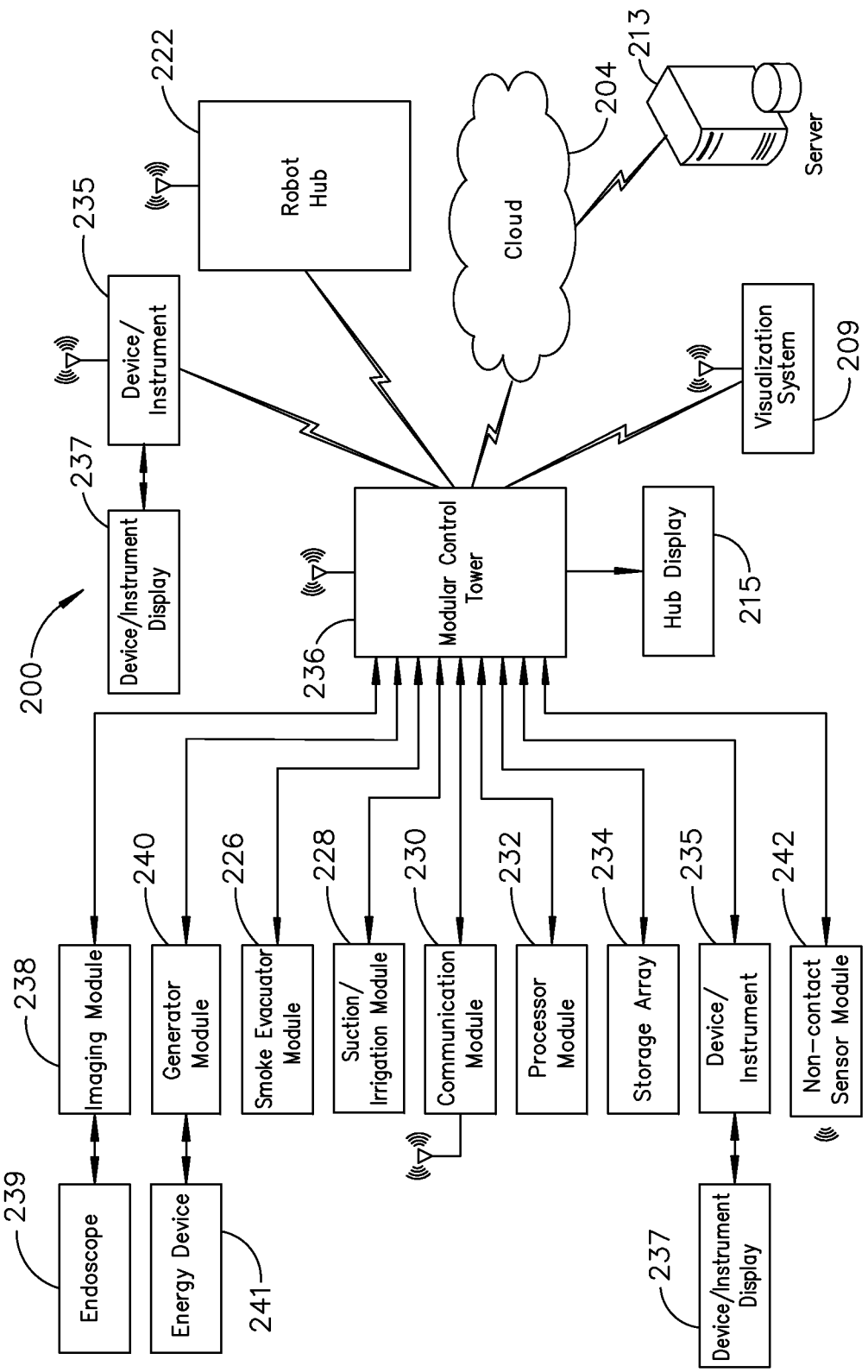
200
Device/Instrument Display
237
Device/ Instrument
235
Robot Hub
222
Cloud
204
Server
213
Visualization System
209
Modular Control Tower
236
Hub Display
215
Imaging Module
238
Generator Module
240
Smoke Evacuator Module
226
Suction/ Irrigation Module
228
Communication Module
230
Processor Module
232
Storage Array
234
Device/ Instrument
235
Non-contact Sensor Module
242
Endoscope
239
Energy Device
241
Device/Instrument Display
237

FIG. 9

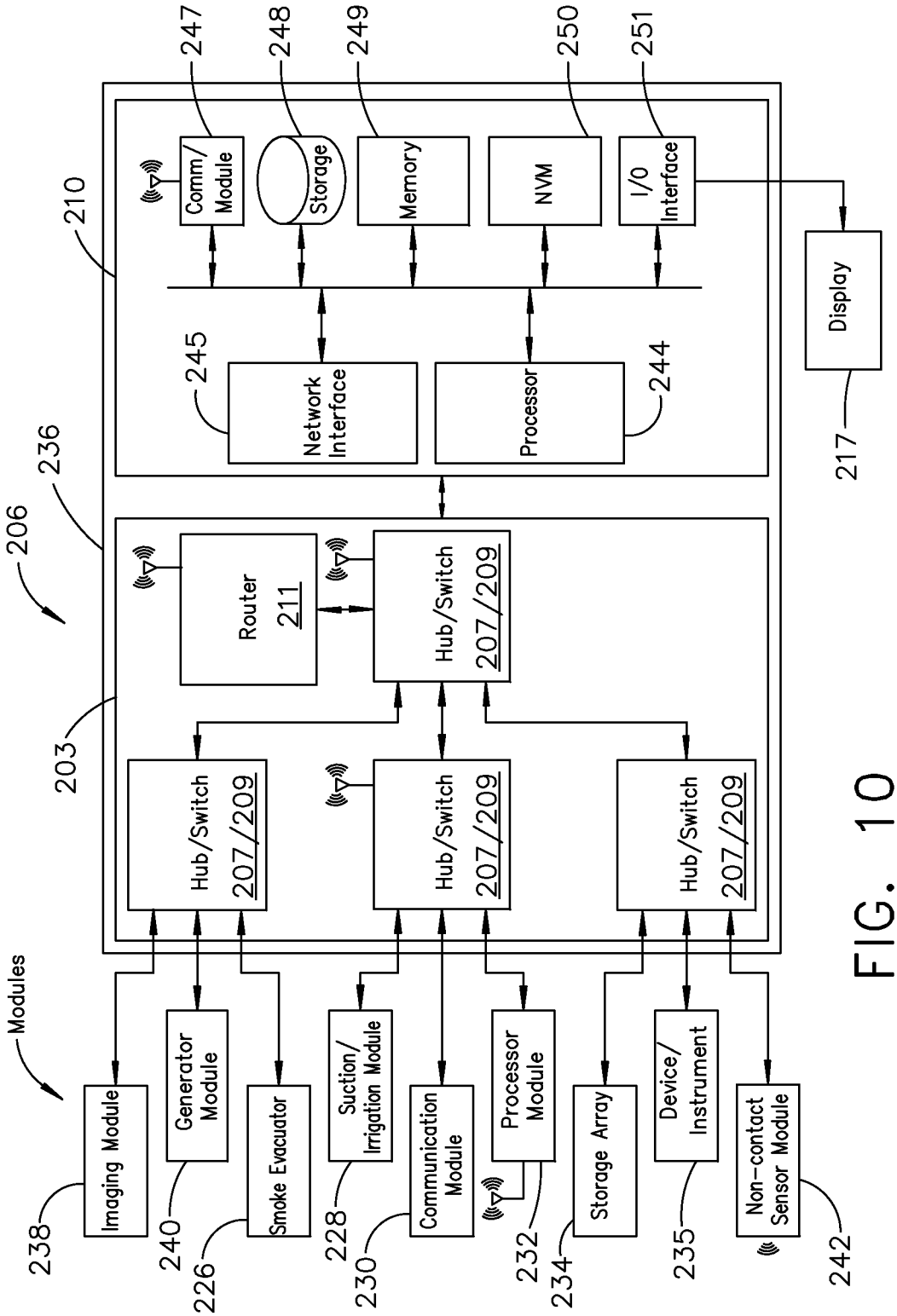
247
248
249
250
251
Comm/ Module
Storage
Memory
NVM
I/O Interface
210
Display
217
245
Network Interface
Processor
244
236
206
Router 211
Hub/Switch 207/209
203
Hub/Switch 207/209
Hub/Switch 207/209
Hub/Switch 207/209
Modules
Imaging Module
Generator Module
Smoke Evacuator
Suction/ Irrigation Module
Communication Module
Processor Module
Storage Array
Device/ Instrument
Non-contact Sensor Module
238
240
226
228
230
232
234
235
242

FIG. 10

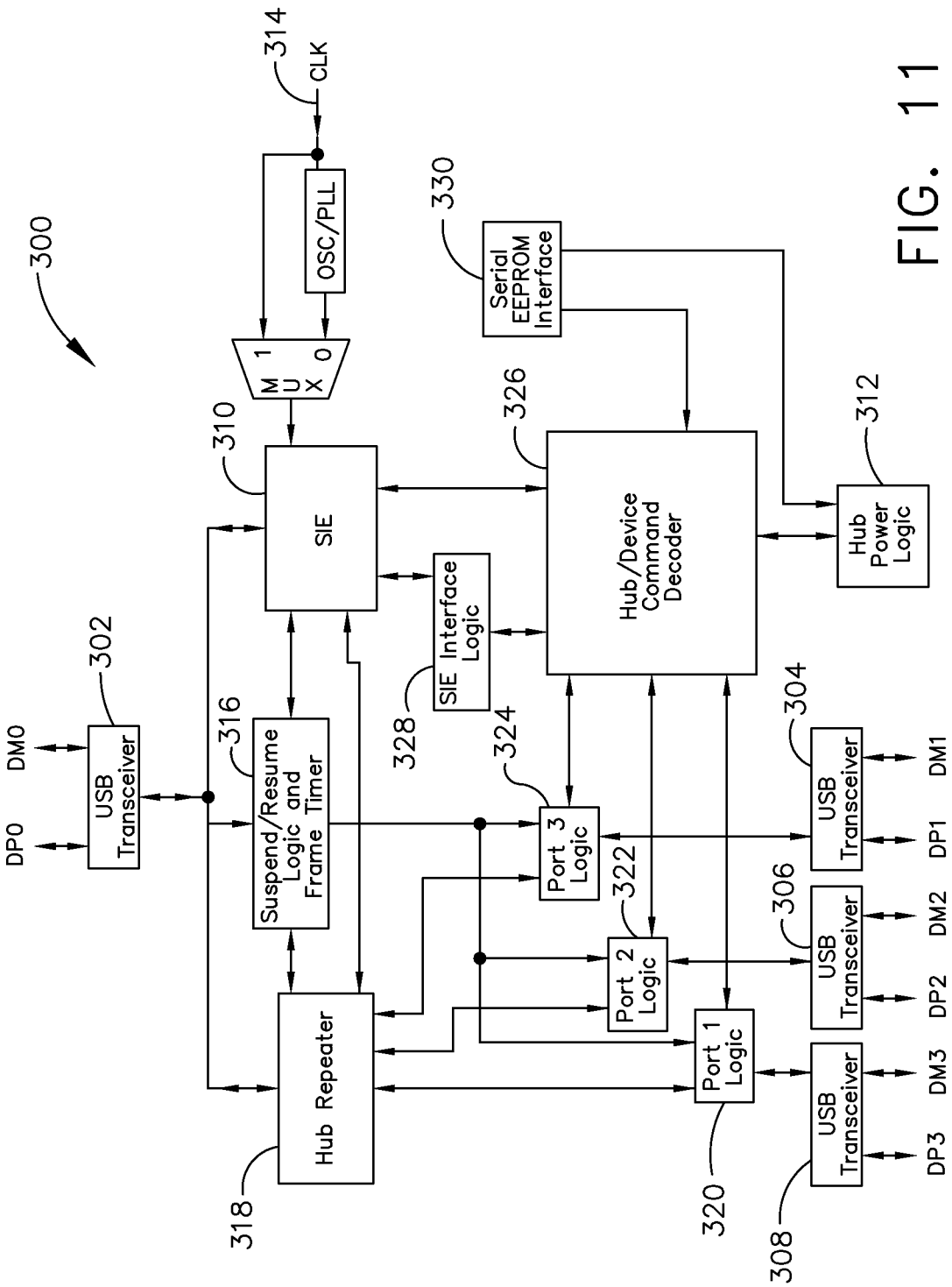
300
314
CLK
OSC/PLL
M
U
X
1
0
330
Serial EEPROM Interface
310
SIE
326
Hub/Device Command Decoder
312
Hub Power Logic
SIE Interface Logic
328
302
USB Transceiver
DM0
DP0
316
Suspend/Resume Logic and Frame Timer
324
Port 3 Logic
304
USB Transceiver
DM1
DP1
322
306
Port 2 Logic
USB Transceiver
DM2
DP2
Hub Repeater
318
Port 1 Logic
320
USB Transceiver
DM3
DP3
308

FIG. 11

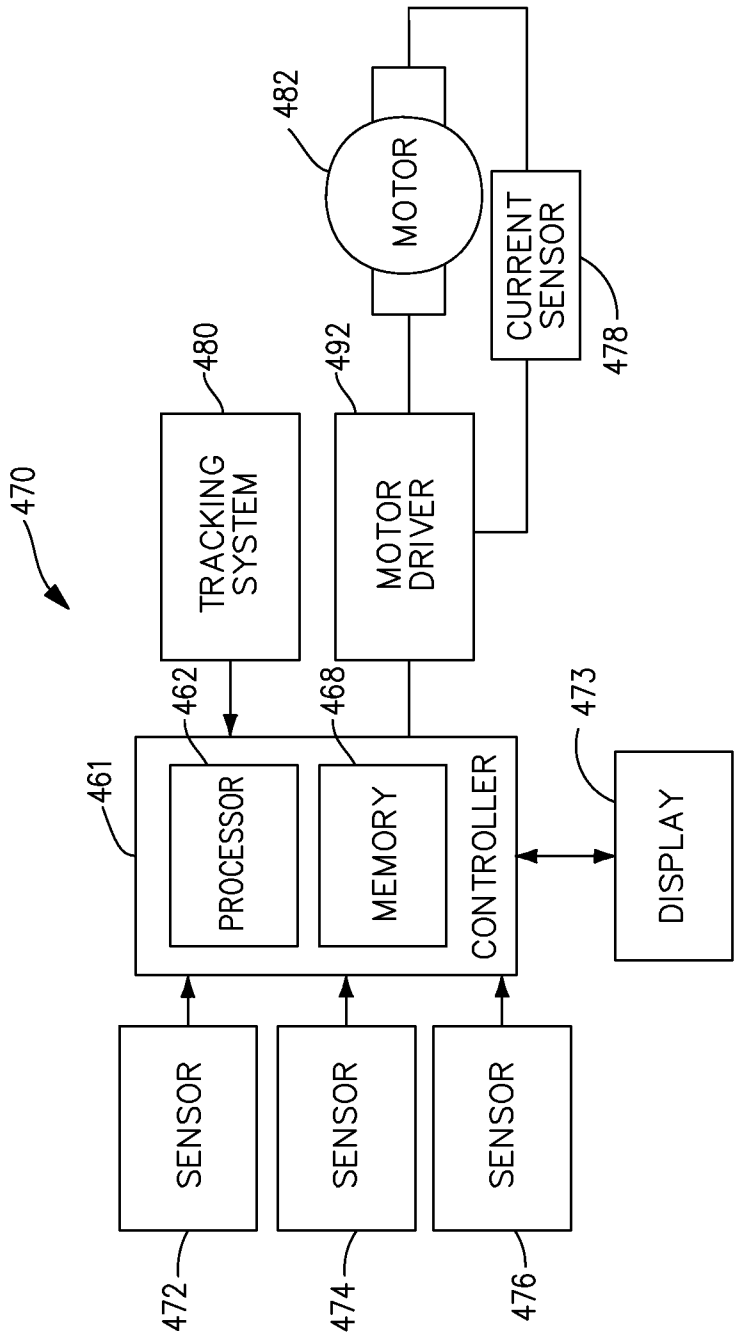
470
TRACKING SYSTEM
480
MOTOR DRIVER
492
MOTOR
482
CURRENT SENSOR
478
461
PROCESSOR
462
MEMORY
468
CONTROLLER
473
DISPLAY
SENSOR
472
SENSOR
474
SENSOR
476

