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Inventor(s)	BONN; Kenlyn S. et al.

JAW MEMBER WITH THERMAL SPREAD MONITORING

Abstract

An electrosurgical system includes an end effector assembly having jaw members with tissue-contacting surfaces movable relative to one another between a spaced-apart position and an approximated position for grasping tissue therebetween. One or more light elements are operably associated with one or both jaw members and oriented to project light onto tissue. A generator couples to the tissue-contacting surfaces and supplies electrosurgical energy thereto for treating tissue grasped therebetween. The generator additionally couples to the light element(s) and one or more sensors configured to receive sensed data therefrom. The generator includes a controller configured to: control the supply of energy to tissue; predict thermal spread beyond the jaw members; and modify the light projected onto tissue from the light element when it is determined that the predicted thermal spread is above a threshold thermal spread.

Inventors:	**BONN; Kenlyn S. (Boulder, CO), COULSON; Rebecca J. (Boulder, CO)**
Applicant:	**Covidien LP** (Mansfield, MA)
Family ID:	**86054318**
Assignee:	**Covidien LP (Mansfield, MA)**
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Background/Summary

CROSS REFERENCE [0001] This application claims the benefit of and priority to U.S. Provisional Patent application Ser. No. 63/324,240, filed on Mar. 28, 2022, the entire disclosure of which is incorporated by reference herein.

FIELD
[0002] The present disclosure relates to surgical systems and methods, and, more particularly, to energy-based surgical systems and methods utilizing sensed data from one or more light elements to predict and/or control thermal spread.
BACKGROUND
[0003] A surgical forceps is a pliers-like instrument that relies on mechanical action between its jaw members to grasp, clamp, and constrict tissue. Energy-based forceps utilize both mechanical clamping action and energy, e.g., monopolar Radio Frequency (RF), bipolar RF, microwave, ultrasonic, light, thermal, or other suitable energy, to heat tissue to thereby treat, e.g., coagulate, cauterize, or seal, tissue grasped between the jaw members. Typically, once tissue is treated, the surgeon has to accurately sever the treated tissue. Accordingly, many energy-based forceps are designed to incorporate a knife that is advanced between the jaw members to cut the treated tissue. As an alternative to a mechanical knife, an energy-based tissue cutting element may be provided to statically or dynamically cut the treated tissue using energy, e.g., the same or different energy as used for treating the tissue.
[0004] While tissue grasped between the jaw members of an electrosurgical forceps is intentionally heated to seal, cut, and/or otherwise treat the tissue, it is at the same time desirable to minimize or inhibit thermal spread, the heating of tissue external to the jaw members as a side effect of the application of energy to tissue grasped between the jaw members.
SUMMARY
[0005] As used herein, the term “distal” refers to the portion that is being described which is farther from an operator (whether a human surgeon or a surgical robot), while the term “proximal” refers to the portion that is being described which is closer to the operator. Terms including “generally,” “about,” “substantially,” and the like, as utilized herein, are meant to encompass variations, e.g., manufacturing tolerances, material tolerances, use and environmental tolerances, measurement variations, and/or other variations, up to and including plus or minus 10 percent. Further, any or all of the aspects described herein, to the extent consistent, may be used in conjunction with any or all of the other aspects described herein.
[0006] Provided in accordance with aspects of the present disclosure is an electrosurgical system which includes an end effector assembly having first and second jaw members each defining an electrically-conductive tissue-contacting surface. One or both of the first or second jaw members is movable relative to the other between a spaced-apart position and an approximated position for

grasping tissue between the tissue-contacting surfaces thereof. One or more light elements is operably associated with one or both jaw members and is oriented to project light onto tissue.
[0007] An electrosurgical generator is electrically coupled to the tissue-contacting surfaces and is configured to supply electrosurgical energy thereto for treating tissue grasped between the tissue-contacting surfaces. The electrosurgical generator is additionally coupled to the one or more light elements and one or more sensors configured to receive sensed data therefrom. The electrosurgical generator includes a controller configured, in real time, to: control the supply of electrosurgical energy to tissue; predict thermal spread beyond the first and second jaw members based at least on the sensed data; and modify the light projected onto tissue from the one or more light elements when it is determined that the predicted thermal spread is above a threshold thermal spread.
[0008] In aspects according to the present disclosure, the one or more sensors is disposed on one of the first or second jaw members. In other aspects according to the present disclosure, the one or more sensors is disposed adjacent an outer periphery of the one or more first or second jaw members.
[0009] In aspects according to the present disclosure, the one or more light elements is one or more light emitting diodes (LED). In other aspects according to the present disclosure, the one or more LEDs is configured to project light onto tissue by varying one or more of intensity, pattern, angle, or color. In still other aspects according to the present disclosure, the system includes two or more LEDs that vary in size and shape along the one or both jaw members.
[0010] In aspects according to the present disclosure, the controller is configured to predict the thermal spread based at least on sensed temperature data from the one or more sensors.
[0011] In aspects according to the present disclosure, the controller is configured to predict the thermal spread based sensed data from one or more sensors including one or more of temperature data, electrical feedback data including power, voltage, current, and impedance, tissue hydration data, or data relating to tissue thickness, tissue type, and tissue mass.
[0012] Provided in accordance with aspects of the present disclosure is an electrosurgical system which includes an end effector assembly having first and second jaw members each defining an electrically-conductive tissue-contacting surface. One or both of the first or second jaw members is movable relative to the other between a spaced-apart position and an approximated position for grasping tissue between the tissue-contacting surfaces thereof. One or more light emitting diodes (LED) is operably coupled to the electrically-conductive tissue-contacting surface of one or more of the jaw members and is oriented to project light onto tissue.
[0013] An electrosurgical generator is electrically coupled to the tissue-contacting surfaces and is configured to supply electrosurgical energy thereto for treating tissue grasped between the tissue-contacting surfaces. The electrosurgical generator is additionally coupled to the one or more LEDs and one or more sensors configured to receive sensed data therefrom. The electrosurgical generator includes a controller configured, in real time, to: control the supply of electrosurgical energy to tissue; predict thermal spread beyond the first and second jaw members based at least on the sensed data; and modify the light projected onto tissue from the one or more LEDs when it is determined that the predicted thermal spread is above a threshold thermal spread.
[0014] In aspects according to the present disclosure, the one or more sensors is disposed on one of the first or second jaw members. In other aspects according to the present disclosure, the one or more sensors is disposed adjacent an outer periphery of one of the first or second jaw members.
[0015] In aspects according to the present disclosure, the system includes a series of LEDs disposed around a side of the electrically-conductive tissue-contacting surface of one or more of the jaw members. In aspects according to the present disclosure, the LEDs are configured to project light onto tissue by varying one or more of intensity, pattern, angle, or color.
[0016] In aspects according to the present disclosure, the series of LEDs vary in size and shape along the side of the electrically-conductive tissue-contacting surface of one or more jaw members.
[0017] In aspects according to the present disclosure, the controller is configured to predict the

