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(54) **ELECTROSURGICAL SEALING TOOL
HAVING HAPTIC FEEDBACK**

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(57) **ABSTRACT**

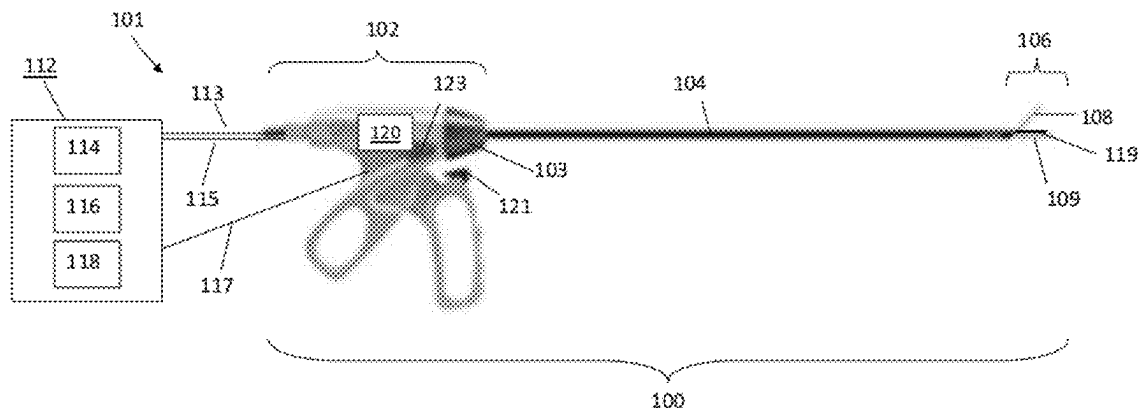
A surgical tool system includes an electrosurgical tool for sealing and transecting tissue and a tactile feedback system integrated onto a handle of the tool that generates relevant feedback in at least the form of haptic effects to the user. The tactile feedback alerts the user of tissue properties, i.e., when tissue located within jaws of the tool is completely sealed, when the tissue is ready to be cut, the cutting rate or speed, the quantity of tissue located within jaws of the tool, and whether a blood vessel is fully located within jaws of tool. In addition, the tactile feedback alerts the user to the operating status of energy application during the procedure.