FIG. 12

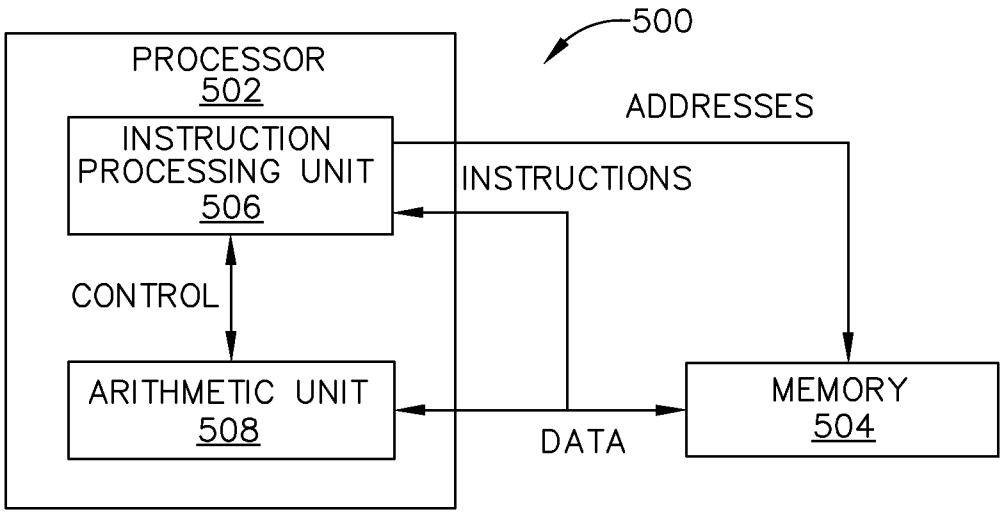

FIG. 13

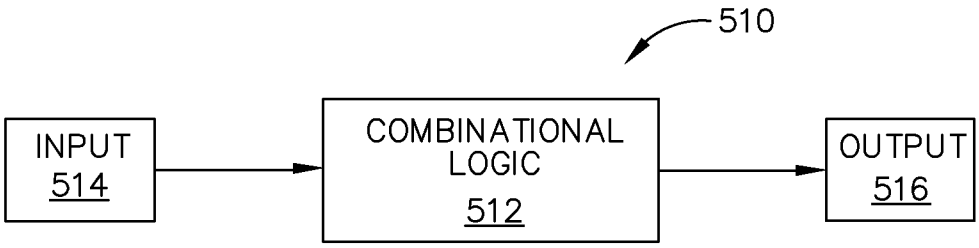

FIG. 14

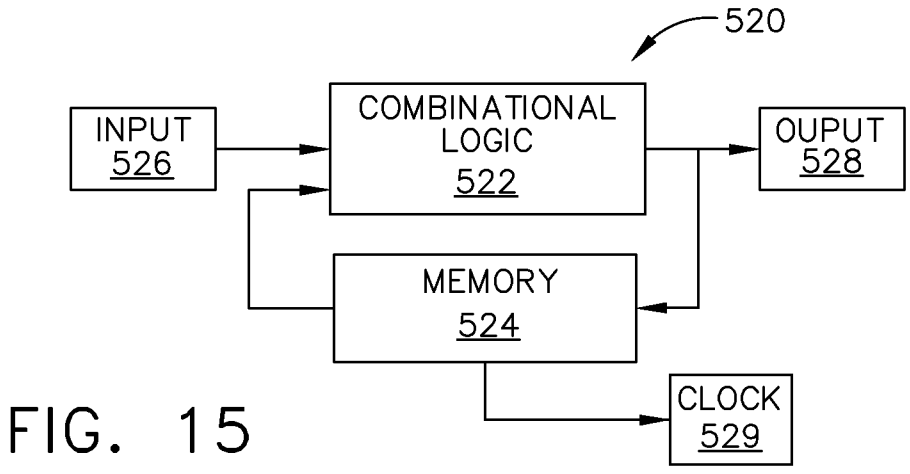

FIG. 15

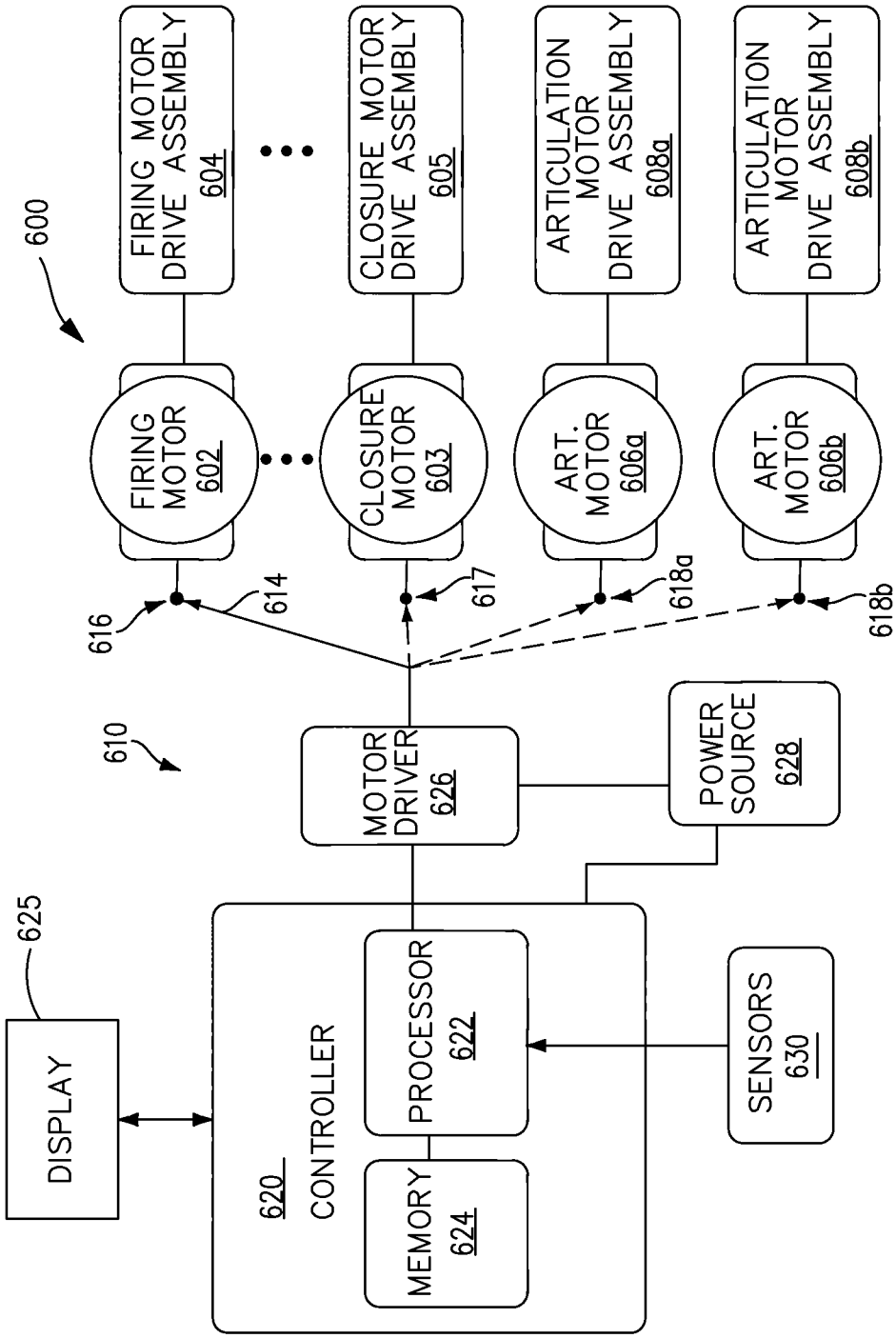
600
FIRING MOTOR DRIVE ASSEMBLY 604
CLOSURE MOTOR DRIVE ASSEMBLY 605
ARTICULATION MOTOR DRIVE ASSEMBLY 608a
ARTICULATION MOTOR DRIVE ASSEMBLY 608b
FIRING MOTOR 602
CLOSURE MOTOR 603
ART. MOTOR 606a
ART. MOTOR 606b
616
614
617
618a
618b
610
MOTOR DRIVER 626
POWER SOURCE 628
625
DISPLAY
620 CONTROLLER
PROCESSOR 622
MEMORY 624
SENSORS 630

FIG. 16

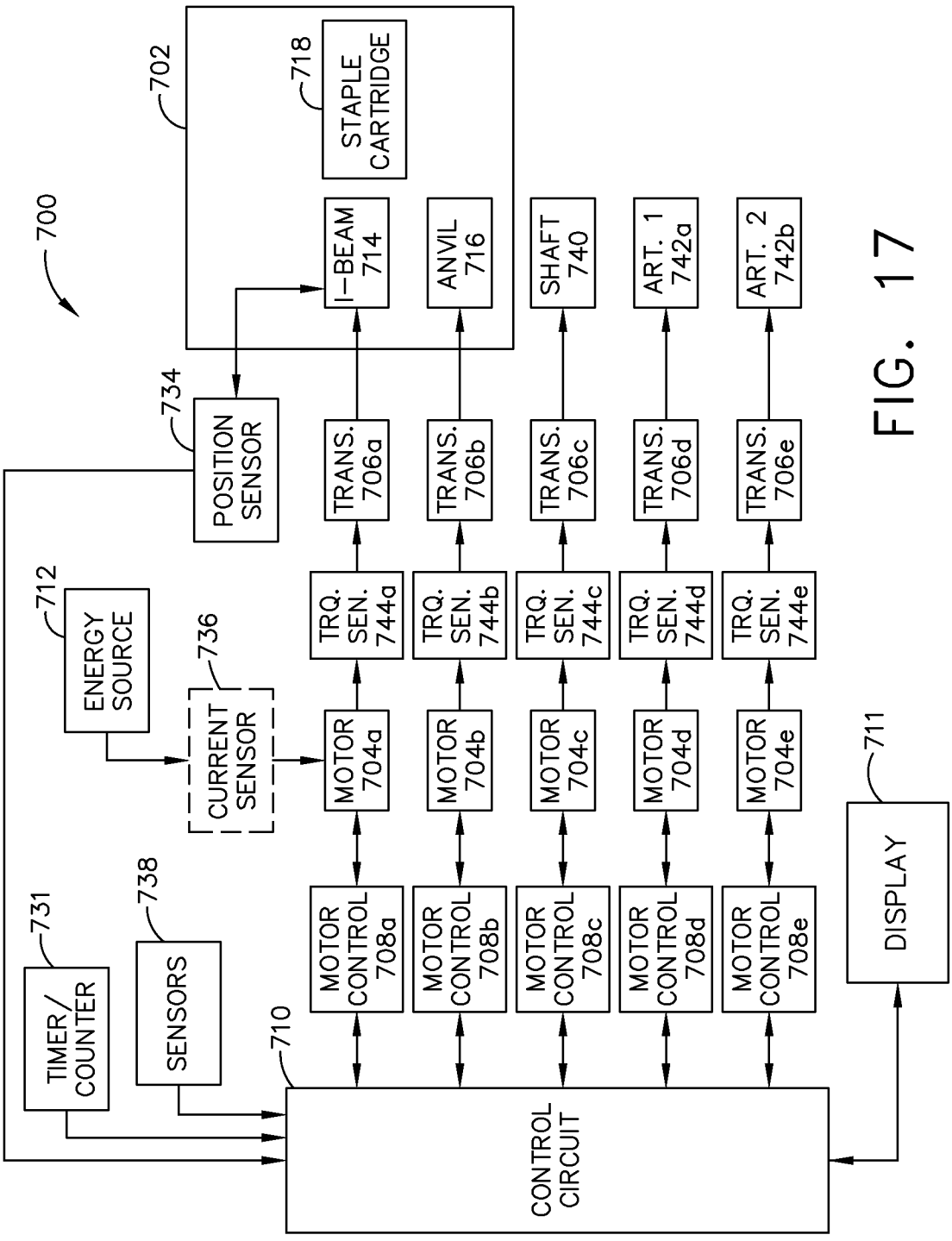
700
702
718
STAPLE CARTRIDGE
I-BEAM 714
ANVIL 716
SHAFT 740
ART. 1 742a
ART. 2 742b
734
POSITION SENSOR
TRANS. 706a
TRANS. 706b
TRANS. 706c
TRANS. 706d
TRANS. 706e
712
ENERGY SOURCE
736
CURRENT SENSOR
TRQ. SEN. 744a
TRQ. SEN. 744b
TRQ. SEN. 744c
TRQ. SEN. 744d
TRQ. SEN. 744e
MOTOR 704a
MOTOR 704b
MOTOR 704c
MOTOR 704d
MOTOR 704e
731
TIMER/ COUNTER
738
SENSORS
MOTOR CONTROL 708a
MOTOR CONTROL 708b
MOTOR CONTROL 708c
MOTOR CONTROL 708d
MOTOR CONTROL 708e
711
DISPLAY
710
CONTROL CIRCUIT

FIG. 17

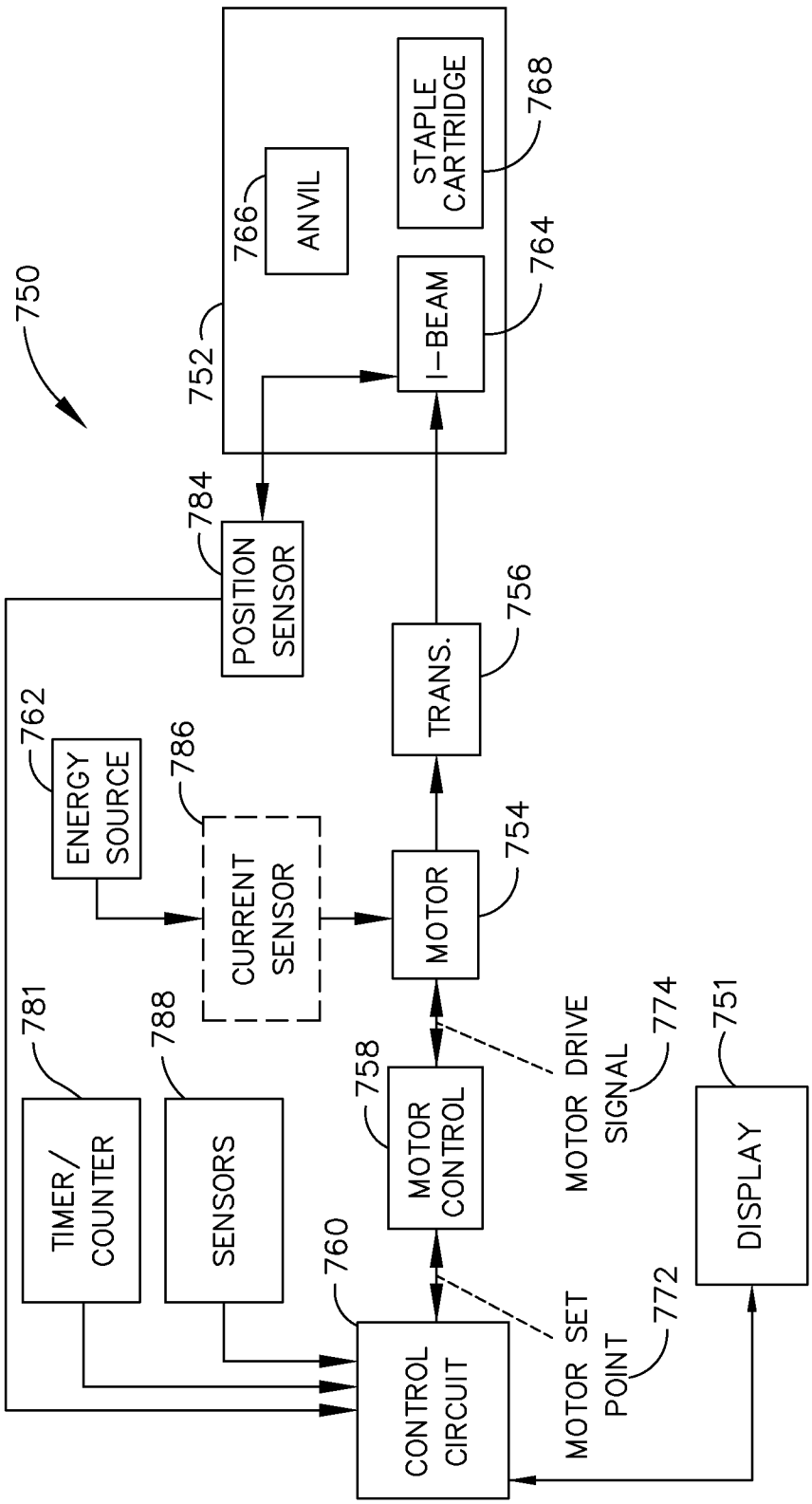
750
752
766
ANVIL
768
STAPLE CARTRIDGE
764
I-BEAM
784
POSITION SENSOR
762
ENERGY SOURCE
786
CURRENT SENSOR
756
TRANS.
754
MOTOR
781
TIMER/ COUNTER
788
SENSORS
758
MOTOR CONTROL
760
CONTROL CIRCUIT
MOTOR DRIVE SIGNAL
774
MOTOR SET POINT
772
751
DISPLAY