thermal spread based at least on sensed temperature data from the one or more sensors and control one or more of intensity, color, pattern or angle of the one or more LEDs thereon.
[0018] In aspects according to the present disclosure, the controller is configured to predict the thermal spread based sensed data from one or more sensors including one or more of temperature data, electrical feedback data including power, voltage, current, and impedance, tissue hydration data, or data relating to tissue thickness, tissue type, and tissue mass.
[0019] Provided in accordance with aspects of the present disclosure is an electrosurgical system which includes a housing having a shaft extending therefrom. An end effector assembly is operably coupled to a distal end of the shaft and includes first and second jaw members each defining an electrically-conductive tissue-contacting surface. One or both of the first or second jaw members is movable relative to the other between a spaced-apart position and an approximated position for grasping tissue between the tissue-contacting surfaces thereof. One or more light emitting diodes (LED) is operably coupled to a distal end of the shaft and is oriented to project light onto tissue disposed between the jaw members.
[0020] An electrosurgical generator is electrically coupled to the tissue-contacting surfaces and is configured to supply electrosurgical energy thereto for treating tissue grasped between the tissue-contacting surfaces. The electrosurgical generator is additionally coupled to the one or more LEDs and one or more sensors configured to receive sensed data therefrom. The electrosurgical generator includes a controller configured, in real time, to: control the supply of electrosurgical energy to tissue; predict thermal spread beyond the first and second jaw members based at least on the sensed data; and modify the light projected onto tissue from the one or more LEDs when it is determined that the predicted thermal spread is above a threshold thermal spread.
[0021] In aspects according to the present disclosure, the one or more LEDs is ring-like and is configured to encompass the distal end of the shaft.
[0022] In aspects according to the present disclosure, the one or more LEDs is configured to project light onto tissue by varying at least one of intensity, pattern, angle, or color.
[0023] In aspects according to the present disclosure, the controller is configured to predict the thermal spread based at least on sensed temperature data from the one or more sensors and control one or more of intensity, color, pattern or angle of the one or more LEDs thereon.
[0024] In aspects according to the present disclosure, the controller is configured to predict the thermal spread based sensed data from one or more sensors including one or more of temperature data, electrical feedback data including power, voltage, current, and impedance, tissue hydration data, or data relating to tissue thickness, tissue type, and tissue mass.

Description

BRIEF DESCRIPTION OF DRAWINGS
[0025] The above and other aspects and features of the present disclosure will become more apparent in view of the following detailed description when taken in conjunction with the accompanying drawings wherein like reference numerals identify similar or identical elements.
[0026] FIG. **1** is a perspective view of a shaft-based electrosurgical forceps provided in accordance with the present disclosure connected to an electrosurgical generator;
[0027] FIG. **2**A is a perspective view of a distal end portion of the forceps of FIG. **1**, wherein the jaw members of the end effector assembly of the forceps are disposed in a spaced-apart position;
[0028] FIG. **2**B is a perspective view of the distal end portion of the forceps of FIG. **2**A, wherein the jaw members are disposed in an approximated position;
[0029] FIG. **2**C is a perspective view of the distal end portion of an alternative embodiment of a jaw member with a series of LEDs for use in accordance with the forceps of FIG. **2**A;
[0030] FIG. **2**D is a perspective view of the distal end portion of an alternative embodiment of a

pair of jaw members with a ring-like LED for use in accordance with the forceps of FIG. **2**A;
[0031] FIG. **3** is a perspective view of a hemostat-style electrosurgical forceps provided in accordance with the present disclosure;
[0032] FIG. **4** is a schematic illustration of a robotic surgical instrument provided in accordance with the present disclosure;
[0033] FIG. **5** is a block diagram of the electrosurgical generator of FIG. **1**;
[0034] FIG. **6** is a block diagram of a controller of the electrosurgical generator of FIG. **5**;
[0035] FIG. **7** is a logic diagram of a machine learning algorithm in accordance with the present disclosure;
[0036] FIGS. **8** and **9** are transverse, cross-sectional views of the jaw members of the end effector assembly of FIG. **2**A shown grasping tissue therebetween and including different configurations of at least one temperature sensor incorporated therein; and
[0037] FIG. **10** is a transverse, cross-sectional view of the jaw members of the end effector assembly of FIG. **2**A shown grasping tissue therebetween and including an external temperature sensing device associated therewith.