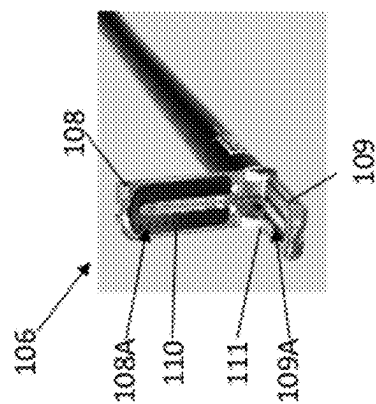
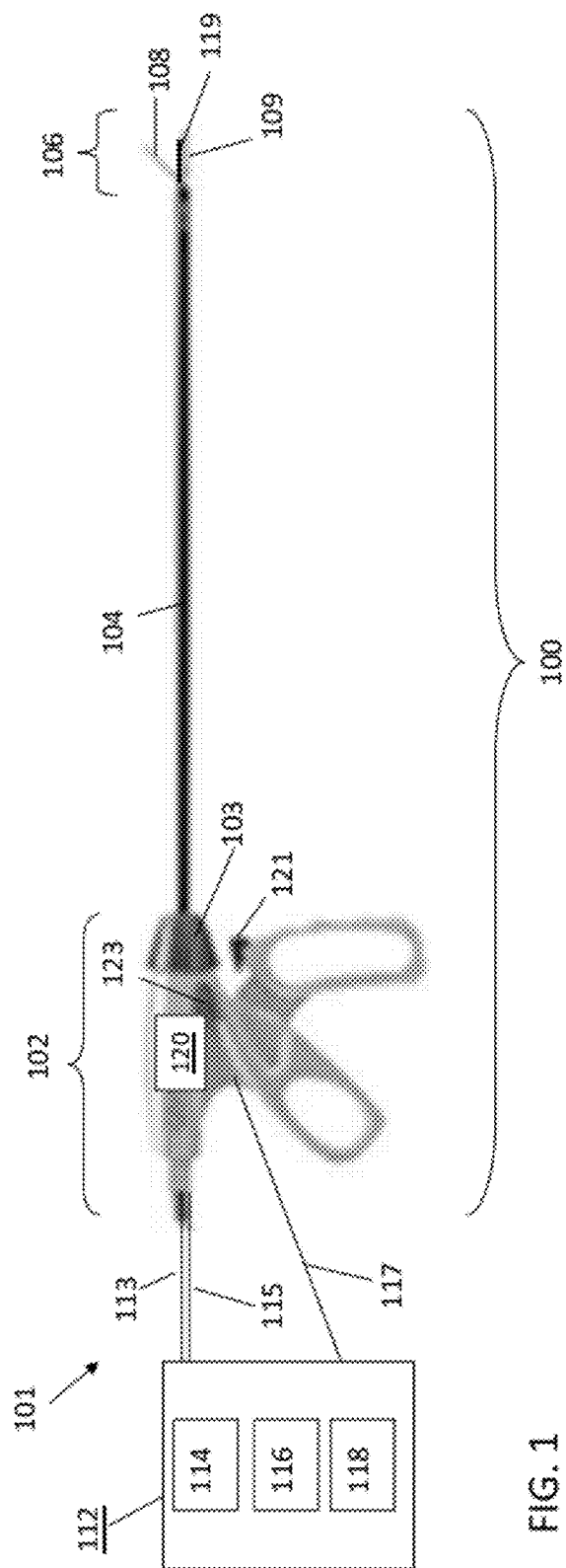