FIG. 18

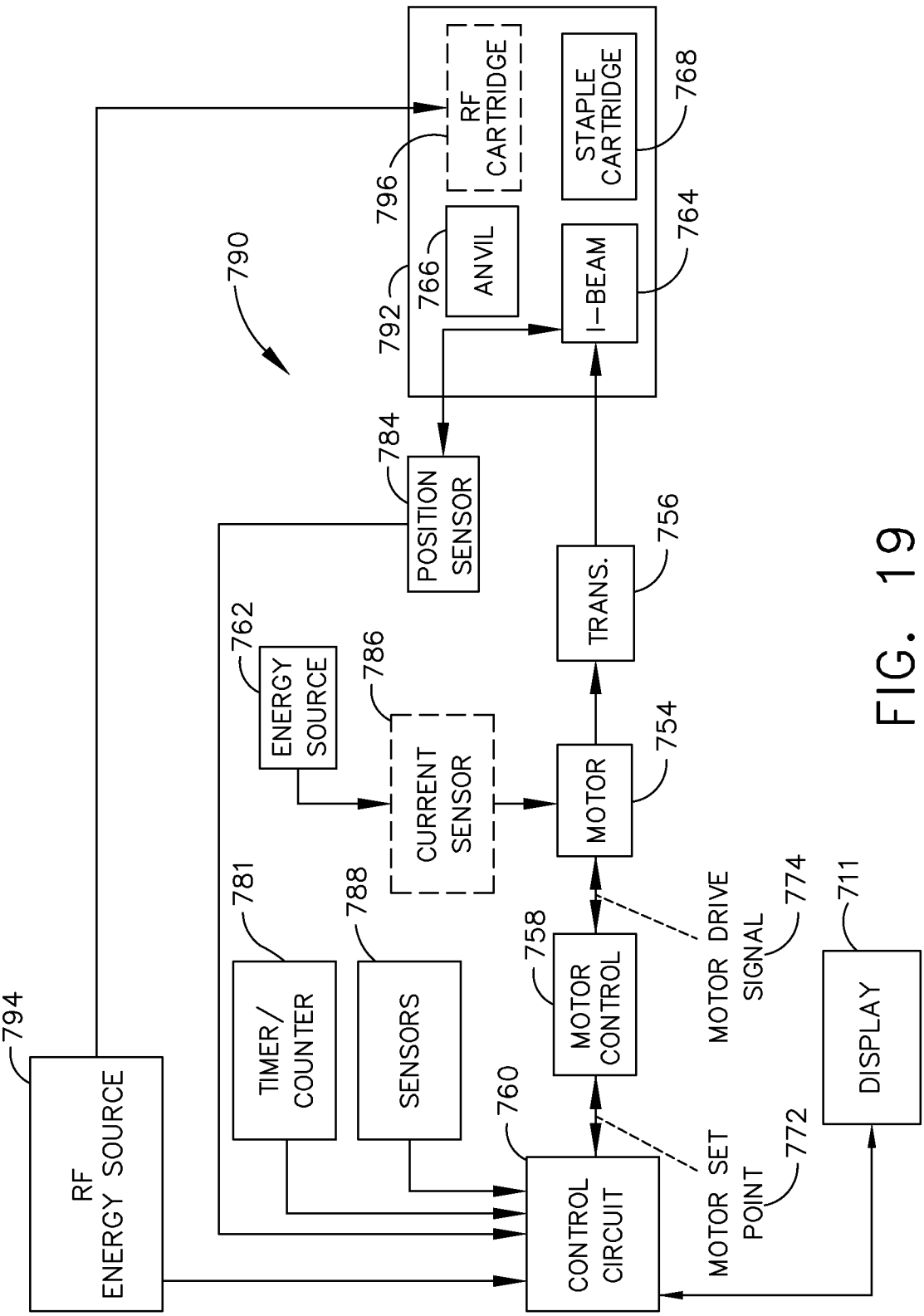
790
796
RF CARTRIDGE
STAPLE CARTRIDGE
768
792
766
ANVIL
I-BEAM
764
784
POSITION SENSOR
762
ENERGY SOURCE
786
CURRENT SENSOR
TRANS.
756
MOTOR
754
781
TIMER/ COUNTER
788
SENSORS
758
MOTOR CONTROL
MOTOR DRIVE SIGNAL
774
711
DISPLAY
794
RF ENERGY SOURCE
760
CONTROL CIRCUIT
MOTOR SET POINT
772

FIG. 19

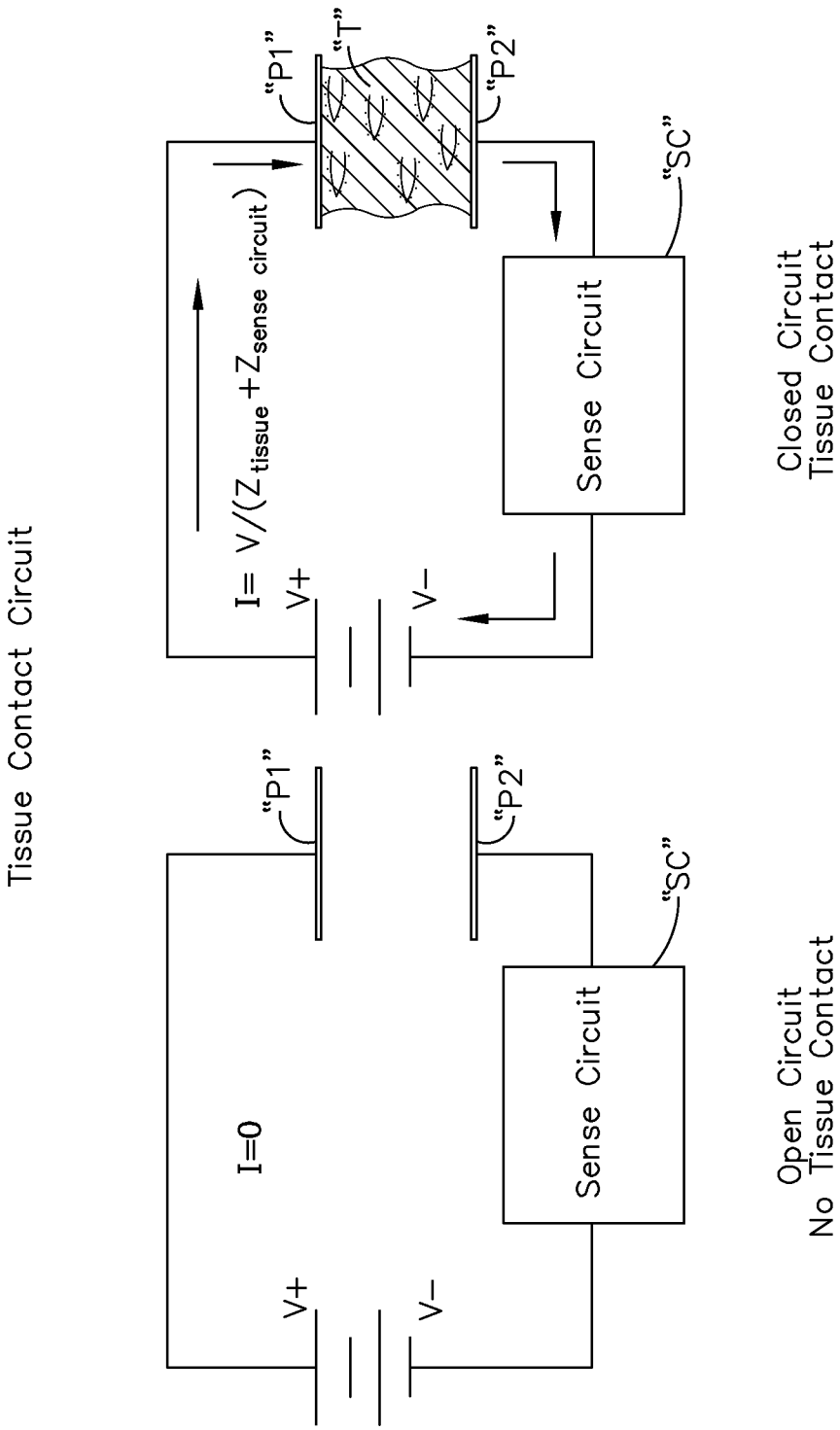
Tissue Contact Circuit
"P1"
"T"
"P2"
"SC"
I= V/(Z tissue +Z sense circuit)
V+
V–
Sense Circuit
Closed Circuit
Tissue Contact
"P1"
"P2"
"SC"
I=0
V+
V–
Sense Circuit
Open Circuit
No Tissue Contact

FIG. 20

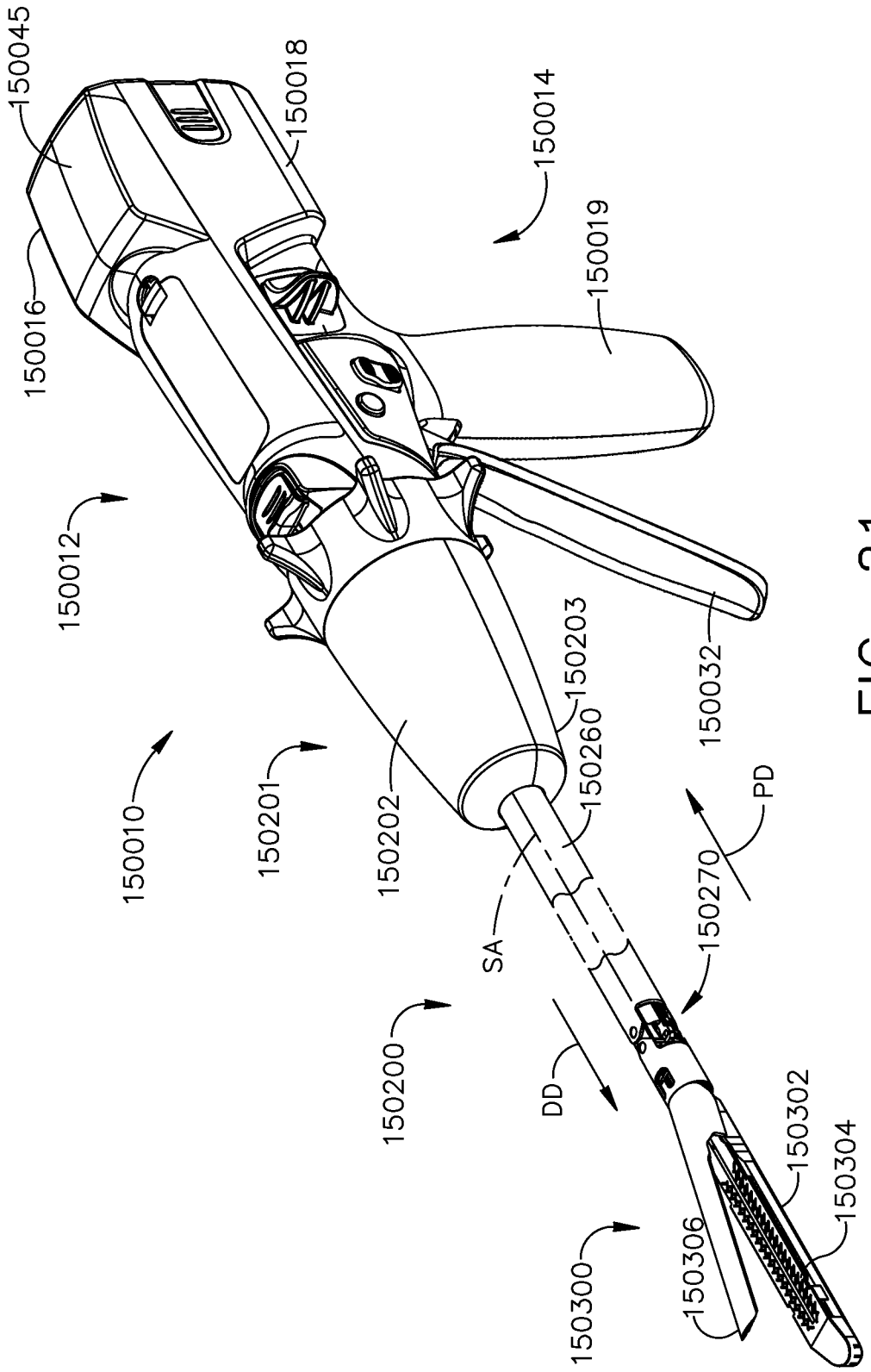
150045
150018
150014
150016
150019
150012
150032
150203
150260
150010
150201
150202
PD
150270
SA
150200
DD
150302
150304
150306
150300

FIG. 21

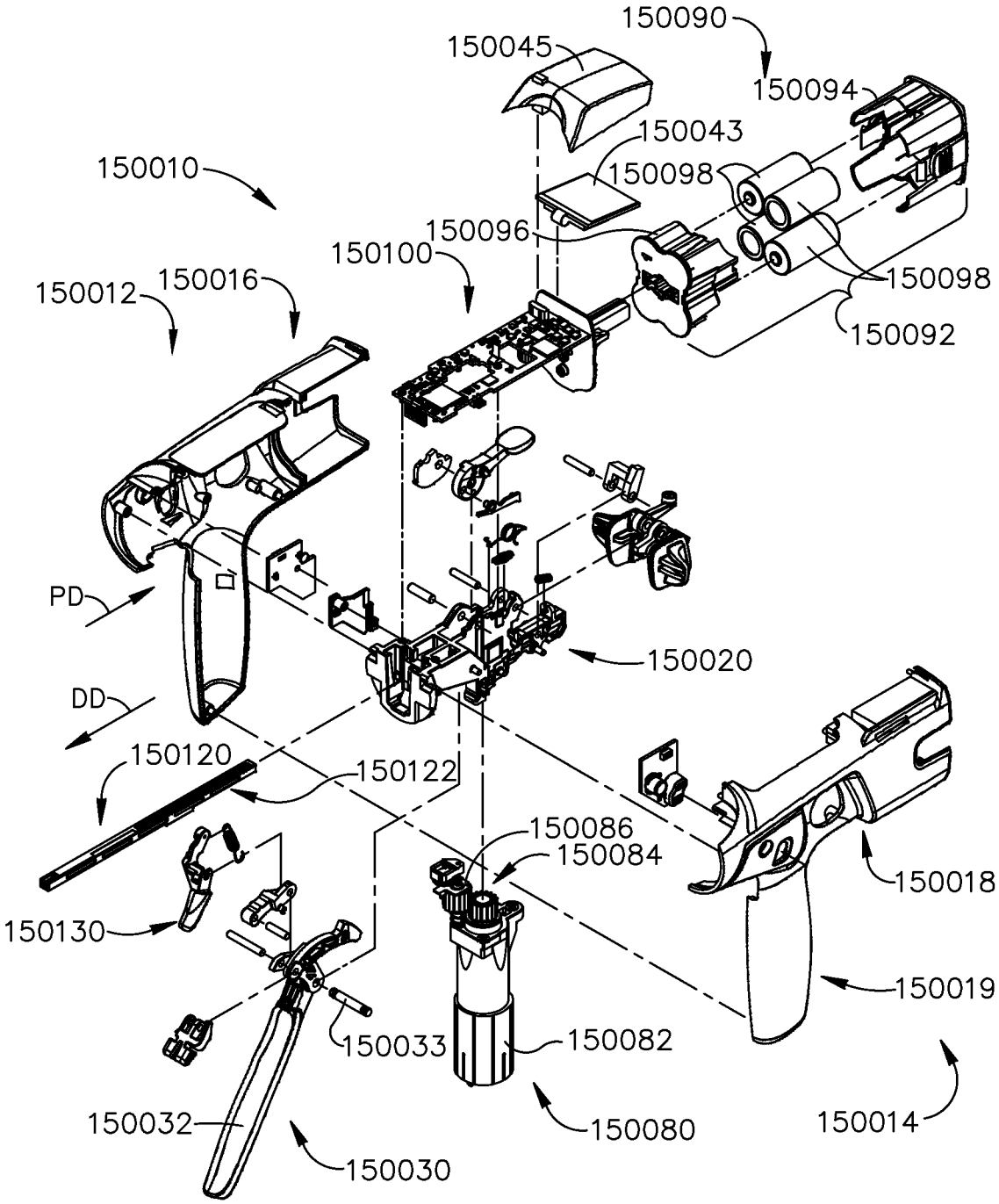
150090
150045
150094
150043
150010
150098
150096
150100
150098
150012
150016
150092
PD
150020
DD
150120
150122
150086
150084
150018
150130
150019
150033
150082
150032
150080
150014
150030