DETAILED DESCRIPTION

[0038] The present disclosure provides energy-based surgical systems and methods utilizing light for predicting and providing feedback for controlling thermal spread. Various exemplary energy-based surgical instruments and systems are detailed below; however, the aspects and features of the present disclosure are not limited thereto as any other suitable energy-based surgical instruments and/or systems are also contemplated for use in accordance with the present disclosure.
[0039] Referring to FIG. **1**, a shaft-based electrosurgical forceps provided in accordance with the present disclosure is shown generally identified by reference numeral **10**. Aspects and features of forceps **10** not germane to the understanding of the present disclosure are omitted to avoid obscuring the aspects and features of the present disclosure in unnecessary detail.
[0040] Forceps **10** includes a housing **20**, a handle assembly **30**, a trigger assembly **60**, a rotating assembly **70**, an activation switch **80**, and an end effector assembly **100**. Forceps **10** further includes a shaft **12** having a distal end portion **14** configured to (directly or indirectly) engage end effector assembly **100** and a proximal end portion **16** that (directly or indirectly) engages housing **20**. Forceps **10** also includes cable **90** that connects forceps **10** to an electrosurgical generator **400**. Cable **90** includes a wire (or wires) (not shown) extending therethrough that has sufficient length to extend through shaft **12** in order to provide energy to one or both tissue-contacting surfaces **114**, **124** of jaw members **110**, **120**, respectively, of end effector assembly **100** (see FIGS. **2**A and **2**B). In aspects, bipolar Radio Frequency (RF) is conducted between tissue-contacting surfaces **114**, **124** of jaw members **110**, **120**, respectively, by energizing tissue-contacting surfaces **114**, **124** to different potentials to establish a potential gradient therebetween, although other suitable energy configurations and/or energy modalities are also contemplated. Activation switch **80** is coupled to tissue-contacting surfaces **114**, **124** (FIGS. **2**A and **2**B) and electrosurgical generator **400** for enabling the selective activation of the supply of energy to jaw members **110**, **120** for treating, e.g., sealing, tissue.
[0041] Handle assembly **30** of forceps **10** includes a fixed handle **50** and a movable handle **40** (although both handles **40**, **50** may move, in aspects). Fixed handle **50** is integrally associated with housing **20** and handle **40** is movable relative to fixed handle **50**. Movable handle **40** of handle assembly **30** is operably coupled to a drive assembly (not shown) that, together, mechanically cooperate to impart movement of one or both of jaw members **110**, **120** of end effector assembly **100** about a pivot **103** between a spaced-apart position (FIG. **2**A) and an approximated position (FIG. **2**B) to grasp tissue between jaw members **110**, **120**. As shown in FIG. **1**, movable handle **40** is initially spaced-apart from fixed handle **50** and, correspondingly, jaw members **110**, **120** of end effector assembly **100** are disposed in the spaced-apart position. Movable handle **40** is depressible from this initial position to a depressed position corresponding to the approximated position of jaw

members **110**, **120** (FIG. **2**B).

[0042] Trigger assembly **60** includes a trigger **62** coupled to housing **20** and movable relative thereto between an un-actuated position and an actuated position. Trigger **62** is operably coupled to a knife **64** (FIG. **2**A), so as to actuate knife **64** (FIG. **2**A) to cut tissue grasped between jaw members **110**, **120** of end effector assembly **100** upon actuation of trigger **62**. As an alternative to knife **64**, other suitable mechanical, electrical, or electromechanical cutting mechanisms (stationary or movable) are also contemplated.

[0043] With additional reference to FIGS. **2**A and **2**B, end effector assembly **100**, as noted above, includes first and second jaw members **110**, **120**. Each jaw member **110**, **120** includes a proximal flange portion **111**, **121**, an outer insulative jaw housing **112**, **122** disposed about the distal portion (not explicitly shown) of each jaw member **110**, **120**, and a tissue-contacting surface **114**, **124**, respectively. Proximal flange portions **111**, **121** are pivotably coupled to one another about pivot **103** for moving jaw members **110**, **120** between the spaced-apart and approximated positions, although other suitable mechanisms for pivoting jaw members **110**, **120** relative to one another are also contemplated. The distal portions of jaw members **110**, **120** are configured to support jaw housings **112**, **122**, and tissue-contacting surfaces **114**, **124**, respectively, thereon.

[0044] Outer insulative jaw housings **112**, **122** of jaw members **110**, **120** support and retain tissue-contacting surfaces **114**, **124** on respective jaw members **110**, **120** in opposed relation relative to one another. Tissue-contacting surfaces **114**, **124** are at least partially formed from an electrically conductive material, e.g., for conducting electrical energy therebetween for treating tissue, although tissue-contacting surfaces **114**, **124** may alternatively be configured to conduct any suitable energy, e.g., thermal, microwave, light, ultrasonic, etc., through tissue grasped therebetween for energy-based tissue treatment. As mentioned above, tissue-contacting surfaces **114**, **124** are coupled to activation switch **80** and electrosurgical generator **400**, e.g., via the wires extending from cable **90** through forceps **10**, such that energy may be selectively supplied to tissue-contacting surface **114** and/or tissue-contacting surface **124** and conducted therebetween and through tissue disposed between jaw members **110**, **120** to treat tissue.

[0045] Continuing with reference to FIGS. **2**A and **2**B, end effector assembly **100** further includes a light element **150** for projecting or illuminating light onto tissue. For example, a single LED strip **150***a* (or a series of LEDs **150***b*—hereinafter collectively “LEDs **150**”) may be disposed on one or both jaw members **110**, **120** on respective outer housings **112**, **122**. As can be appreciated, any number of LEDs **150** (or other type of light source) are used to provide a halo-like effect around the jaw members **110**, **120** to predict or to demonstrate one or more tissue conditions, e.g., thermal spread, relative to or around the jaw members **110**, **120** based on one or more tissue parameters or tissue feedback taken from one or more tissue sensors, e.g., generally identified as sensors **401** disposed within generator **400**. Tissue parameters such as tissue impedance, tissue temperature, tissue hydration, tissue thickness, power, dz/dt, or other generator settings may be utilized alone or in combination for this purpose and programmed to interact with the LEDs **150** to produce a desired effect for visual feedback for the surgeon. For the purpose herein, thermal spread is initially discussed.

[0046] For example, the intensity of the LEDs **150** reflected or illuminated onto the tissue adjacent the jaw members **110**, **120** can be managed to indicate the predicted thermal spread relative to the jaw members **110**, **120** based on tissue feedback from one or more tissue parameters or tissue feedback taken from one or more tissue sensors **401**, e.g., tissue impedance, tissue temperature, tissue hydration, or other generator settings. In embodiments, the LEDs **150** may be programmed to include a pattern or color-coded (or change in color) to reflect thermal spread and illuminate the tissue for visual feedback to the surgeon. For example, the LEDs **150** may change from green to varying levels of red to reflect a worsening thermal spread condition or the LEDs **150** may start flashing in greater intensity as thermal spread worsens or spreads beyond a preferred distance from the jaw members **110**, **120**.