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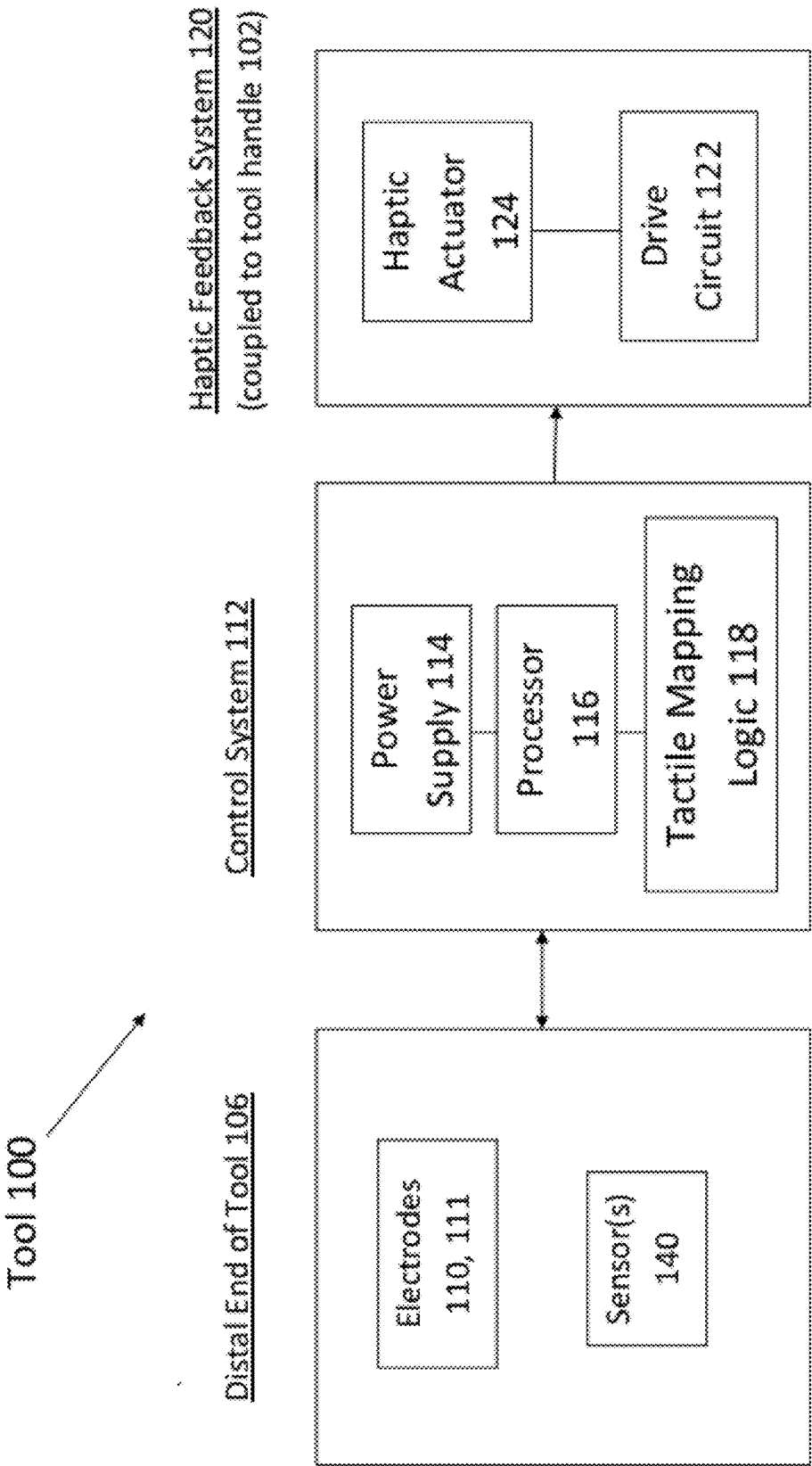