FIG. 22

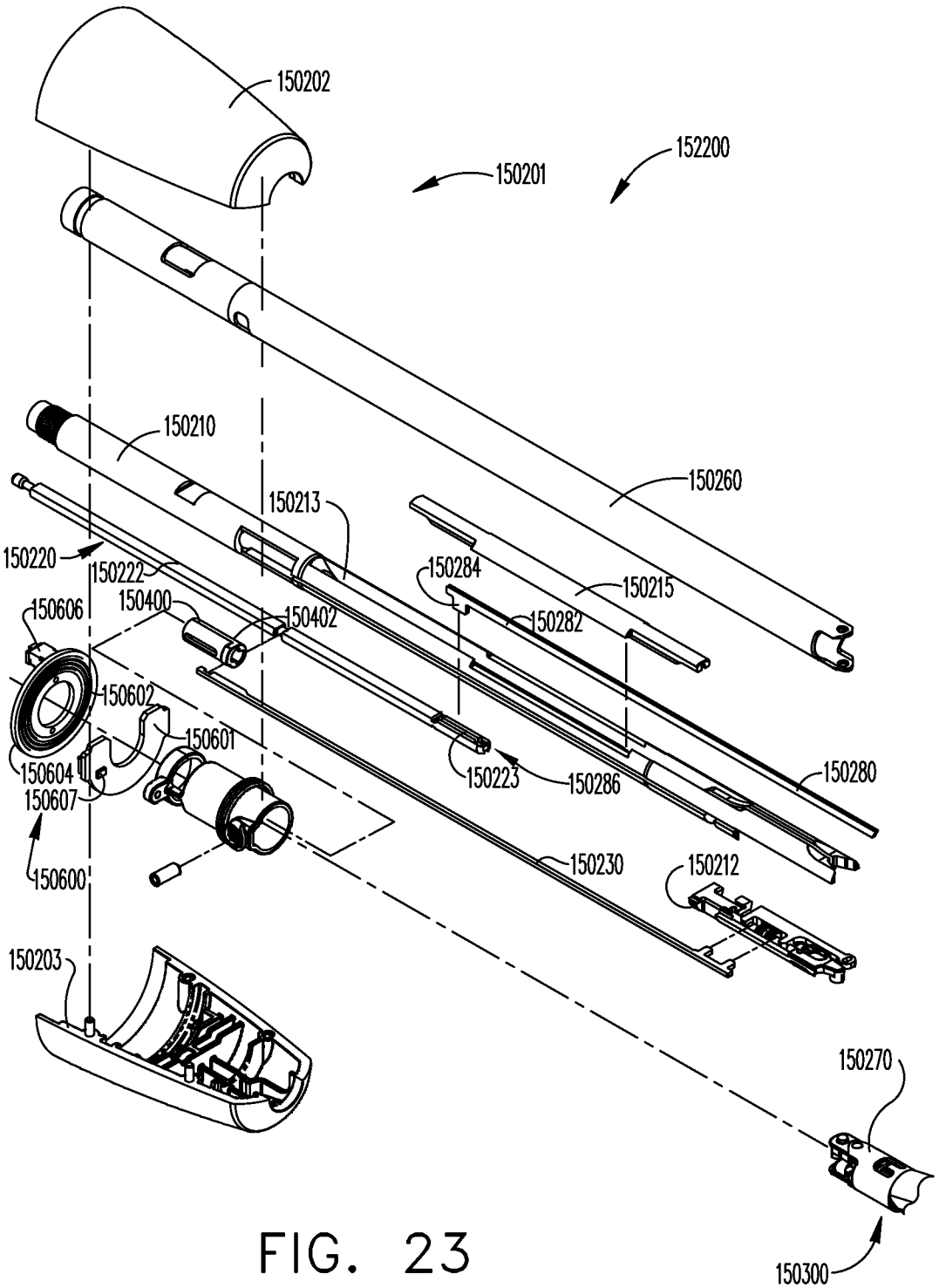
150202
150201
152200
150210
150260
150213
150220
150222
150284
150215
150400
150402
150606
150282
150602
150601
150604
150607
150223
150286
150280
150230
150212
150600
150203
150270
150300

FIG. 23

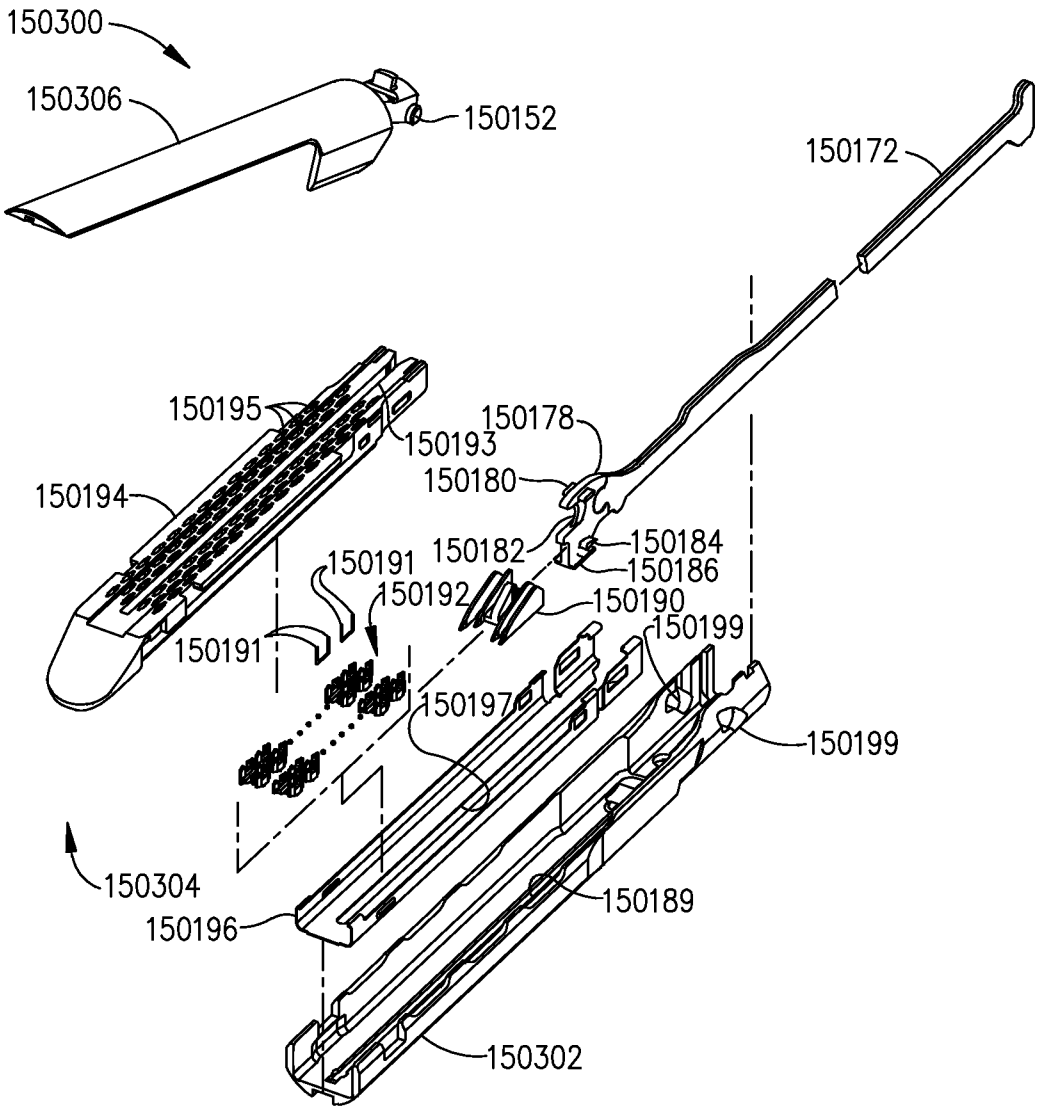
150300
150306
150152
150172
150195
150193
150178
150180
150194
150182
150184
150186
150191
150192
150190
150199
150191
150197
150199
150304
150189
150196
150302

FIG. 24

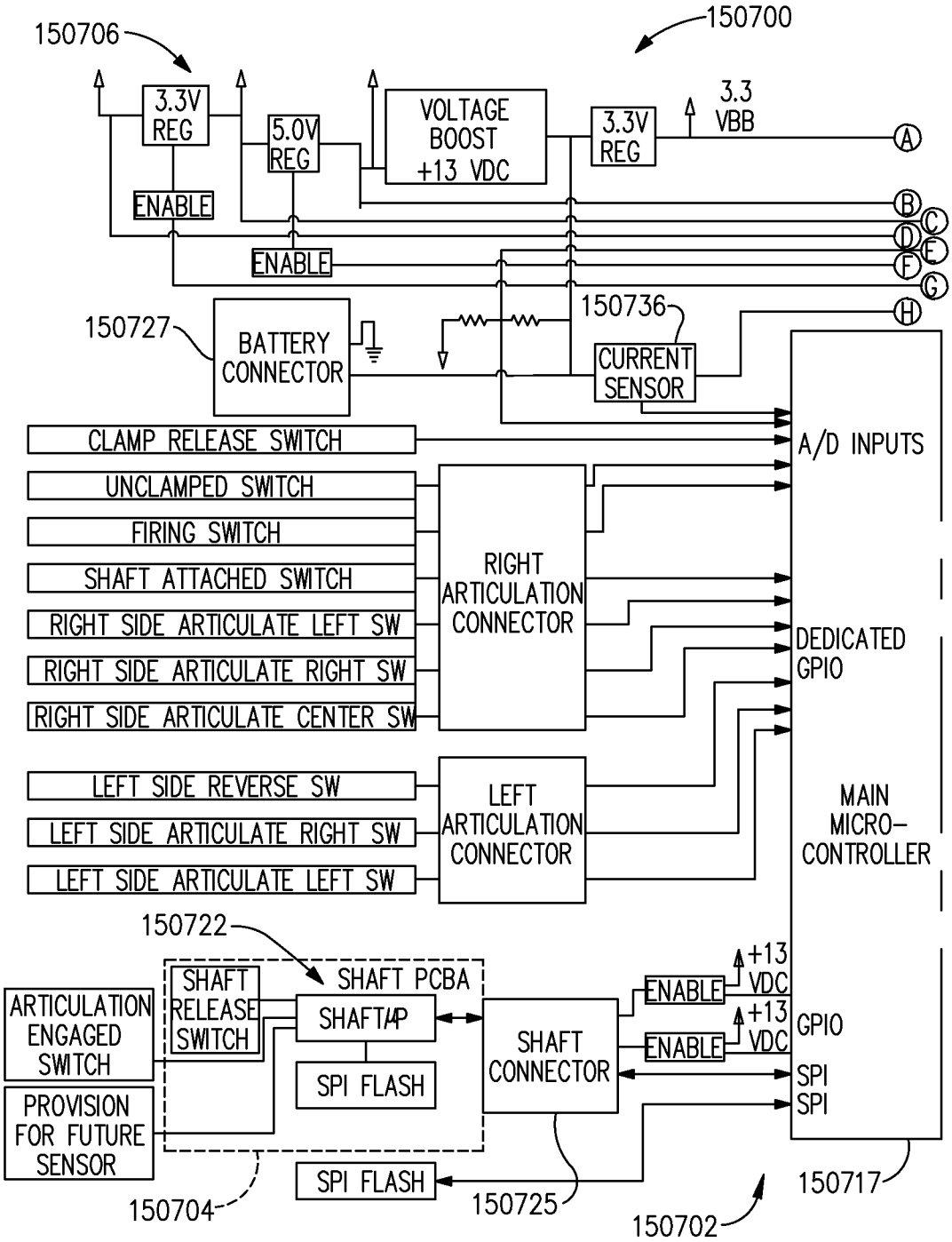
150706
150700
3.3V REG
5.0V REG
VOLTAGE BOOST +13 VDC
3.3V REG
3.3 VBB
A
B
C
D
E
F
G
H
ENABLE
ENABLE
150727
BATTERY CONNECTOR
150736
CURRENT SENSOR
CLAMP RELEASE SWITCH
UNCLAMPED SWITCH
FIRING SWITCH
SHAFT ATTACHED SWITCH
RIGHT SIDE ARTICULATE LEFT SW
RIGHT SIDE ARTICULATE RIGHT SW
RIGHT SIDE ARTICULATE CENTER SW
RIGHT ARTICULATION CONNECTOR
LEFT SIDE REVERSE SW
LEFT SIDE ARTICULATE RIGHT SW
LEFT SIDE ARTICULATE LEFT SW
LEFT ARTICULATION CONNECTOR
A/D INPUTS
DEDICATED GPIO
MAIN MICRO-CONTROLLER
150722
SHAFT PCBA
SHAFT RELEASE SWITCH
SHAFT µP
SPI FLASH
ARTICULATION ENGAGED SWITCH
PROVISION FOR FUTURE SENSOR
SHAFT CONNECTOR
ENABLE
ENABLE
+13 VDC
+13 VDC
GPIO
SPI
SPI
SPI FLASH
150704
150725
150702
150717

FIG. 25A

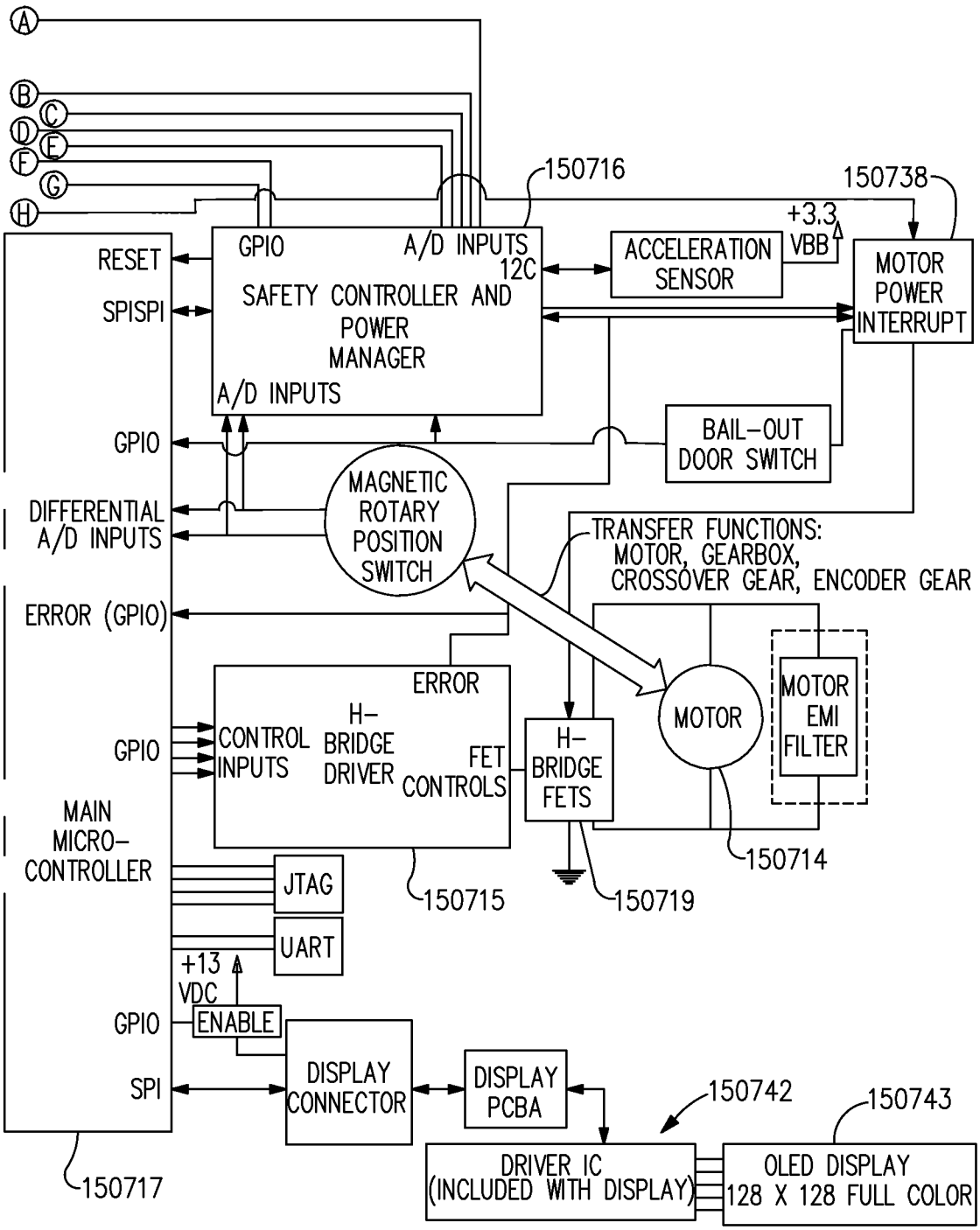
A
B
C
D
E
F
G
H
150716
150738
+3.3
VBB
RESET
SPISPI
GPIO
A/D INPUTS
12C
SAFETY CONTROLLER AND
POWER
MANAGER
A/D INPUTS
ACCELERATION
SENSOR
MOTOR
POWER
INTERRUPT
GPIO
BAIL-OUT
DOOR SWITCH
DIFFERENTIAL
A/D INPUTS
MAGNETIC
ROTARY
POSITION
SWITCH
TRANSFER FUNCTIONS:
MOTOR, GEARBOX,
CROSSOVER GEAR, ENCODER GEAR
ERROR (GPIO)
ERROR
GPIO
CONTROL
INPUTS
H-
BRIDGE
DRIVER
FET
CONTROLS
H-
BRIDGE
FETS
MOTOR
MOTOR
EMI
FILTER
MAIN
MICRO-
CONTROLLER
JTAG
150715
150719
150714
UART
+13
VDC
GPIO
ENABLE
SPI
DISPLAY
CONNECTOR
DISPLAY
PCBA
150742
150743
DRIVER IC
(INCLUDED WITH DISPLAY)
OLED DISPLAY
128 X 128 FULL COLOR
150717