[0047] In embodiments, the LEDs **150** may be utilized to reflect other tissue properties or additional tissue properties. For example, the LEDs **150** may be utilized or programmed to provide passive feedback relating to the tissue impedance proximate the outer periphery of the jaw members **110**, **120** or proximate the outer jaw housings **112**, **122** to located critical structures such as nerves. Similar to above, color coding or flashing patterns may be utilized in this instance as well. In other embodiments, the LEDs **150** could be programmed to reflect safe handling temperatures of the jaw members **110**, **120** or tissue proximate the jaw members **110**, **120** after a completed seal cycle.

[0048] The same or a different set of LEDs **150** may be utilized for other purposes. In embodiments, various sensors (not shown) may be employed to analyze the light reflected through or back from tissue emanating from the LEDs **150** via one or more optical sensors or the like. For example, tissue hydration levels may be determined by analyzing the light reflected through tissue and this information may be used by the generator **400** to control power during a sealing cycle to regulate, among other things, e.g., a sealing cycle duration or even to control thermal spread.

[0049] As best shown in FIG. **2**C, a series of LEDs **150** may also be disposed below and around the entire peripheral side of a seal plate, e.g., side **124***b* of seal plate **124**, and positioned to reflect towards tissue grasped between jaw members, e.g., jaw member **120** is shown. Any pattern of LEDs **150** (strips or shapes) in varying sizes, colors and intensities is contemplated depending upon a particular purpose. For example, an LED strip **150***c* may be disposed around a distal end, e.g., distal end **124***a* of the seal plate **124** of jaw member **120** which may have a higher intensity to illuminate tissue distal to jaw member **120** and allow the surgeon to better visualize the tissue and tissue properties as described above for dissection purposes. The LEDs **150** on the side **124***b* of sealing plate **124** may be programmed to predict lateral thermal spread therefrom by altering color or pattern as described above.

[0050] FIG. **2**D shows another embodiment of a jaw member **120** having a series of LEDs **150** disposed around a portion or ring **160** which operably engages or abuts the distal end **14** of the shaft **12**. The ring **160** houses LEDs **150** and may be selectively engageable, programmable and positionable on the shaft **12** to illuminate towards tissue grasped between jaw members **110**, **120**. Any pattern of LEDs **150** (strips or shapes) in varying sizes, colors and intensities is contemplated depending upon a particular purpose and the ring **160** may be utilized with any of the LEDs **150** described above depending upon a particular purpose. The ring **160** itself may be a single LED that fits atop the distal end of the shaft **12** and may be configured to illuminate in different directions or angles depending upon a particular purpose. For example, the ring **160** may be configured to or programmed to illuminate toward or adjacent to tissue when being utilized to identify thermal spread, or for dissection or visualization, etc. and, in some instance, the ring **160** may be programmed to illuminate proximally when retracting the forceps **10** from tissue to allow the surgeon to avoid critical tissue or sensitive tissue structures.

[0051] Referring to FIG. **3**, a hemostat-style electrosurgical forceps provided in accordance with the present disclosure is shown generally identified by reference numeral **310**. Aspects and features of forceps **310** not germane to the understanding of the present disclosure are omitted to avoid obscuring the aspects and features of the present disclosure in unnecessary detail.

[0052] Forceps **310** includes two elongated shaft members **312***a*, **312***b*, each having a proximal end portion **316***a*, **316***b*, and a distal end portion **314***a*, **314***b*, respectively. Forceps **310** is configured for use with an end effector assembly **100**′ similar to end effector assembly **100** (FIGS. **2**A and **2**B). More specifically, end effector assembly **100**′ includes first and second jaw members **110**′, **120**′ attached to respective distal end portions **314***a*, **314***b* of shaft members **312***a*, **312***b*. Jaw members **110**′, **120**′ are pivotably connected about a pivot **103**′. Each shaft member **312***a*, **312***b* includes a handle **317***a*, **317***b* disposed at the proximal end portion **316***a*, **316***b* thereof. Each handle **317***a*, **317***b* defines a finger hole **318***a*, **318***b* therethrough for receiving a finger of the user. As can be appreciated, finger holes **318***a*, **318***b* facilitate movement of the shaft members **312***a*, **312***b* relative to one another to, in turn, pivot jaw members **110′**, **120′** from the spaced-apart position, wherein jaw members **110′**, **120′** are disposed in spaced relation relative to one another, to the approximated position, wherein jaw members **110′**, **120′** cooperate to grasp tissue therebetween.

[0053] One of the shaft members **312***a*, **312***b* of forceps **310**, e.g., shaft member **312***b*, includes a proximal shaft connector **319** configured to connect forceps **310** to electrosurgical generator **400** (FIG. **1**). Proximal shaft connector **319** secures a cable **390** to forceps **310** such that the user may selectively supply energy to jaw members **110′**, **120′** for treating tissue. More specifically, an activation switch **380** is provided for supplying energy to jaw members **110′**, **120′** to treat tissue upon sufficient approximation of shaft members **312***a*, **312***b*, e.g., upon activation of activation switch **380** via shaft member **312***a*.

[0054] Forceps **310** further includes a trigger assembly **360** including a trigger **362** coupled to one of the shaft members, e.g., shaft member **312***a*, and movable relative thereto between an un-actuated position and an actuated position. Trigger **362** is operably coupled to a knife (not shown; similar to knife **64** (FIG. **2**A) of forceps **10** (FIG. **1**)) so as to actuate the knife to cut tissue grasped between jaw members **110′**, **120′** of end effector assembly **100′** upon movement of trigger **362** to the actuated position. Similarly as noted above with respect to forceps **10** (FIG. **1**), other suitable cutting mechanisms are also contemplated.