FIG. 2

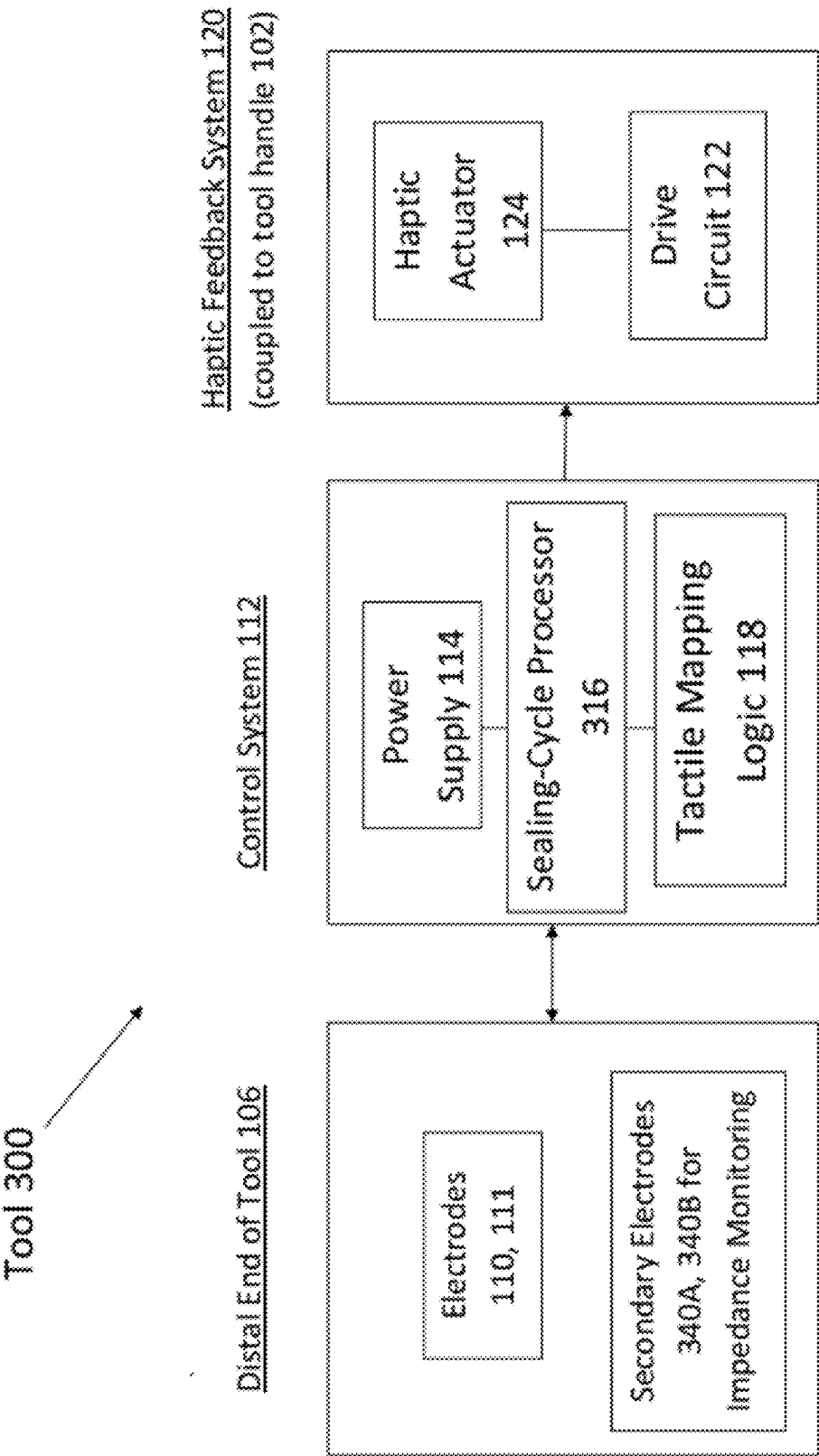


FIG. 3