FIG. 25B

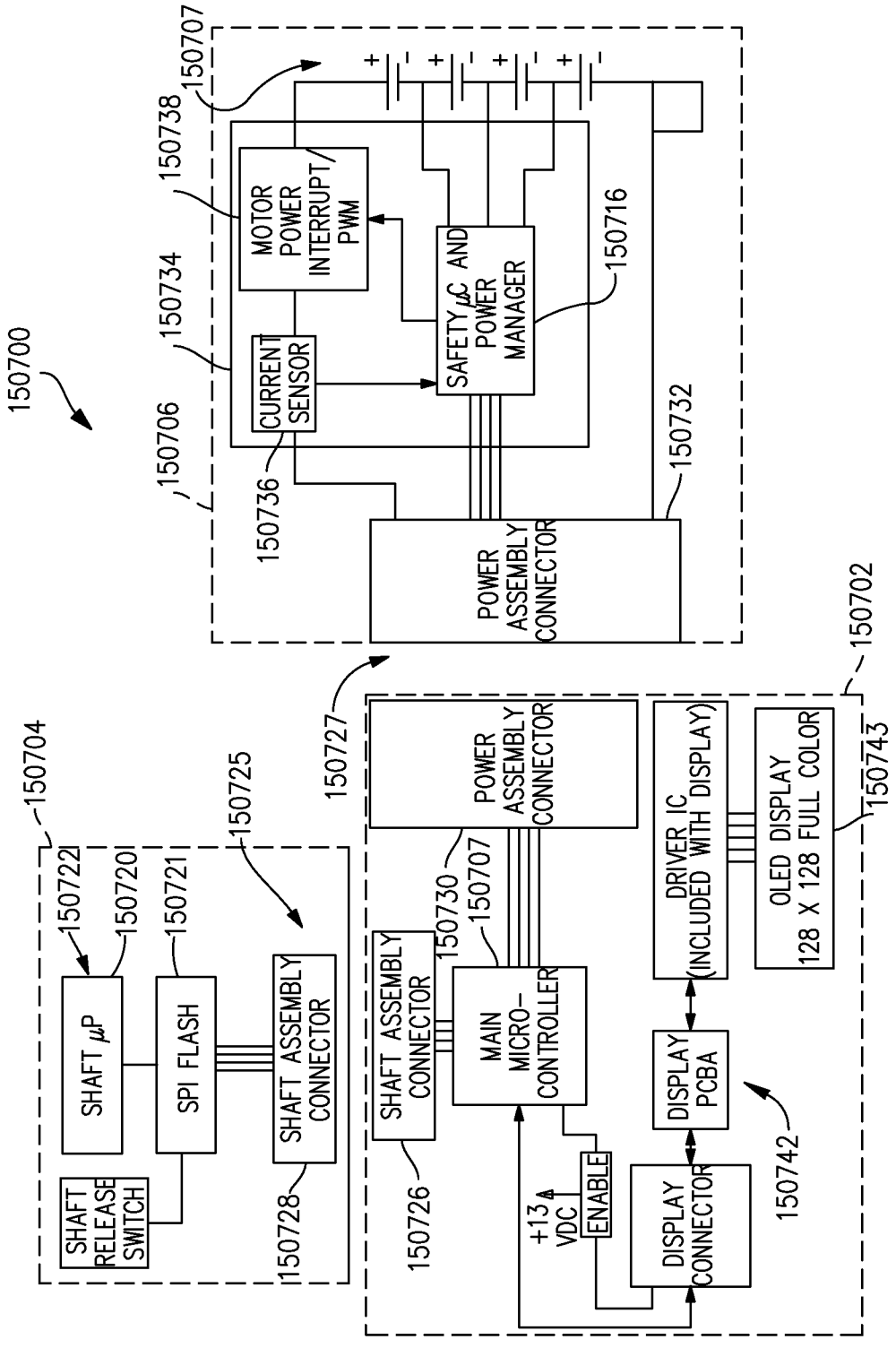
150700
150707
150738
150734
150706
150716
150732
150736
MOTOR POWER INTERRUPT PWM
CURRENT SENSOR
SAFETY µC AND POWER MANAGER
POWER ASSEMBLY CONNECTOR
150704
150725
150727
150702
150722
150720
150721
150730
150707
150726
150728
150742
150743
SHAFT µP
SPI FLASH
SHAFT ASSEMBLY CONNECTOR
SHAFT RELEASE SWITCH
MAIN MICRO-CONTROLLER
+13 VDC
ENABLE
DISPLAY PCBA
DISPLAY CONNECTOR
DRIVER IC (INCLUDED WITH DISPLAY)
OLED DISPLAY 128 X 128 FULL COLOR

FIG. 26

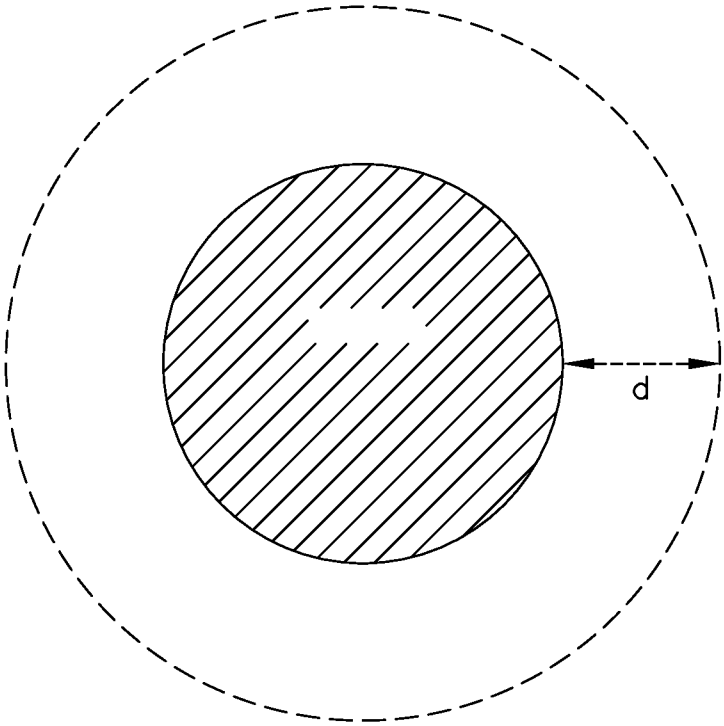

FIG. 27

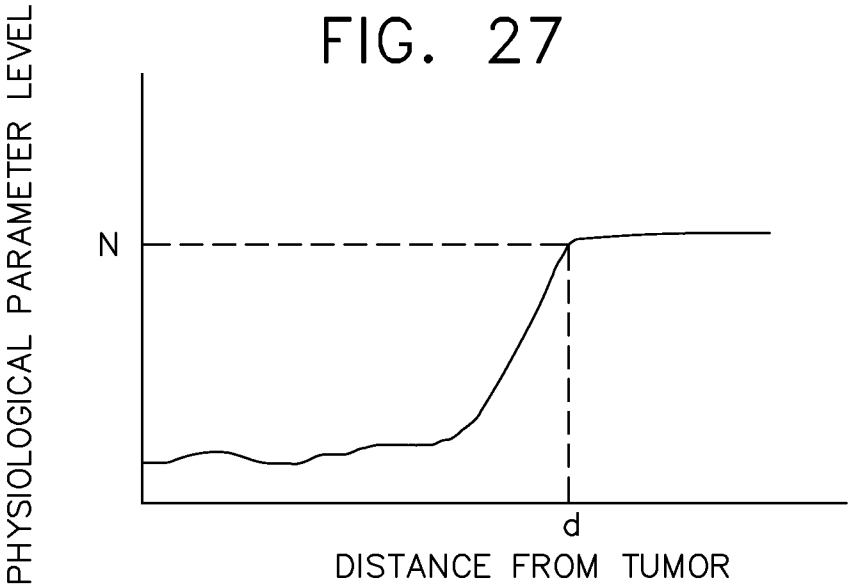

FIG. 28

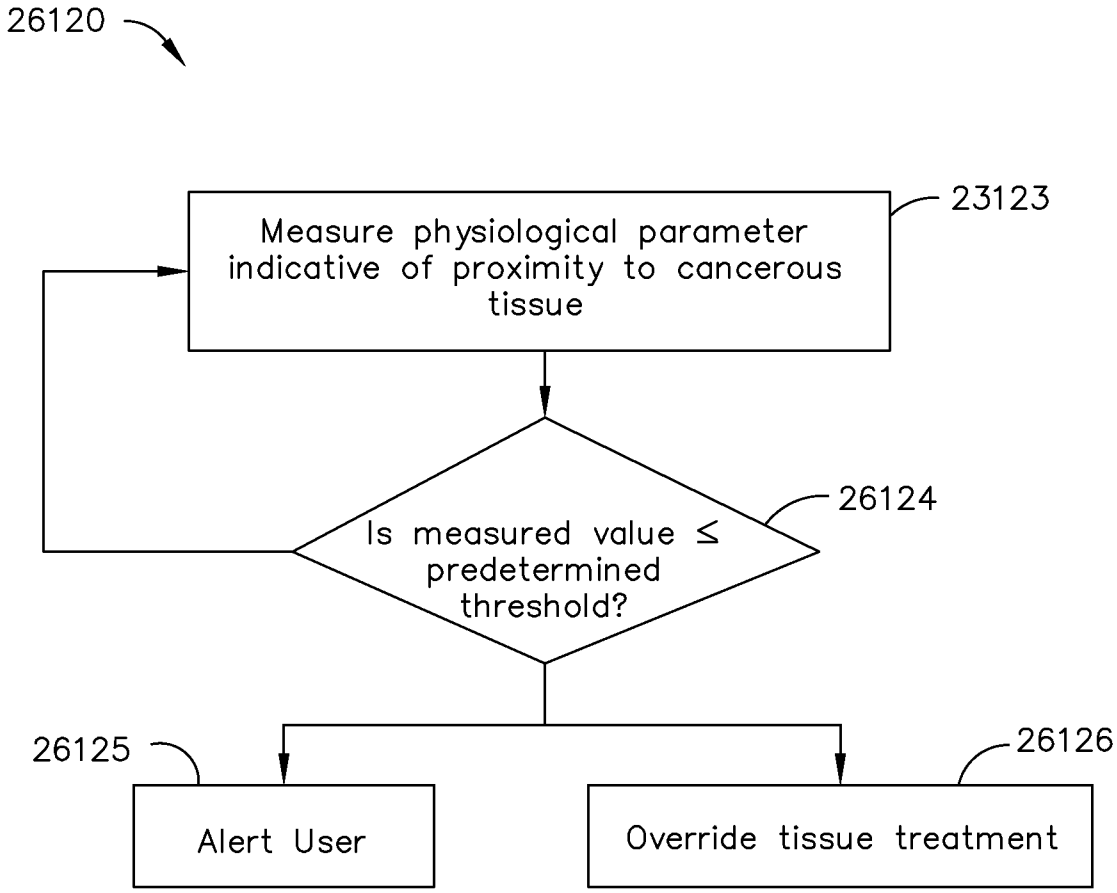
26120
Measure physiological parameter indicative of proximity to cancerous tissue
23123
Is measured value ≤ predetermined threshold?
26124
26125
Alert User
26126
Override tissue treatment

FIG. 29

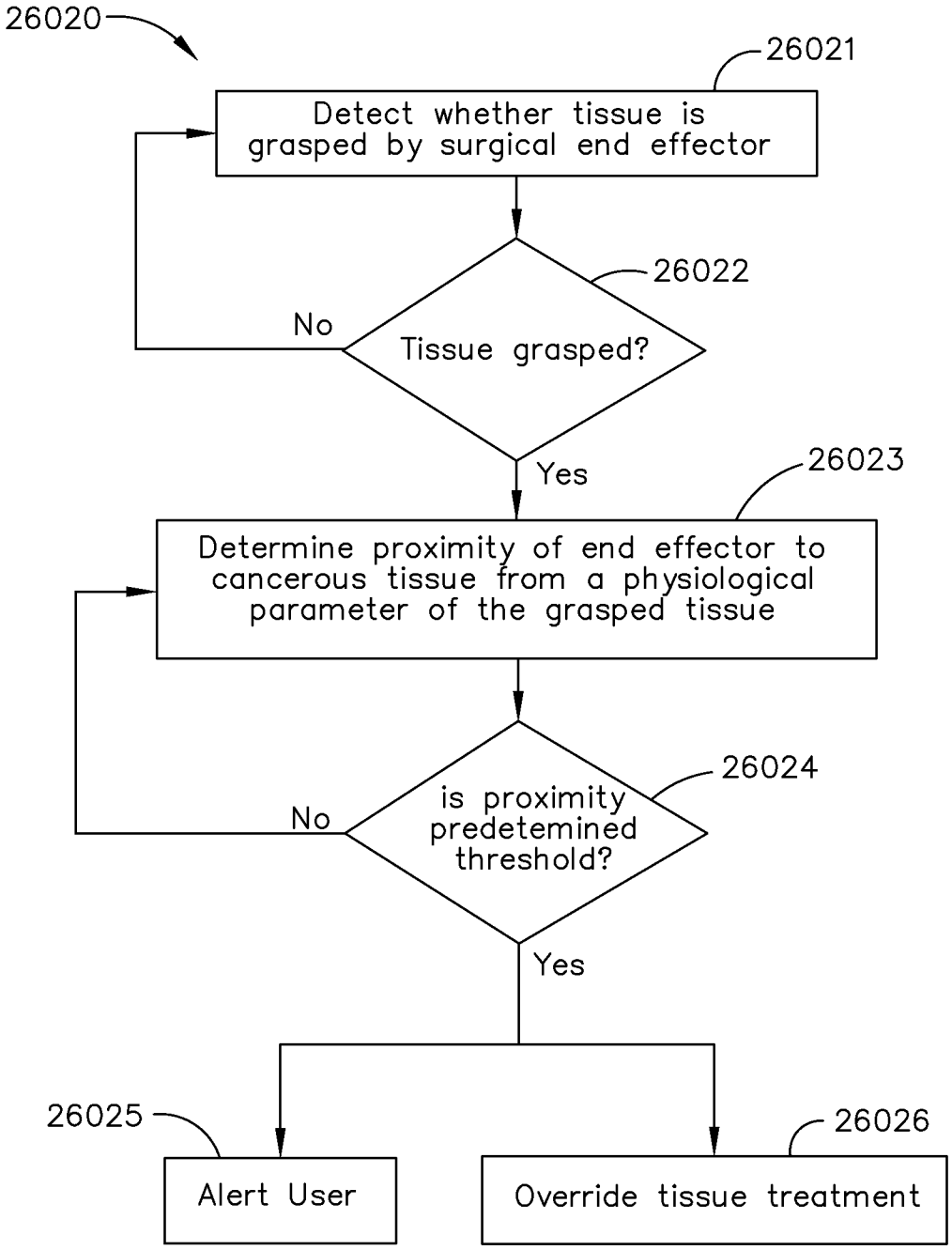
26020
26021
Detect whether tissue is grasped by surgical end effector
26022
Tissue grasped?
No
Yes
26023
Determine proximity of end effector to cancerous tissue from a physiological parameter of the grasped tissue
26024
is proximity predetemined threshold?
No
Yes
26025
Alert User
26026
Override tissue treatment