[0055] Referring to FIG. **4**, a robotic surgical instrument provided in accordance with the present disclosure is shown generally identified by reference numeral **1000**. Aspects and features of robotic surgical instrument **1000** not germane to the understanding of the present disclosure are omitted to avoid obscuring the aspects and features of the present disclosure in unnecessary detail.

[0056] Robotic surgical instrument **1000** includes a plurality of robot arms **1002**, **1003**; a control device **1004**; and an operating console **1005** coupled with control device **1004**. Operating console **1005** may include a display device **1006**, which may be set up in particular to display three-dimensional images; and manual input devices **1007**, **1008**, by means of which a surgeon may be able to telemanipulate robot arms **1002**, **1003** in a first operating mode. Robotic surgical instrument **1000** may be configured for use on a patient **1013** lying on a patient table **1012** to be treated in a minimally invasive manner. Robotic surgical instrument **1000** may further include a database **1014**, in particular coupled to control device **1004**, in which are stored, for example, pre-operative data from patient **1013** and/or anatomical atlases.

[0057] Each of the robot arms **1002**, **1003** may include a plurality of members, which are connected through joints, and an attaching device **1009**, **1011**, to which may be attached, for example, an end effector assembly **1100**, **1200**, respectively. End effector assembly **1100** is similar to end effector assembly **100** (FIGS. **2**A-**2**D), although other suitable end effector assemblies for coupling to attaching device **1009** are also contemplated. End effector assembly **1100** is connected to electrosurgical generator **400** (FIG. **1**), which may be integrated into or separate from robotic surgical instrument **1000**. End effector assembly **1200** may be any end effector assembly, e.g., an endoscopic camera, other surgical tool, etc. Robot arms **1002**, **1003** and end effector assemblies **1100**, **1200** may be driven by electric drives, e.g., motors, that are connected to control device **1004**. Control device **1004** (e.g., a computer) may be configured to activate the motors, in particular by means of a computer program, in such a way that robot arms **1002**, **1003**, their attaching devices **1009**, **1011**, and end effector assemblies **1100**, **1200** execute a desired movement and/or function according to a corresponding input from manual input devices **1007**, **1008**, respectively. Control device **1004** may also be configured in such a way that it regulates the movement of robot arms **1002**, **1003** and/or of the motors.

[0058] Referring to FIG. **1**-**2**D and **5**, electrosurgical generator **400** is shown as a schematic block diagram. Generator **400** may be utilized as a stand-alone generator (as shown in FIG. **1**), may be incorporated into a surgical instrument **10**, **310**, **1000** (FIGS. **1**, **3**, and **4**, respectively), or may be provided in any other suitable manner. Generator **400** includes sensor circuitry **422**, a controller **424**, a high voltage DC power supply (“HVPS”) **426** and an RF output stage **428**. Sensor circuitry

422 is configured to receive sensor feedback, e.g., feedback representative of temperature from temperature sensor(s) **250**, and to relay the same to controller **424**. Voltage, current, power, impedance, and/or other electrical feedback associated with the delivery of energy, e.g., bipolar RF energy, to tissue may also be communicated to controller **424** to control the energy output. Further, controller **424** may implement and track the progression of energy-delivery (e.g., for sealing tissue), and/or the progression of an implemented energy-delivery algorithm (e.g., a tissue sealing algorithm), such as, for example, by determining a stage of the tissue sealing algorithm, a time remaining to completion of tissue sealing, etc. This progression status information related to tissue sealing (or other tissue treatment) may be utilized for various purposes, such as detailed below.

[0059] Controller **424** is configured to control the output of energy from HVPS **426** to RF output stage **428** and, thus, the application of energy from tissue-contacting surfaces **114**, **124** of jaw members **110**, **120** to tissue grasped therebetween. HVPS **426**, under the direction of controller **424**, provides high voltage DC power to RF output stage **428** which converts the high voltage DC power into bipolar RF energy for delivery to tissue-contacting **114**, **124** of jaw members **110**, **120**, respectively, of end effector assembly **100** (see FIGS. **2**A and **2**B). In particular, RF output stage **428** generates sinusoidal waveforms of high frequency RF energy. RF output stage **428** may be configured to generate waveforms having various duty cycles, peak voltages, crest factors, and other properties. Other suitable configurations are also contemplated such as for example, pulsed energy output, other waveforms, etc.

[0060] In aspects, controller **424** of generator **400** may control energy delivery in accordance with a tissue sealing algorithm to seal tissue grasped between tissue-contacting **114**, **124** of jaw members **110**, **120**, respectively, of end effector assembly **100** such as, for example, the tissue sealing algorithm detailed in U.S. Pat. No. 9,186,200 entitled "System and Method for Tissue Sealing" and issued on Nov. 17, 2015, or the tissue sealing algorithm detailed in U.S. Pat. No. 10,617,463 entitled "System and Method for Controlling Power in an Electrosurgical Generator" and issued on Apr. 14, 2020, the entire contents of each of which is hereby incorporated herein by reference.

[0061] With additional reference to FIG. **6**, controller **424** includes a processor **520** connected to a computer-readable storage medium or a memory **530** which may be a volatile type memory, e.g., RAM, or a non-volatile type memory, e.g., flash media, disk media, etc. In aspects, processor **520** may be, without limitation, a digital signal processor, a microprocessor, an ASIC, a graphics processing unit (GPU), field-programmable gate array (FPGA), or a central processing unit (CPU). Memory **530** can be random access memory, read-only memory, magnetic disk memory, solid state memory, optical disc memory, and/or another type of memory. In aspects, memory **530** can be separate from controller **424** and can communicate with processor **520** through communication buses of a circuit board and/or through communication cables such as serial ATA cables or other types of cables. Memory **530** includes computer-readable instructions that are executable by processor **520** to operate controller **424**. Controller **424** includes a network interface **540** to communicate with other computers or a server. In aspects, a storage device **510** may be used for storing data. In aspects, controller **424** may include one or more FPGAs **550**. FPGA **550** may be used for executing various algorithms, e.g., fixed algorithms, machine learning algorithms, etc.