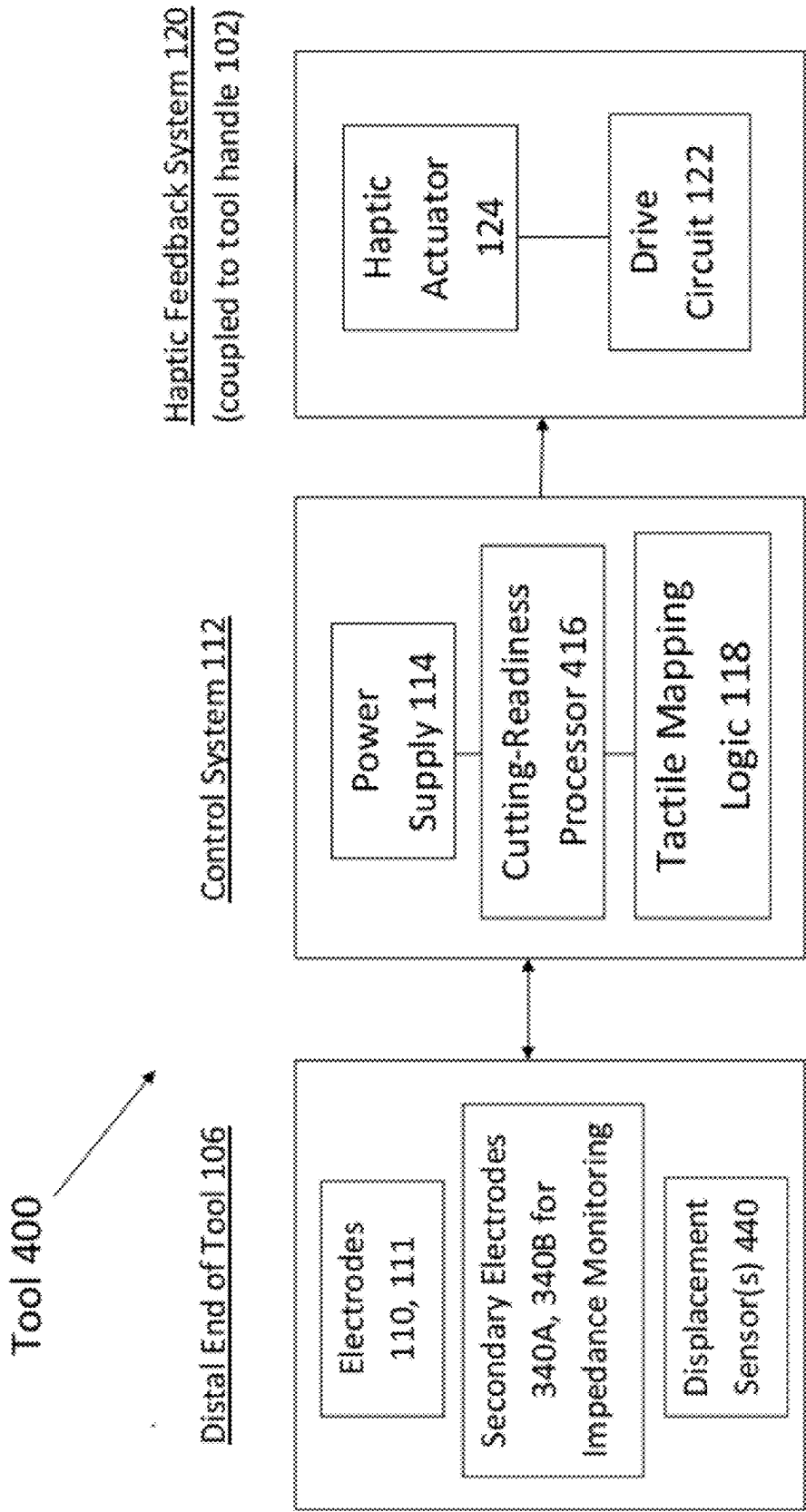


FIG. 4