FIG. 30

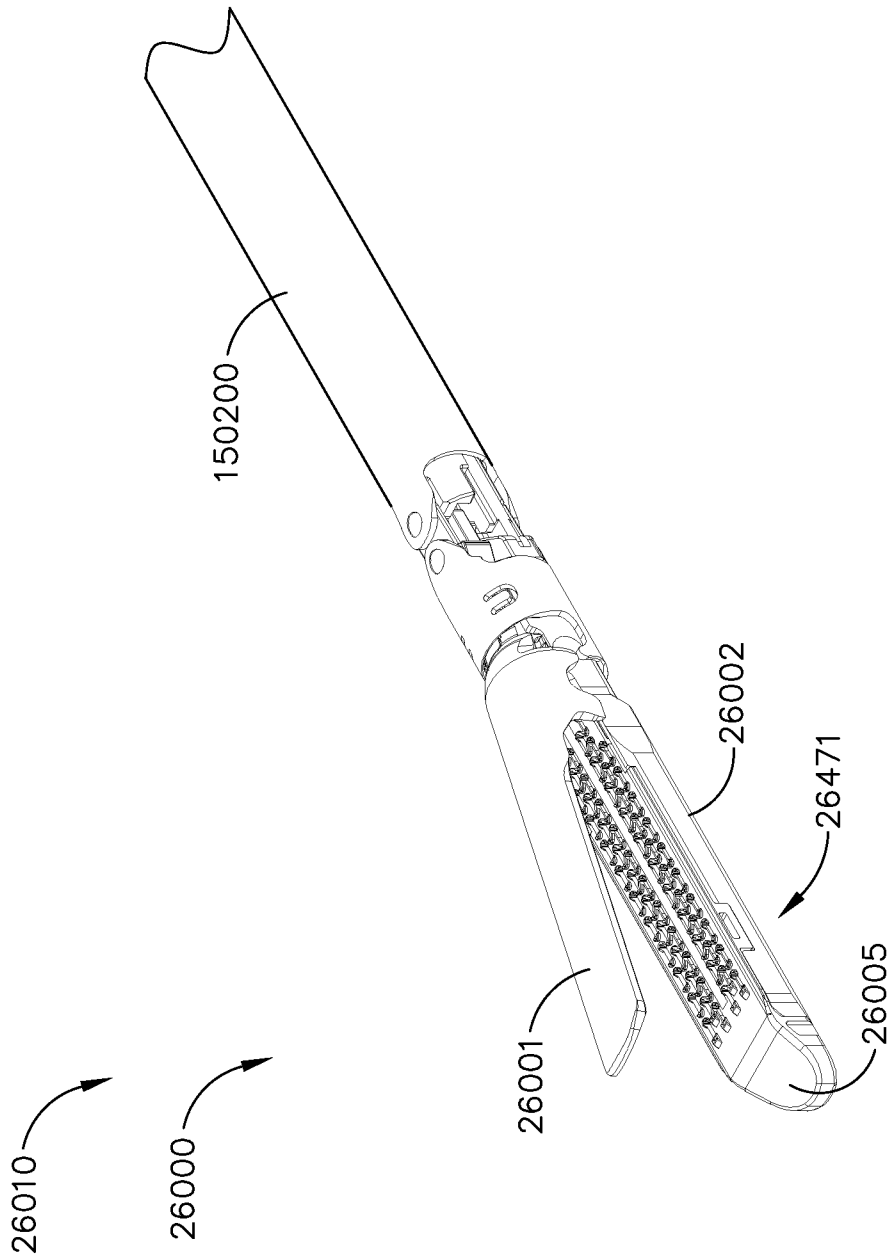

FIG. 31

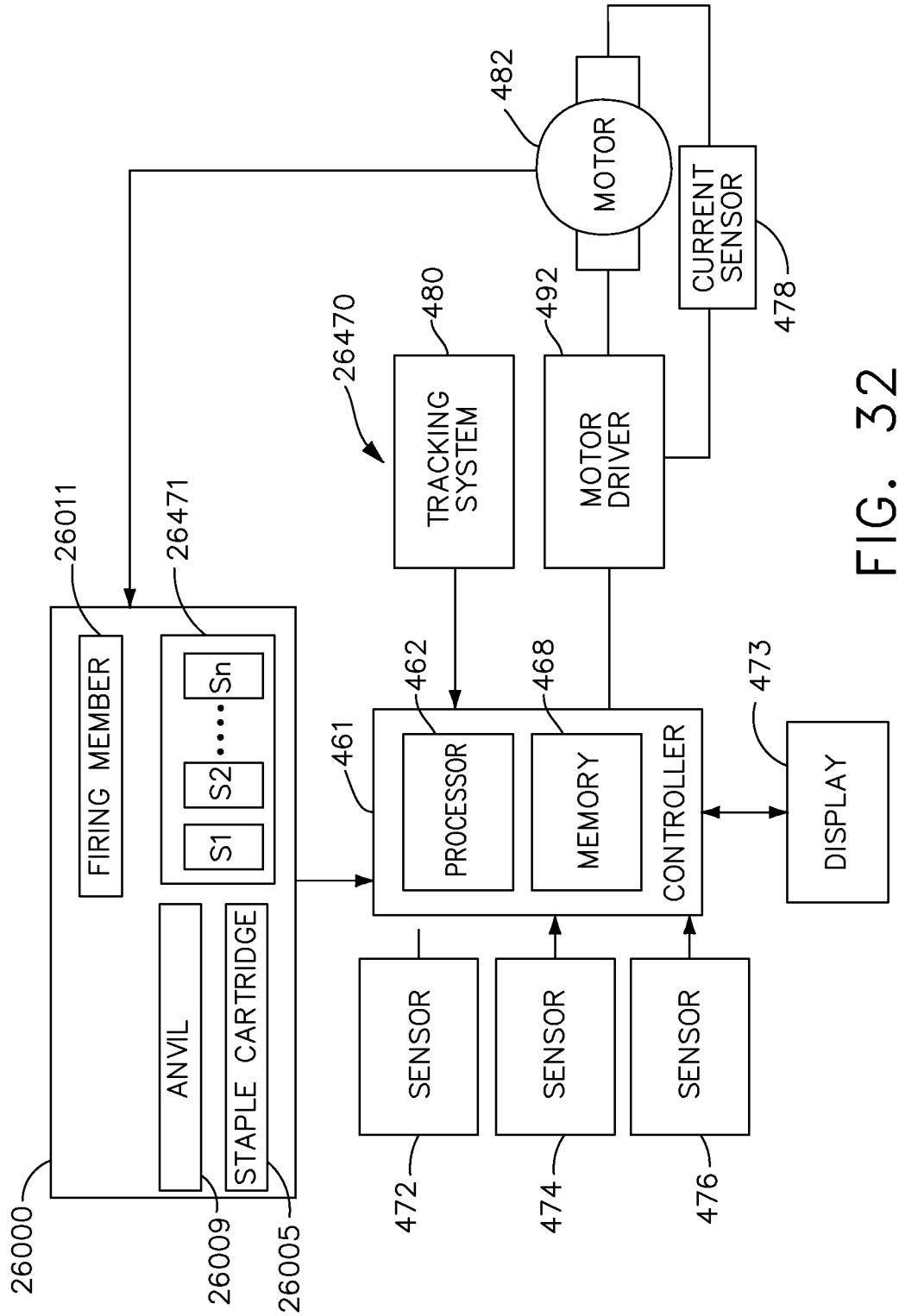
482
MOTOR
CURRENT SENSOR
478
26470
480
492
TRACKING SYSTEM
MOTOR DRIVER
26011
26471
462
468
473
461
FIRING MEMBER
S1
S2
Sn
PROCESSOR
MEMORY
CONTROLLER
DISPLAY
ANVIL
STAPLE CARTRIDGE
SENSOR
SENSOR
SENSOR
26000
26009
26005
472
474
476

FIG. 32

Sensor Signal	Proximity
R1	D1
R2	D2
R3	D3
.	.
.	.
.	.
Rn	Dn

FIG. 33

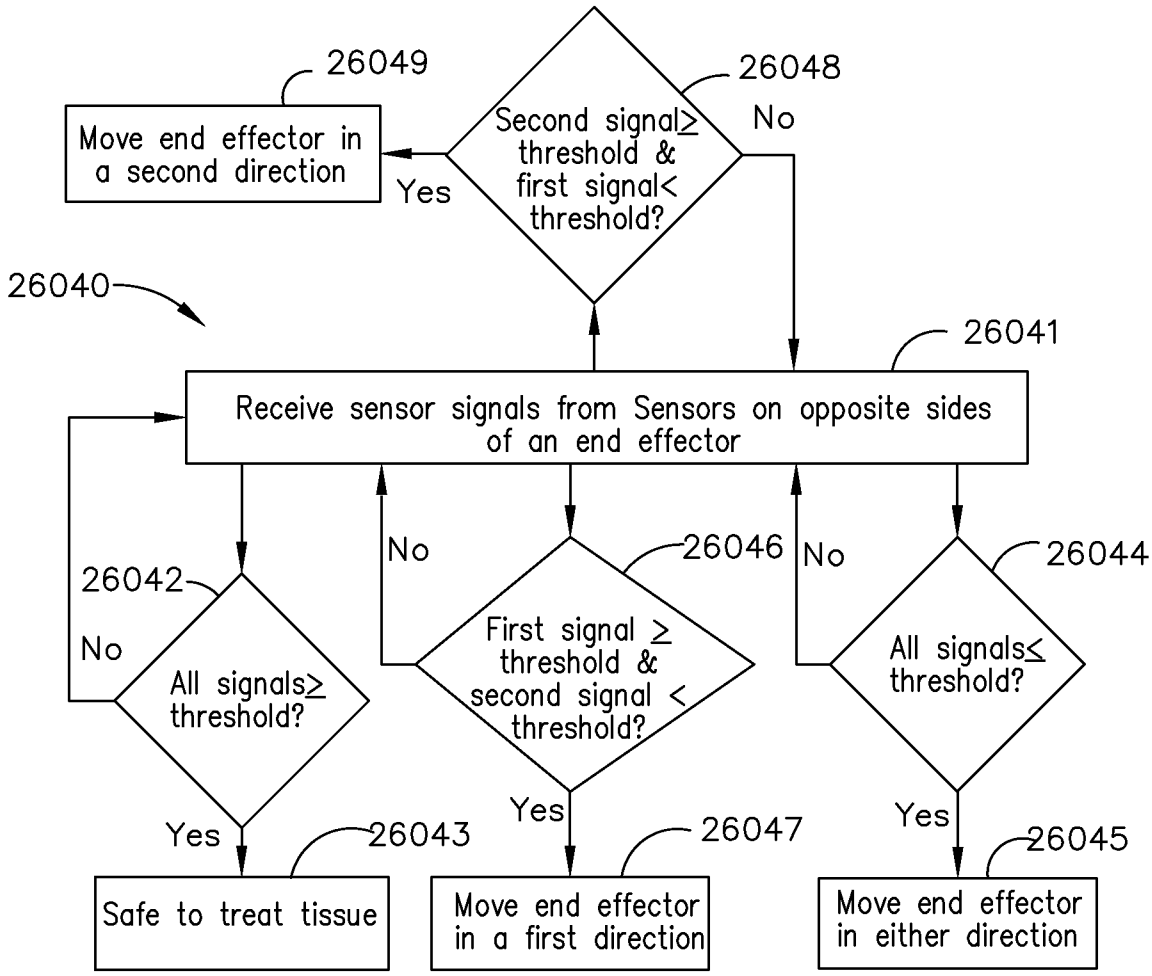

FIG. 34

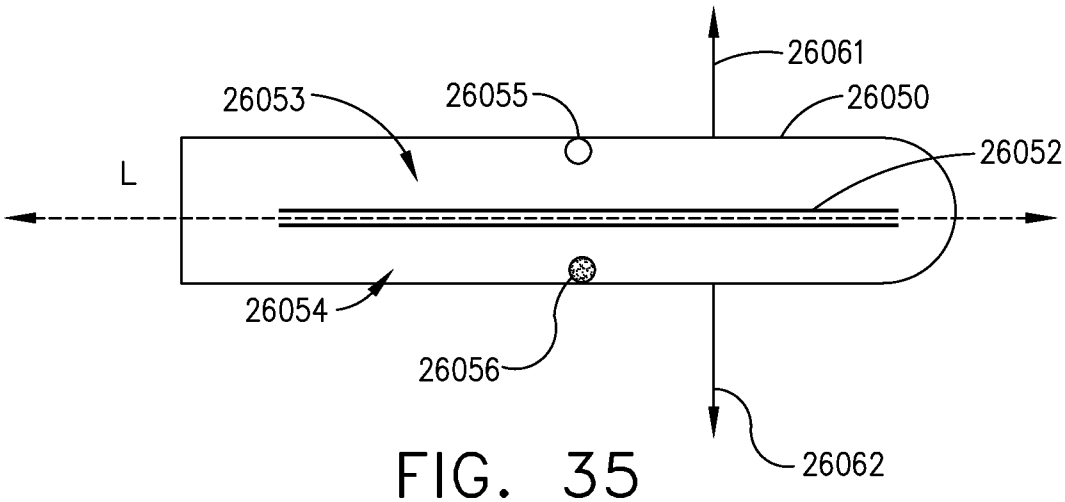
26061
26053
26055
26050
26052
L
26054
26056
26062

FIG. 35

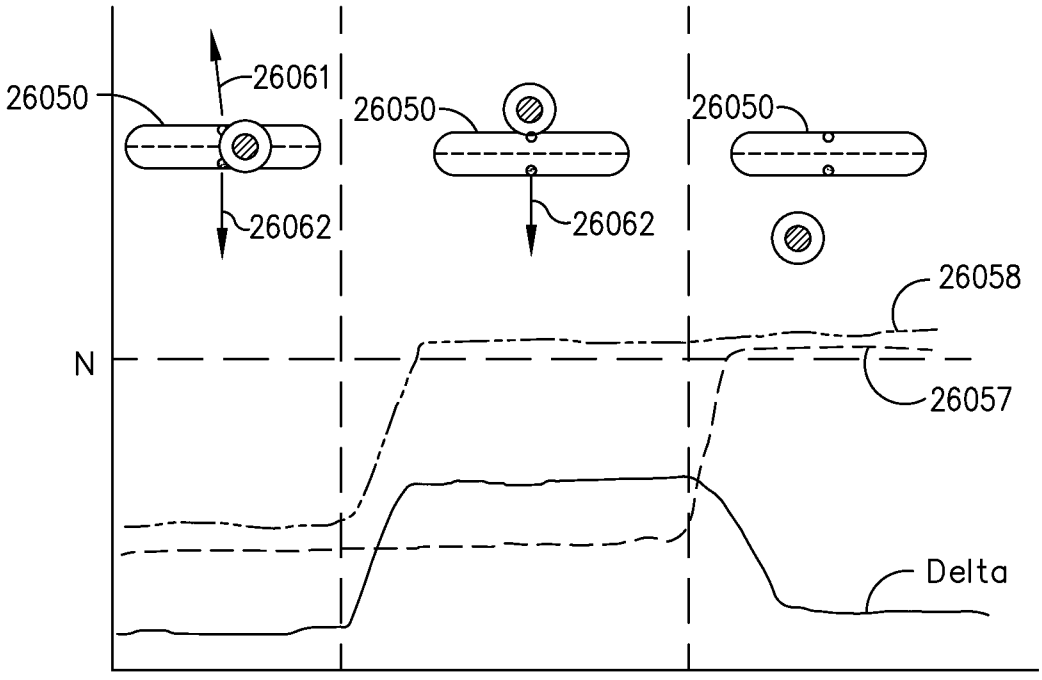
26050
26061
26062
26050
26062
26050
26058
N
26057
Delta