[0062] Memory **530** stores suitable instructions, to be executed by processor **520**, for receiving the sensed data, e.g., sensed temperature data from sensor circuitry **422** (FIG. **5**) and/or any other suitable feedback or other data, accessing storage device **510** of controller **424**, and predicting thermal spread based upon the sensed data and/or other data, in real time. Memory **530** further stores suitable instructions, to be executed by processor **520**, to provide an alert to the user, e.g., an audible alert (such as a tone), a visual alert (such as a flashing light), and/or a tactile alert (such as vibration of housing **20** (FIG. **1**)), based upon the predicted thermal spread and/or to control energy delivery based thereon. Although illustrated as part of generator **400**, it is also contemplated that controller **424** may be remote from generator **400**, e.g., on a remote server, and accessible by generator **400** via a wired or wireless connection. In configurations where controller **424** is remote, it is contemplated that controller **424** may be accessible by and connected to multiple generators **400**.

[0063] Controller **424**, more specifically, is configured to receive the sensor feedback from sensor circuitry **422** regarding the sensed temperature(s) and/or to receive or otherwise utilize other feedback data (including, for example, the progression status information, electrical feedback data, etc.) to predict thermal spread in real time during the application of energy to tissue. Based on the predicted thermal spread, controller **424** may output a suitable alert to the user indicating that a potentially unacceptable amount of thermal spread (e.g., an amount of thermal spread exceeding a thermal spread threshold in volumetric size, distance from jaw members **110**, **120**, and/or temperature) has been predicted. Additionally or alternatively, controller **424** may be configured to automatically control the output of energy from HVPS **426** to RF output stage **428** such that thermal spread can be avoided or minimized (in volumetric size, distance from jaw members **110**, **120**, and/or temperature) to below a threshold amount of thermal spread. In this instance, the controller **424**, which is also coupled to the LEDs **150**, alters one or more of the color, intensity, angle, pattern, or other aspect of the LEDs **150** to alert the user of the predicted thermal spread condition.

[0064] That is, rather than determining a prior, present, or immediate future amount of thermal spread (which may thus be unavoidable and/or irreversible), controller **424** is configured to predict the progression of thermal spread sufficiently far into the future (e.g., 1 second, 3 seconds, 5 seconds, etc. in the future) to enable, in instances where an unacceptable amount of thermal spread is predicted, an alert to be provided, via LEDs **150**, to the user for the user modify the tissue treatment, and/or to control energy-delivery automatically (e.g., to control energy-delivery parameters, stop energy delivery altogether, etc.). If the user determines (visually) that the predicted thermal spread is within acceptable limits, the energy-delivery may continue without modification. In this manner, predicted unacceptable thermal spread can be avoided before unintended tissue damage occurs. It is noted that the prediction of thermal spread need not be made with regard to a pre-set or pre-determined future time but, rather, the future time may be dynamically selected based on, for example, an estimated sealing time remaining, the tissue treatment being performed, etc.

[0065] Predicting thermal spread, as mentioned above, is based on temperature data and/or other feedback data such as, for example, electrical feedback data (e.g., voltage, current, power, impedance, hydration, tissue thickness, etc.), the progression status information, etc. The other feedback data may also include, for example, tissue mass data, jaw angle data, tissue type data, etc. Non-feedback data such as, for example, retrieved or input patient data, retrieved or input data relating to the procedure to be performed, etc. may also be utilized. Further, coefficient data may be stored, obtained, or otherwise provided for utilization such as, for example, thermal conductivity of tissue (in aspects, of the particular tissue type, tissue mass, etc. identified), thermal conductivity of the particular end effector assembly **100** (FIG. **1**) utilized, etc. The temperature data, electrical data, and/or other data may be snapshot data (e.g., at a particular moment in time) or may be trend data (e.g., changing over time). In aspects, as noted above, the temperature data may be temperature data associated with the outer periphery of jaw members **110**, **120** (see FIGS. **2**A-**2**D) and/or the environment and/or tissue adjacent thereto; in other aspects, the temperature data may be temperature data associated with tissue-contacting surfaces **114**, **124** of jaw members **110**, **120** and/or tissue disposed therebetween. In aspects, at least the temperature data and impedance data are utilized to predict thermal spread. In additional or alternative aspects, the progression status information is utilized in the prediction of thermal spread by enabling determination of whether thermal spread and/or the rate thereof is likely to increase, decrease, or stay the same based on the present and/or upcoming expected energy delivery parameters or energy delivery stage(s). For example, even where the present temperature, thermal spread, and/or other conditions are the same, the predicted thermal spread may be different in a situation where tissue treatment is close to completion or where a drop off in energy application (or thermal conductivity of tissue) is expected, as compared to a situation where an increase in energy application (or thermal conductivity of tissue) is expected.

[0066] Regardless of the particular data utilized, thermal spread may be predicted, for example, by plotting the data along one or more curves, utilizing one or more look-up tables, matching the data to empirical or theoretical (e.g., modeled) data and the corresponding results, inputting the data into a one or more fixed algorithms, and/or in any other suitable manner or combinations of manners. In aspects, machine learning is utilized to predict or facilitate the prediction of thermal spread, as detailed below.

[0067] With reference to FIGS. **6** and **7**, in aspects where one or more machine learning machine learning algorithms **608** are used, storage device **510** of controller **424** stores the one or more machine learning algorithms **608**. The machine learning algorithm(s) **608** may be trained on and learn from stored settings **604**, e.g., theoretical data, empirical data, and/or other data initially input into the one or more machine learning applications, and/or the sensed data **602** from sensor circuitry **422** (FIG. **5**) (or other sensed, feedback, or input data) in order to enable the machine learning application(s) to output a prediction of thermal spread **610**. In aspects, training the machine learning algorithm may be performed by a computing device outside of generator **400** and the resulting algorithm may be communicated to controller **424** of generator **400**.