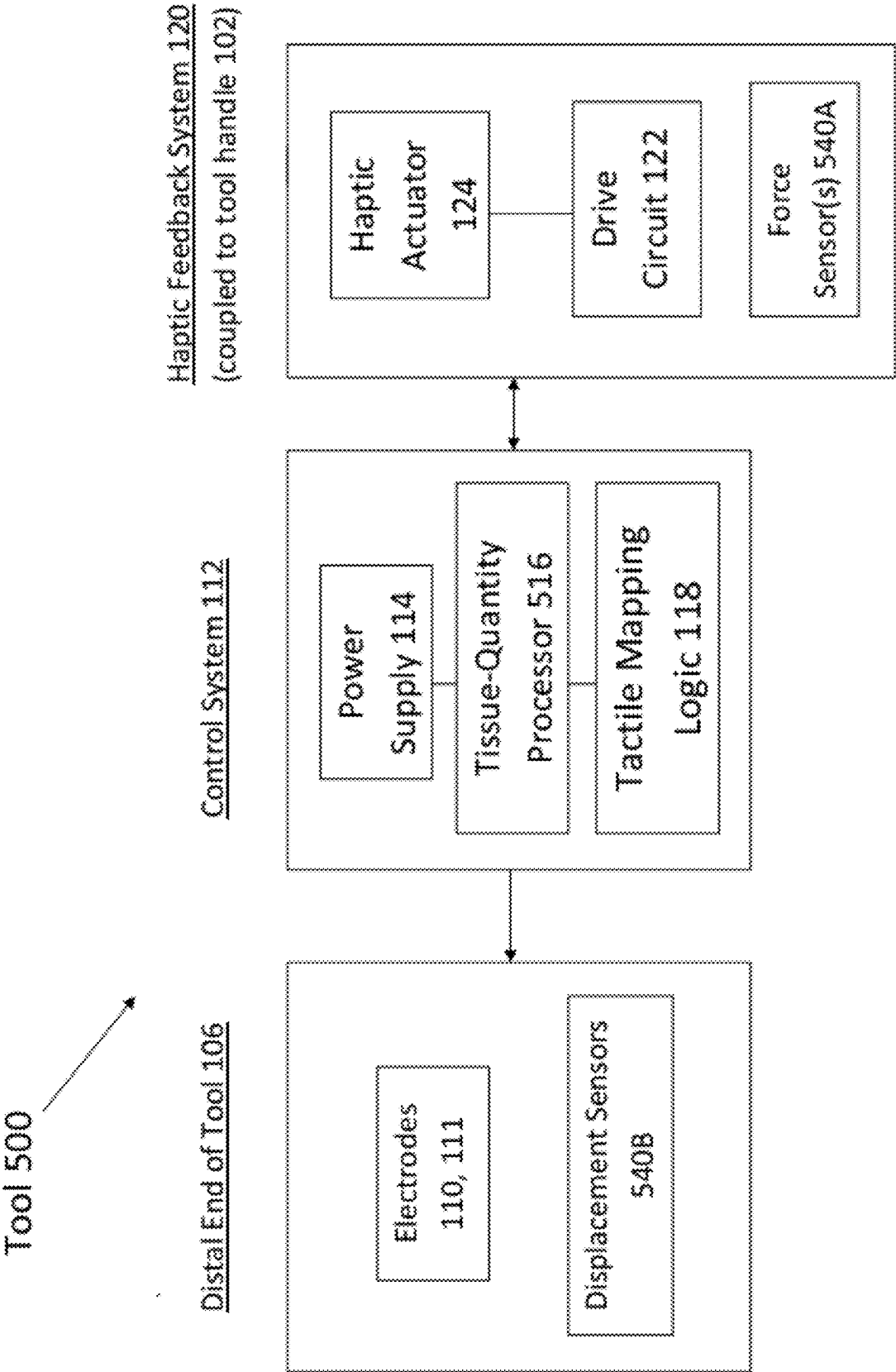


FIG. 5

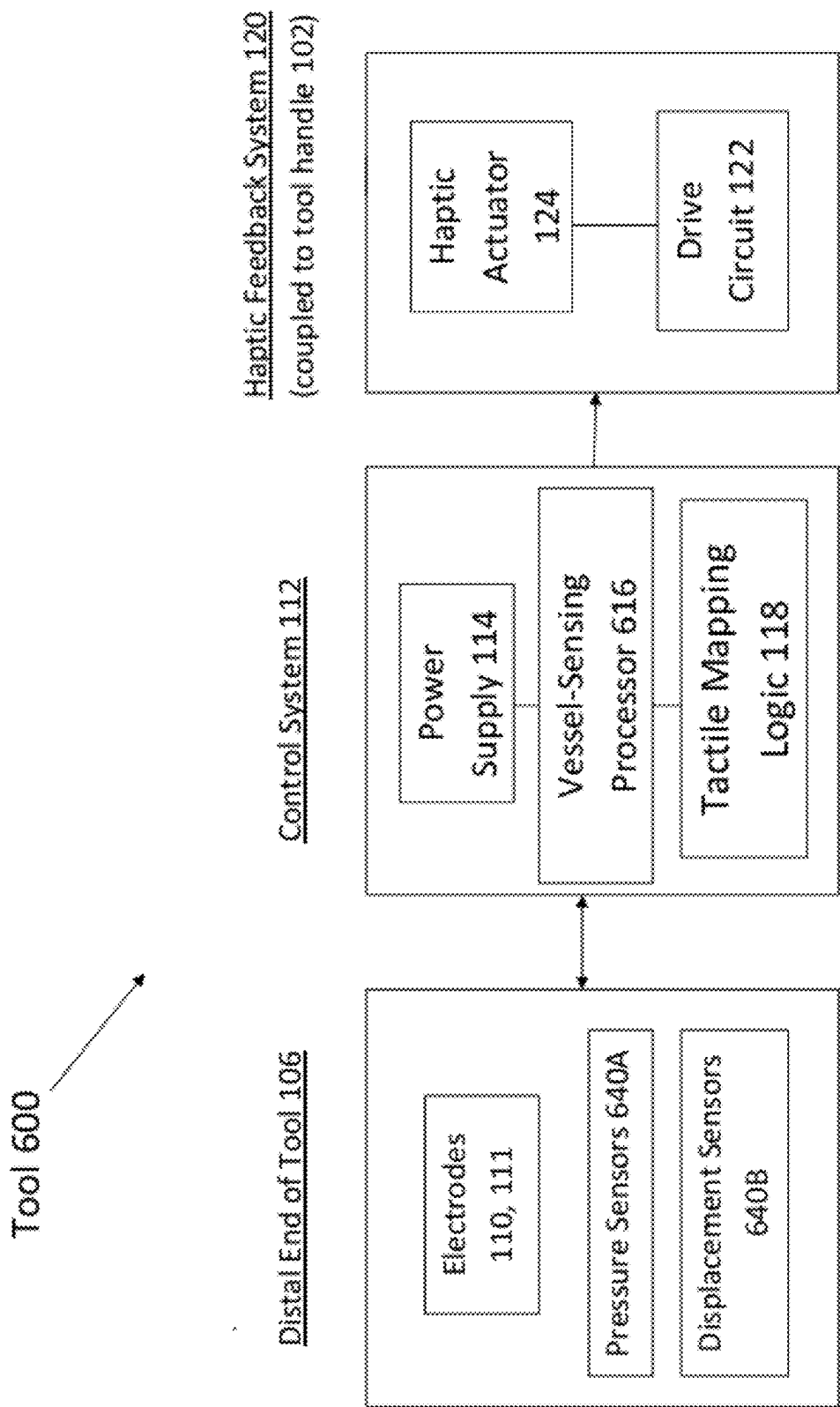