FIG. 36

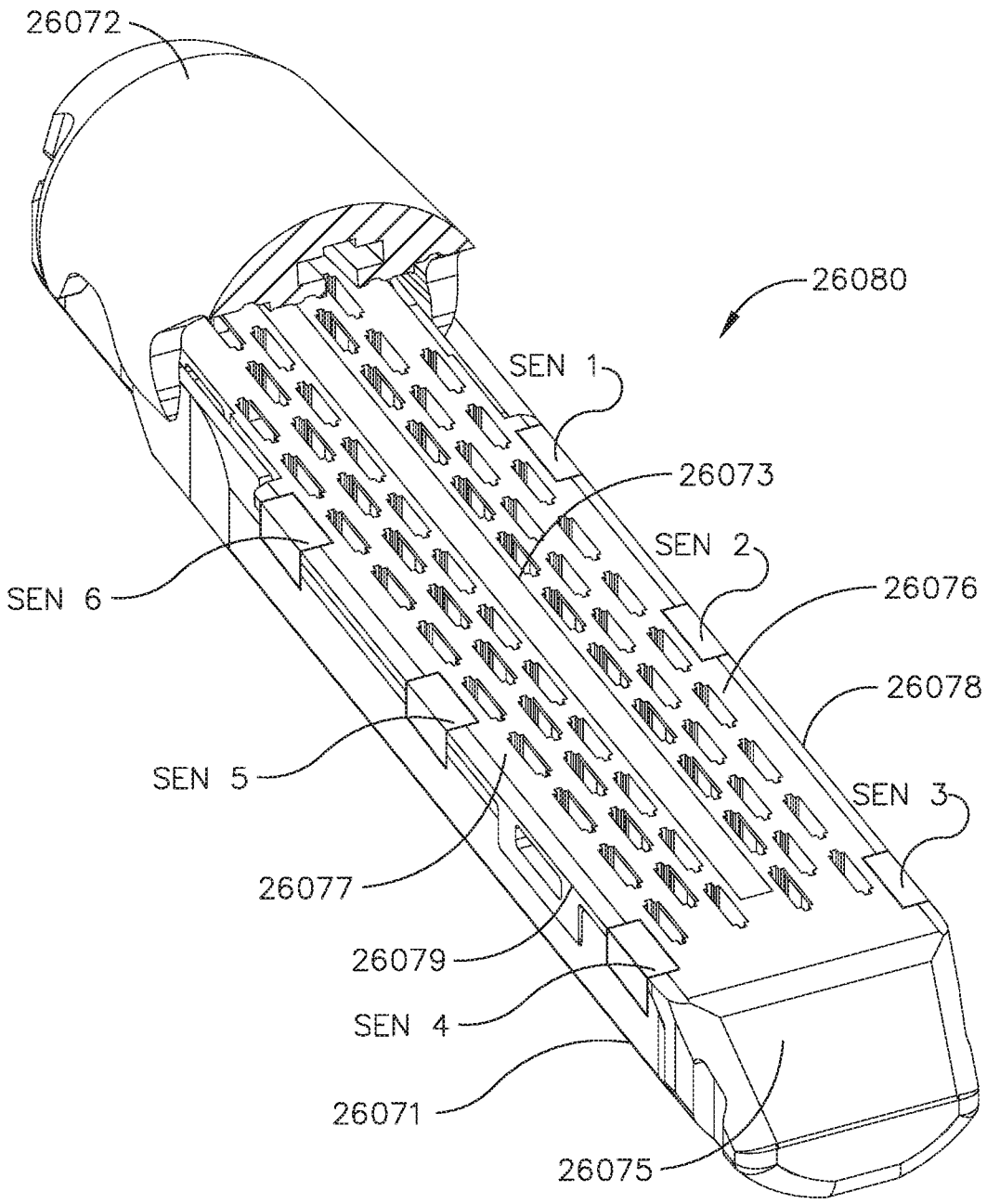
26072
26080
SEN 1
26073
SEN 2
SEN 6
26076
26078
SEN 5
SEN 3
26077
26079
SEN 4
26071
26075

FIG. 37

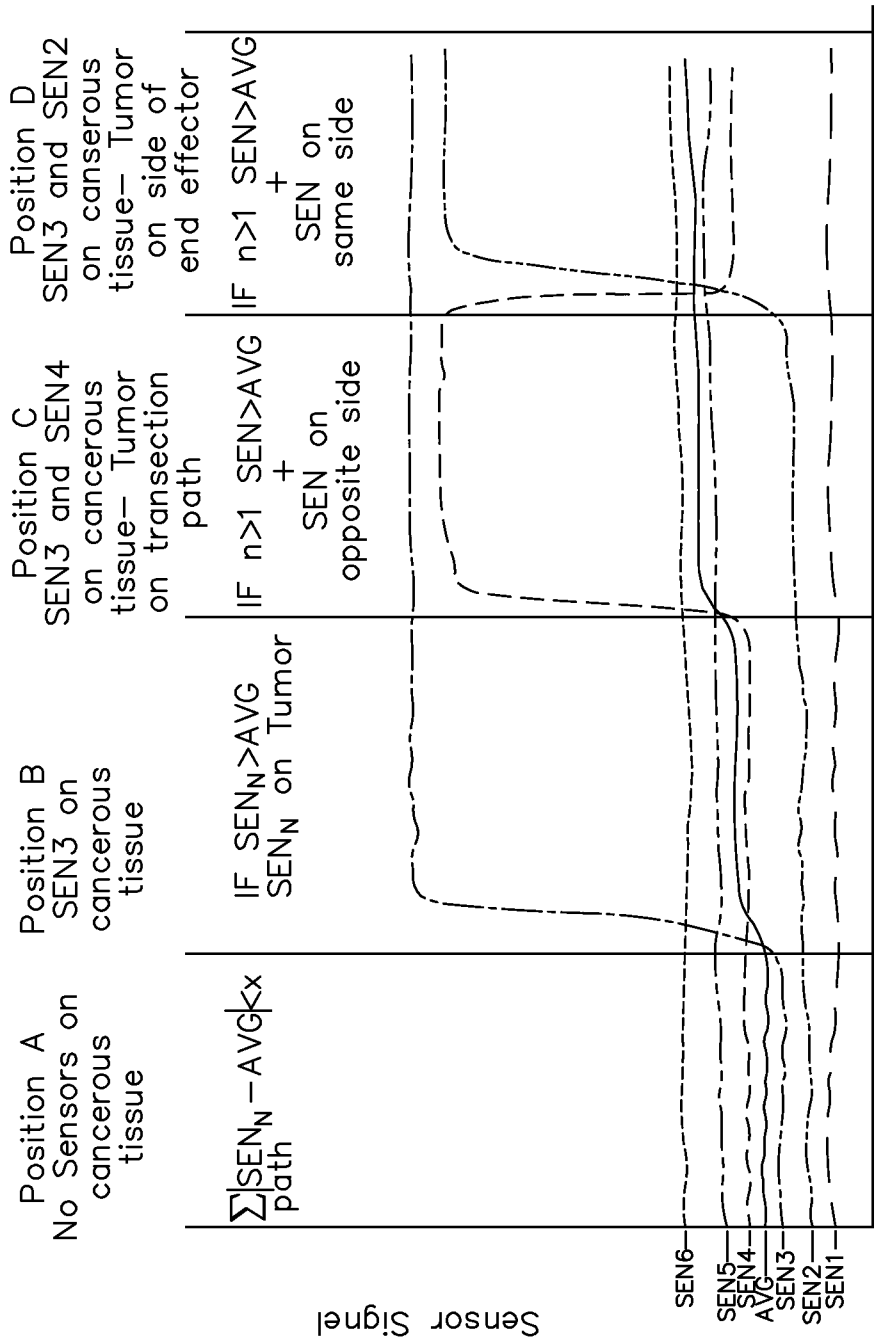
Position A
No Sensors on cancerous tissue
$\sum|SEN_N - AVG| < x$
path
Position B
SEN3 on cancerous tissue
IF $SEN_N > AVG$
SEN_N on Tumor
Position C
SEN3 and SEN4 on cancerous tissue– Tumor on transection path
IF n>1 SEN>AVG
+
SEN on opposite side
Position D
SEN3 and SEN2 on canserous tissue– Tumor on side of end effector
IF n>1 SEN>AVG
+
SEN on same side
Sensor Signal
Time
SEN6
SEN5
SEN4
AVG
SEN3
SEN2
SEN1

FIG. 38

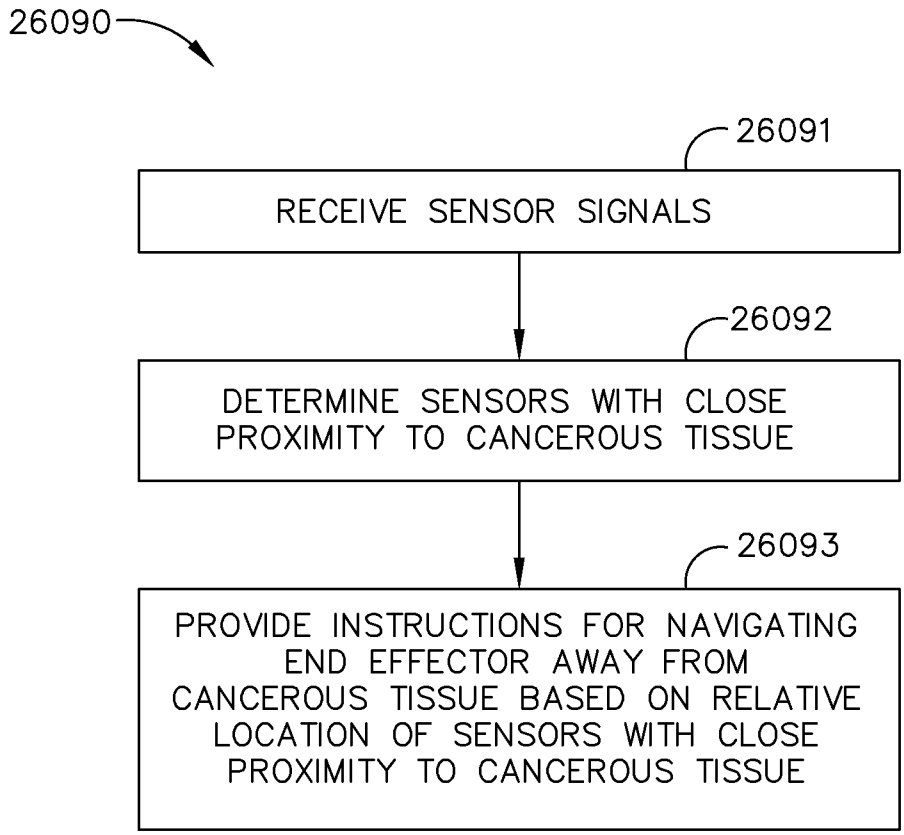
26090
26091
RECEIVE SENSOR SIGNALS
26092
DETERMINE SENSORS WITH CLOSE PROXIMITY TO CANCEROUS TISSUE
26093
PROVIDE INSTRUCTIONS FOR NAVIGATING END EFFECTOR AWAY FROM CANCEROUS TISSUE BASED ON RELATIVE LOCATION OF SENSORS WITH CLOSE PROXIMITY TO CANCEROUS TISSUE

FIG. 39

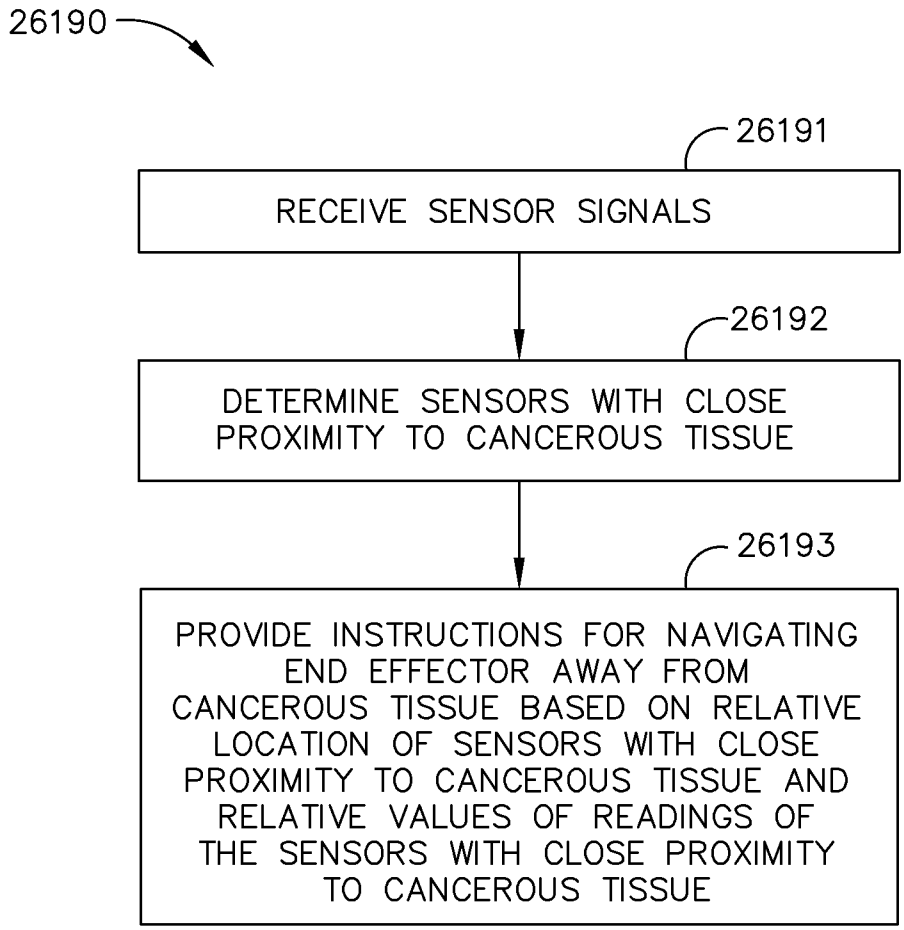
26190
26191
RECEIVE SENSOR SIGNALS
26192
DETERMINE SENSORS WITH CLOSE PROXIMITY TO CANCEROUS TISSUE
26193
PROVIDE INSTRUCTIONS FOR NAVIGATING END EFFECTOR AWAY FROM CANCEROUS TISSUE BASED ON RELATIVE LOCATION OF SENSORS WITH CLOSE PROXIMITY TO CANCEROUS TISSUE AND RELATIVE VALUES OF READINGS OF THE SENSORS WITH CLOSE PROXIMITY TO CANCEROUS TISSUE