[0068] Turning back to FIGS. **1**-**2**D, **5**, and **6**, in aspects, controller **424** utilizes the predicted thermal spread and communicates the same to a computing device, e.g., of controller **424**, for use in controlling the output of energy from HVPS **426** to RF output stage **428**. This controlling may include starting, continuing, modifying, or stopping the output of energy. More specifically: a tissue treating algorithm stored in storage device **510** of controller **424** may be implemented, modified, stopped, switched to another tissue treating algorithm, etc.; the waveform output may be modified, stopped, switched to another tissue treating waveform; a setting may be changed, e.g., power may be increased or decreased; and/or an energy output time may be increased or decreased. That is, the energy output is adapted, e.g., reduced, if necessary, in accordance with the predicted thermal spread. In this manner, undesirable predicted thermal spread can be avoided before any potential tissue damage occurs or to minimize potential tissue damage. Where the predicted thermal spread is within acceptable limits, the output of energy from HVPS **426** to RF output stage **428** may be unchanged. In other aspects, where the predicted thermal spread is within acceptable limits (and sufficiently minimal), the output of energy from HVPS **426** to RF output stage **428** may be modified, e.g., increased, to, for example, expedite the tissue treatment.

[0069] The particular control to be implemented, if deemed necessary based on the predicted thermal spread, may be determined, for example, by plotting the data along one or more curves, utilizing one or more look-up tables, matching the data to empirical or theoretical (e.g., modeled) data and the corresponding results, inputting the data into a one or more fixed algorithms, utilizing one or more machine learning algorithms, and/or in any other suitable manner or combinations of manners.

[0070] Turning to FIGS. **8**-**10**, detailed below are aspects of temperature sensor configurations incorporated into or associated with jaw member **110** and/or jaw member **120** of end effector assembly **100** (or any other end effector assembly detailed herein or suitable for use in accordance with the present disclosure) for providing the temperature data for use in predicting thermal spread. More specifically, as detailed above, the temperature sensor(s) is configured to communicate sensor feedback to sensor circuitry **422** of generator **400** (see FIG. **5**) which, in turn, is configured to communicate with controller **424** (see FIG. **6**) to enable the prediction of thermal spread in real time during the application of energy to tissue. It is contemplated that other types of sensors may be utilized for similar purposes, impedance, hydration, etc.

[0071] Referring to FIG. **8**, in aspects, first and second temperature sensors **732** are disposed on opposing lateral sides of jaw member **110**, although additional or alternate temperature sensors **732** may be disposed on opposing lateral sides of jaw member **120** and/or only one temperature sensor **732** on one lateral side (of either or both jaw members **110**, **120** on the same or different sides) may be provided. Temperature sensors **732**, positioned in this manner, enable sensing of: temperatures of the peripheral edges of jaw members **110**, **120**; a temperature of an exterior surface of one or both of jaw members **110**, **120**; a temperature of an exterior environment adjacent one or both of jaw members **110**, **120**; and/or a temperature of tissue exterior of and adjacent to one or both of jaw members **110**, **120**.

[0072] With reference to FIG. **9**, in aspects, first and second temperature sensors **732** are disposed on jaw members **110**, **120** and associated with respective tissue-contacting surfaces **114**, **124** thereof, although a temperature sensor **732** may be disposed on only one of jaw members **110**, **120**. Temperature sensors **732**, positioned in this manner, enable sensing of a temperature of one or both of tissue-contacting surfaces **114**, **124** and/or a temperature of tissue disposed between tissue-contacting surfaces **114**, **124**.

[0073] As shown in FIG. **10**, temperature sensing may be provided by a device **740** external and independent of end effector assembly **100**. Device **740** may be, for example, a thermal camera, infrared scanner, or other suitable temperature sensing device including one or more temperature sensors **742**. Temperature sensor(s) **742** may be positioned to enable sensing of: a temperature of the peripheral edge(s) of jaw member(s) **110**, **120**; a temperature of an exterior surface of end effector assembly **100**; a temperature of an exterior environment adjacent end effector assembly **100**; and/or a temperature of tissue exterior of and adjacent to end effector assembly **100**. Other suitable locations and/or configurations of temperature sensors, including combinations of the above and/or other suitable temperature sensors, whether incorporated into end effector assembly **100** or remote therefrom, are also contemplated.

[0074] As mentioned above, LEDs **150** may be utilized to alert the user of other predictable tissue conditions in addition to thermal spread based on other types of sensors or feedback from various tissue parameters during the sealing process, impedance, steam, temperature, power, dz/dt, or other generator settings.

[0075] It should be understood that various aspects disclosed herein may be combined in different combinations than the combinations specifically presented hereinabove and in the accompanying drawings. In addition, while certain aspects of the present disclosure are described as being performed by a single module or unit for purposes of clarity, it should be understood that the techniques of this disclosure may be performed by a combination of units or modules associated with, for example, a surgical system.

[0076] In one or more examples, the described techniques may be implemented in hardware, software, firmware, or any combination thereof. If implemented in software, the functions may be stored as one or more instructions or code on a computer-readable medium and executed by a hardware-based processing unit. Computer-readable media may include non-transitory computer-readable media, which corresponds to a tangible medium such as data storage media (e.g., RAM, ROM, EEPROM, flash memory, or any other medium that can be used to store desired program code in the form of instructions or data structures and that can be accessed by a computer).

[0077] Instructions may be executed by one or more processors, such as one or more digital signal processors (DSPs), general purpose microprocessors, application specific integrated circuits (ASICs), field programmable logic arrays (FPGAs), or other equivalent integrated or discrete logic circuitry. Accordingly, the term “processor” as used herein may refer to any of the foregoing structures or any other physical structure suitable for implementation of the described techniques. Also, the techniques could be fully implemented in one or more circuits or logic elements.

[0078] While several aspects of the disclosure have been shown in the drawings, it is not intended that the disclosure be limited thereto, as it is intended that the disclosure be as broad in scope as the art will allow and that the specification be read likewise. Therefore, the above description should not be construed as limiting, but merely as exemplifications of particular configurations. Those skilled in the art will envision other modifications within the scope and spirit of the claims appended hereto.