FIG. 6

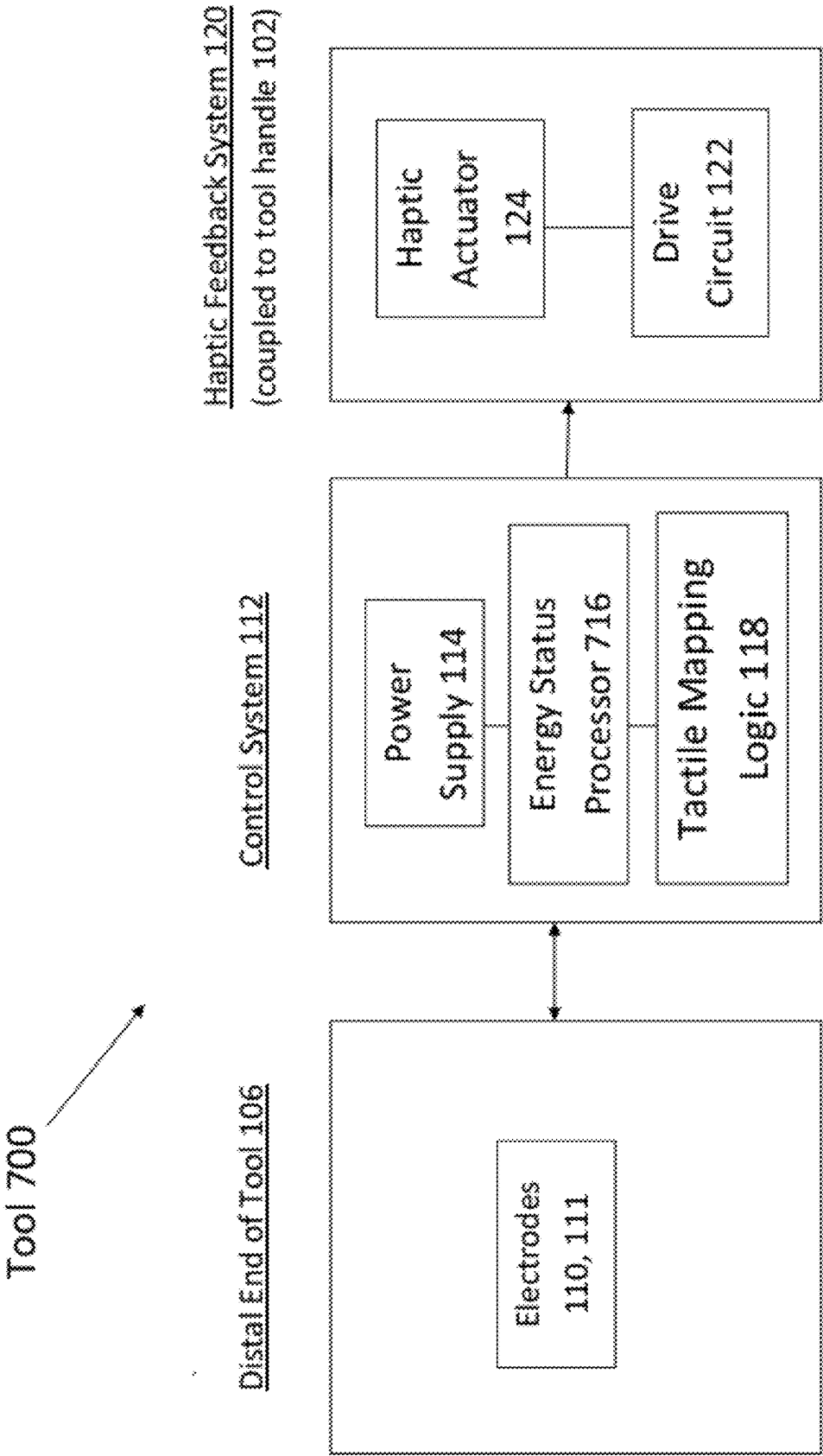