FIG. 40

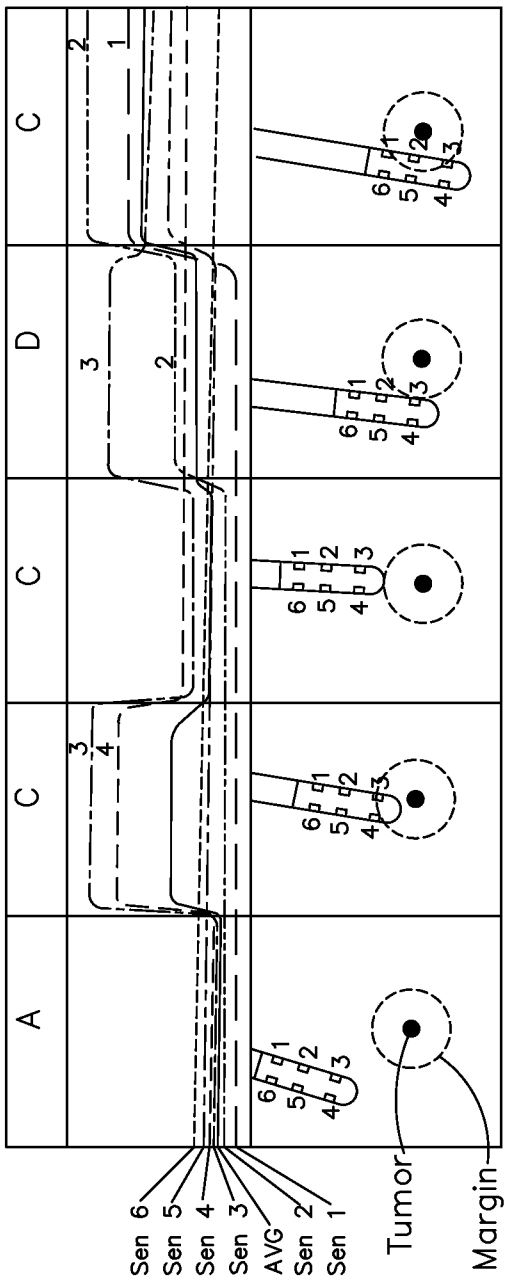

FIG. 41

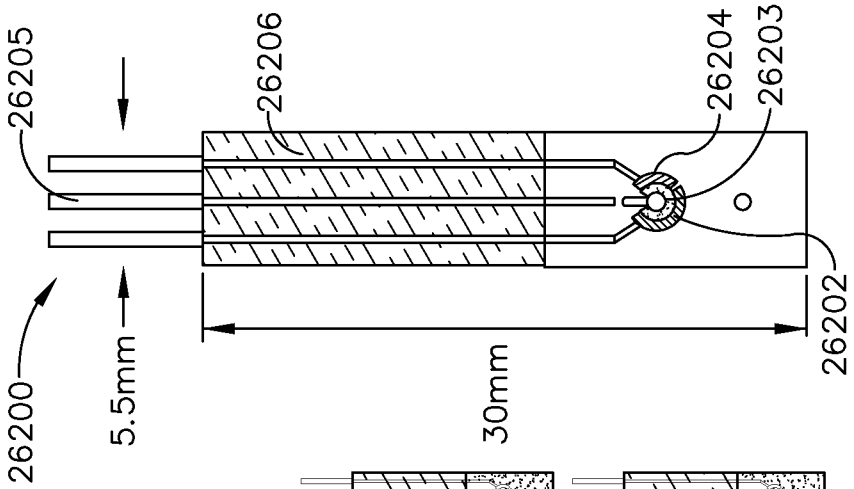

FIG. 43

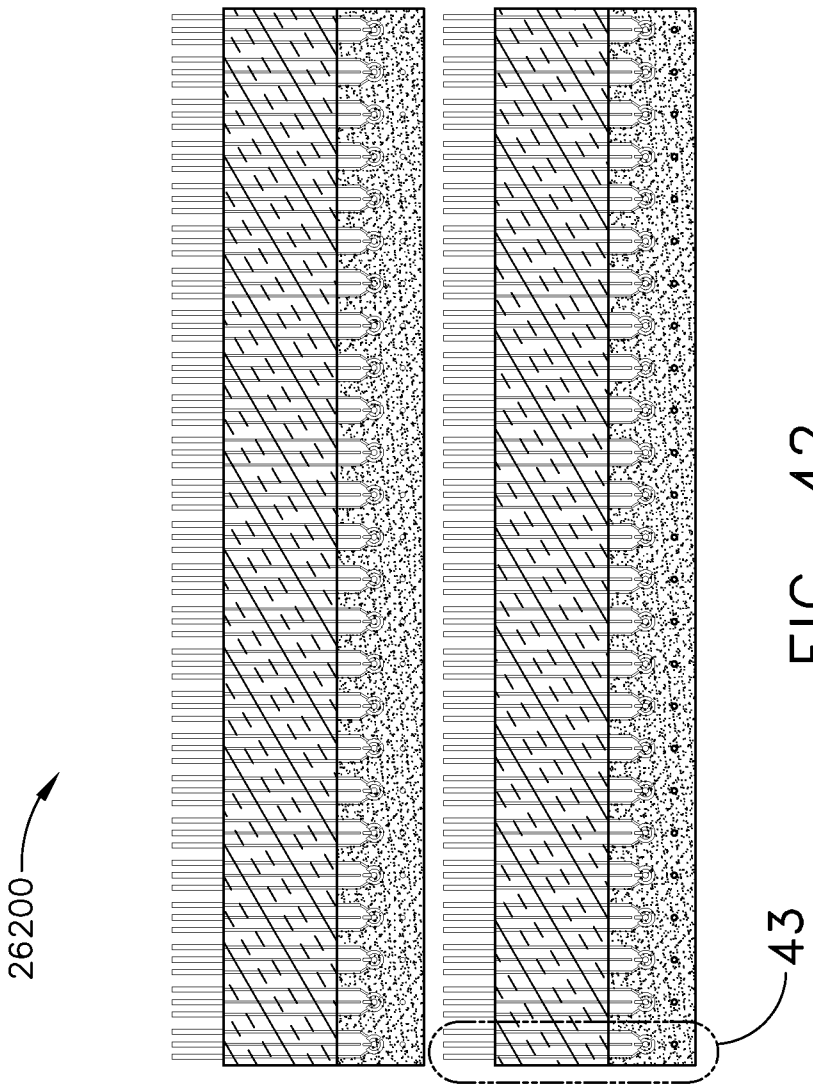

FIG. 42

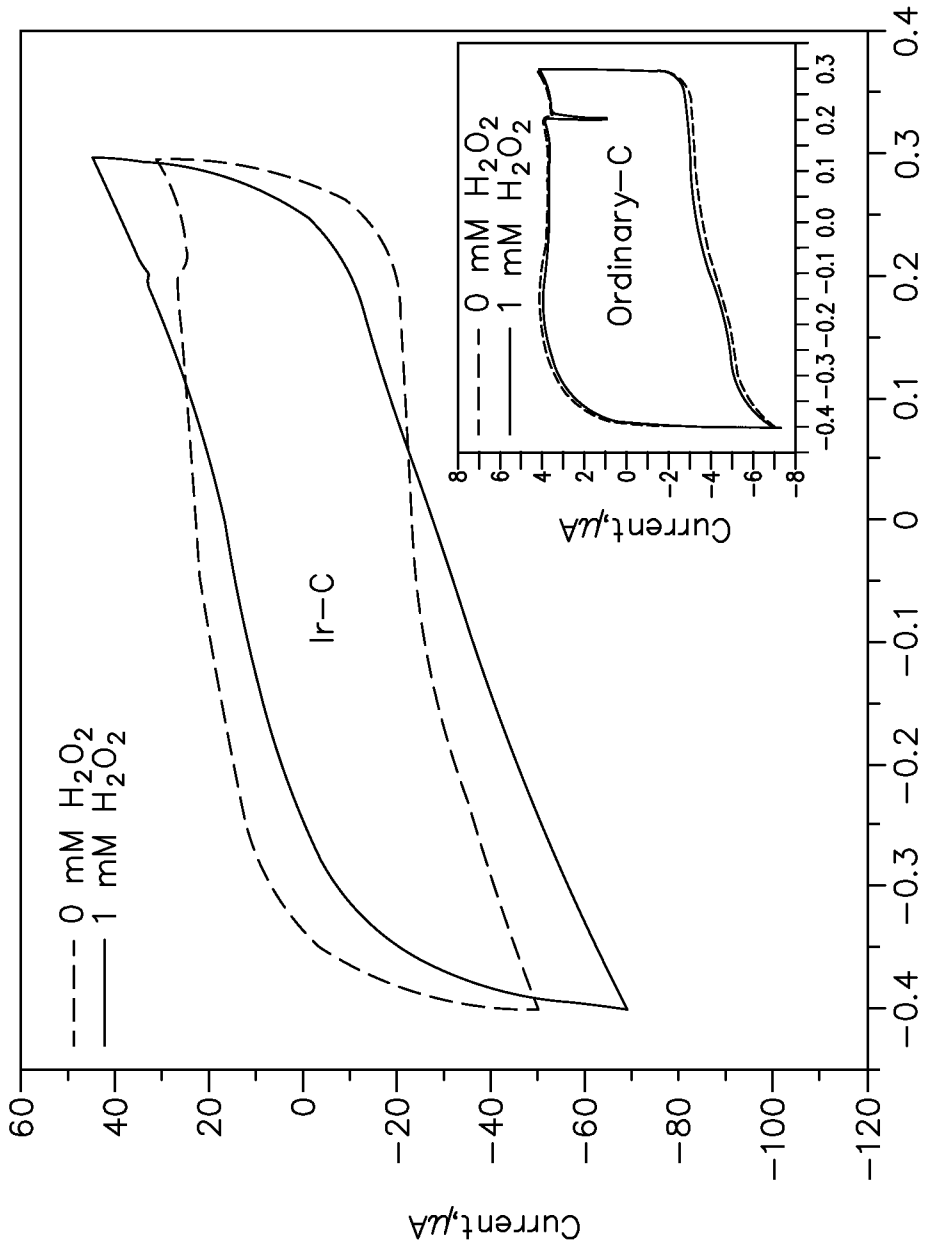

FIG. 44

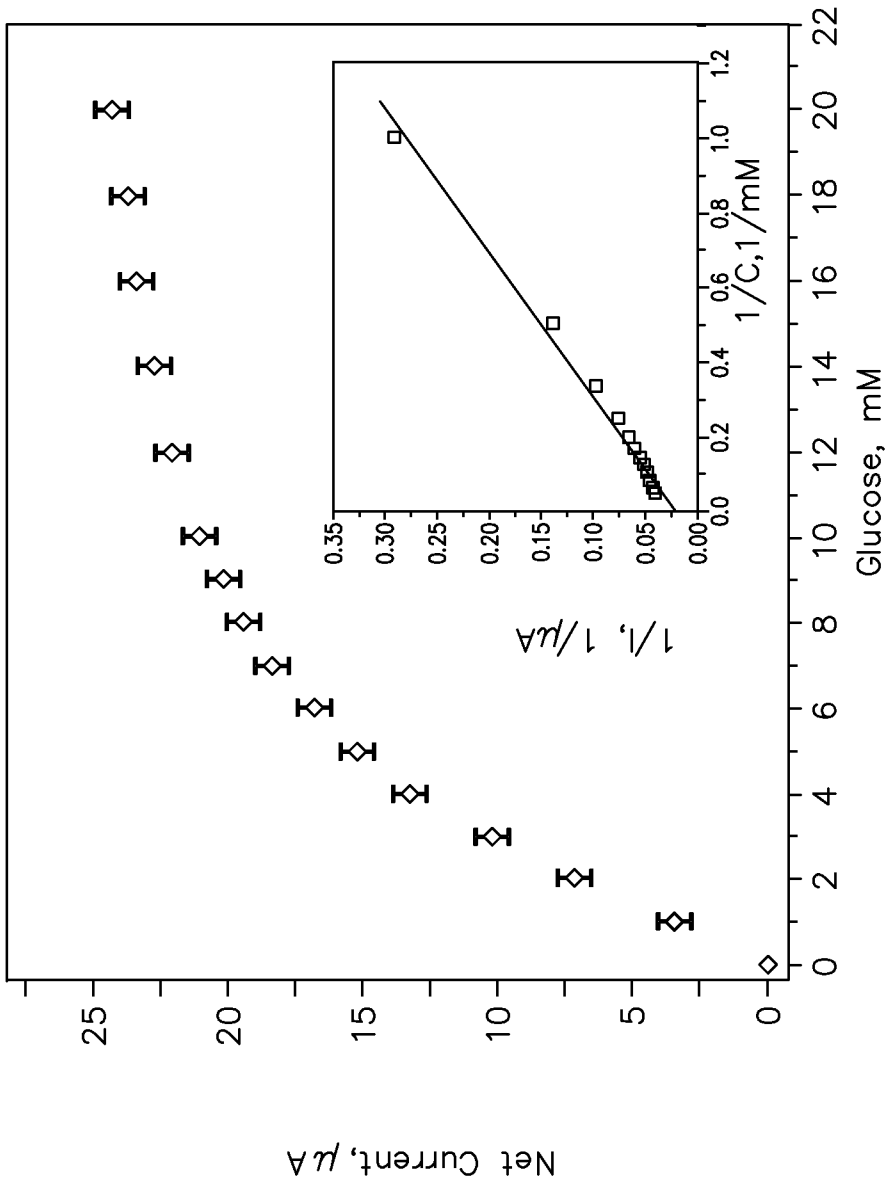

FIG. 45

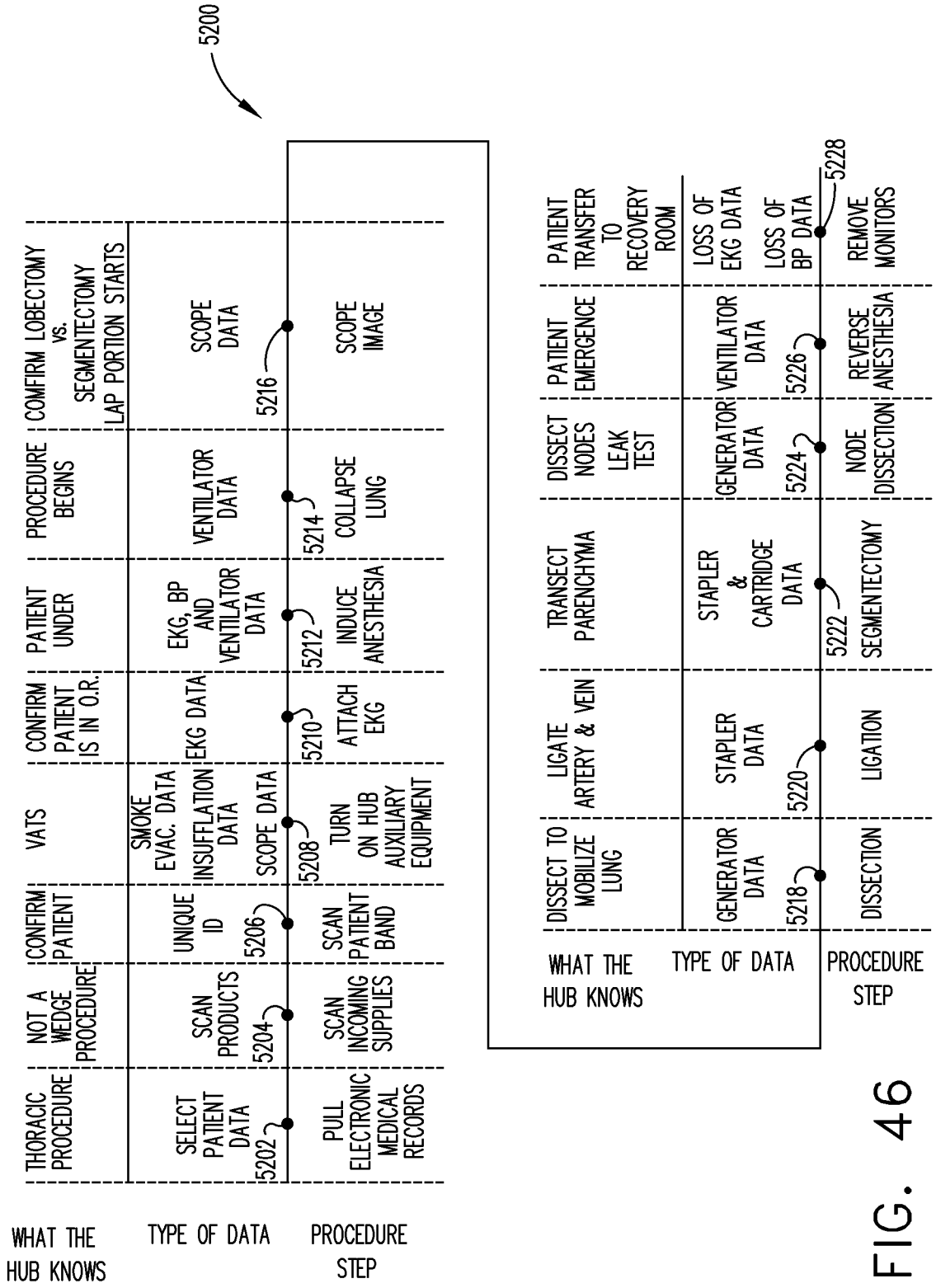
5200
THORACIC PROCEDURE
NOT A WEDGE PROCEDURE
CONFIRM PATIENT
VATS
CONFIRM PATIENT IS IN O.R.
PATIENT UNDER
PROCEDURE BEGINS
COMFIRM LOBECTOMY vs. SEGMENTECTOMY LAP PORTION STARTS
SELECT PATIENT DATA
5202
SCAN PRODUCTS
5204
UNIQUE ID
5206
SMOKE EVAC. DATA
INSUFFLATION DATA
SCOPE DATA
5208
EKG DATA
EKG, BP AND VENTILATOR DATA
5212
VENTILATOR DATA
5214
SCOPE DATA
5216
PULL ELECTRONIC MEDICAL RECORDS
SCAN INCOMING SUPPLIES
SCAN PATIENT BAND
TURN ON HUB AUXILIARY EQUIPMENT
5210
ATTACH EKG
INDUCE ANESTHESIA
COLLAPSE LUNG
SCOPE IMAGE
WHAT THE HUB KNOWS
TYPE OF DATA
PROCEDURE STEP
DISSECT TO MOBILIZE LUNG
LIGATE ARTERY & VEIN
TRANSECT PARENCHYMA
DISSECT NODES
PATIENT EMERGENCE
PATIENT TRANSFER TO RECOVERY ROOM
GENERATOR DATA
5218
STAPLER DATA
5220
STAPLER & CARTRIDGE DATA
5222
GENERATOR DATA
5224
VENTILATOR DATA
5226
LOSS OF EKG DATA
LOSS OF BP DATA
5228
DISSECTION
LIGATION
SEGMENTECTOMY
NODE DISSECTION
REVERSE ANESTHESIA
REMOVE MONITORS
WHAT THE HUB KNOWS
TYPE OF DATA
PROCEDURE STEP

FIG. 46

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2018/057328

A. CLASSIFICATION OF SUBJECT MATTER
INV. G16H40/63 A61B17/068
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G16H A61B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2016/066909 A1 (BABER DANIEL L [US] ET AL) 10 March 2016 (2016-03-10)	1,5-7,9, 13-15, 17,20
A	paragraphs [0002] - [0003]; figure 91 paragraph [0314]; figure 41	2-4,8, 10-12, 16,18,19

X	US 2014/246476 A1 (HALL STEVEN G [US] ET AL) 4 September 2014 (2014-09-04)	1,5-7,9, 13-15
A	paragraph [0260]; figure 107	2-4,8, 10-12, 16-20

X	US 2016/073909 A1 (ZAND JASON MATTHEW [US] ET AL) 17 March 2016 (2016-03-17)	1,5-7,9, 13-15, 17,20
A	paragraphs [0059] - [0060]; figures 2a,2b	2-4,8, 10-12, 16,18,19

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 December 2018	07/01/2019

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Reinbold, Bernhard

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
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