Claims

1. An electrosurgical system, comprising: an end effector assembly including first and second jaw members each defining an electrically-conductive tissue-contacting surface, at least one of the first or second jaw members movable relative to the other between a spaced-apart position and an approximated position for grasping tissue between the tissue-contacting surfaces thereof; at least one light element operably associated with at least one jaw member and oriented to project light onto tissue; and an electrosurgical generator electrically coupled to the tissue-contacting surfaces and configured to supply electrosurgical energy thereto for treating tissue grasped between the tissue-contacting surfaces, the electrosurgical generator additionally coupled to the at least one light element and at least one sensor configured to receive sensed data therefrom, wherein the electrosurgical generator includes a controller configured, in real time, to: control the supply of electrosurgical energy to tissue; predict thermal spread beyond the first and second jaw members based at least on the sensed data; and modify the light projected onto tissue from the at least one light element when it is determined that the predicted thermal spread is above a threshold thermal spread.
2. The electrosurgical system according to claim 1, wherein the at least one sensor is disposed on one of the first or second jaw members.
3. The electrosurgical system according to claim 2, wherein the at least one sensor is disposed adjacent an outer periphery of the at least one of the first or second jaw members.
4. The electrosurgical system according to claim 1, wherein the at least one light element is at least one light emitting diode (LED).
5. The electrosurgical system according to claim 4, wherein the at least one LED is configured to project light onto tissue by varying at least one of intensity, pattern, angle, or color.
6. The electrosurgical system according to claim 4, wherein the system includes at least two LEDs that vary in size and shape along the at least one jaw member.
7. The electrosurgical system according to claim 1, wherein the controller is configured to predict the thermal spread based at least on sensed data from the at least one sensor including at least one of temperature data, electrical feedback data including power, voltage, current, and impedance, tissue hydration data, or data relating to tissue thickness, tissue type, and tissue mass.
8. An electrosurgical system, comprising: an end effector assembly including first and second jaw members each defining an electrically-conductive tissue-contacting surface, at least one of the first or second jaw members movable relative to the other between a spaced-apart position and an approximated position for grasping tissue between the tissue-contacting surfaces thereof; at least one light emitting diode (LED) operably coupled to the electrically-conductive tissue-contacting surface of at least one jaw member and oriented to project light onto tissue; and an electrosurgical generator electrically coupled to the tissue-contacting surfaces and configured to supply electrosurgical energy thereto for treating tissue grasped between the tissue-contacting surfaces, the electrosurgical generator additionally coupled to the at least one light element and at least one sensor configured to receive sensed data therefrom, wherein the electrosurgical generator includes a controller configured, in real time, to: control the supply of electrosurgical energy to tissue; predict thermal spread beyond the first and second jaw members based at least on the sensed data; and modify the light projected onto tissue from the at least one LED when it is determined that the predicted thermal spread is above a threshold thermal spread.
9. The electrosurgical system according to claim 8, wherein the at least one sensor is disposed on one of the first or second jaw members.
10. The electrosurgical system according to claim 8, wherein the at least one sensor is disposed

adjacent an outer periphery of the at least one of the first or second jaw members.

11. The electrosurgical system according to claim 8, wherein the system includes a series of LEDs disposed around a side of the electrically-conductive tissue-contacting surface of the at least one jaw member.

12. The electrosurgical system according to claim 11, wherein the LEDs are configured to project light onto tissue by varying at least one of intensity, pattern, angle, or color.

13. The electrosurgical system according to claim 11, wherein the series of LEDs vary in size and shape along the side of the electrically-conductive tissue-contacting surface of the at least one jaw member.

14. The electrosurgical system according to claim 8, wherein the controller is configured to predict the thermal spread based at least on sensed temperature data from the at least one sensor and control at least one of the intensity, color, pattern or angle of the at least one LED thereon.

15. The electrosurgical system according to claim 8, wherein the controller is configured to predict the thermal spread based at least on sensed data from the at least one sensor including at least one of temperature data, electrical feedback data including power, voltage, current, and impedance, tissue hydration data, or data relating to tissue thickness, tissue type, and tissue mass.

16. An electrosurgical system, comprising: a housing having a shaft extending therefrom; an end effector assembly operably coupled to a distal end of the shaft and including first and second jaw members each defining an electrically-conductive tissue-contacting surface, at least one of the first or second jaw members movable relative to the other between a spaced-apart position and an approximated position for grasping tissue between the tissue-contacting surfaces thereof; at least one light emitting diode (LED) operably coupled to a distal end of the shaft and oriented to project light onto tissue disposed between the jaw members; and an electrosurgical generator electrically coupled to the tissue-contacting surfaces and configured to supply electrosurgical energy thereto for treating tissue grasped between the tissue-contacting surfaces, the electrosurgical generator additionally coupled to the at least one light element and at least one sensor configured to receive sensed data therefrom, wherein the electrosurgical generator includes a controller configured, in real time, to: control the supply of electrosurgical energy to tissue; predict thermal spread beyond the first and second jaw members based at least on the sensed data; and modify the light projected onto tissue from the at least one LED when it is determined that the predicted thermal spread is above a threshold thermal spread.

17. The electrosurgical system according to claim 16, wherein the at least one LED is ring-like and configured to encompass the distal end of the shaft.

18. The electrosurgical system according to claim 16, wherein the at least one LED is configured to project light onto tissue by varying at least one of intensity, pattern, angle, or color.

19. The electrosurgical system according to claim 16, wherein the controller is configured to predict the thermal spread based at least on sensed temperature data from the at least one sensor and control at least one of the intensity, color, pattern or angle of the at least one LED thereon.

20. The electrosurgical system according to claim 16, wherein the controller is configured to predict the thermal spread based at least on sensed data from the at least one sensor including at least one of temperature data, electrical feedback data including power, voltage, current, and impedance, tissue hydration data, or data relating to tissue thickness, tissue type, and tissue mass.