FIG. 7

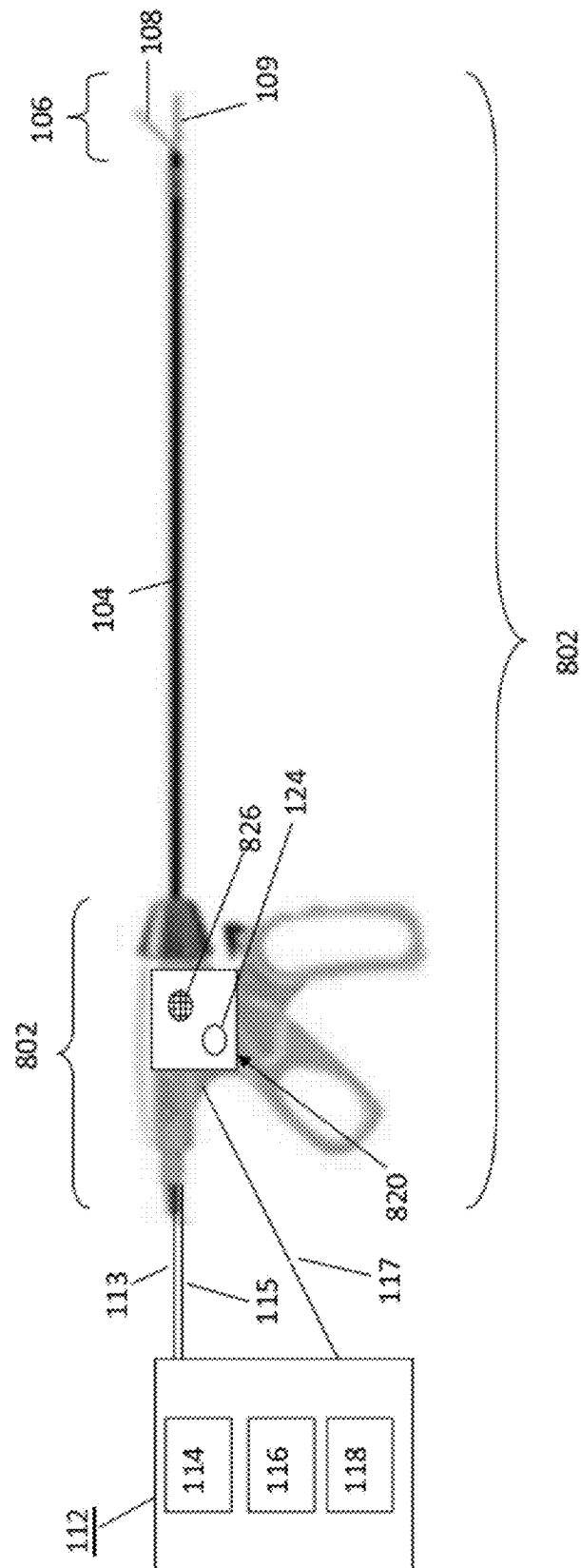


FIG. 8

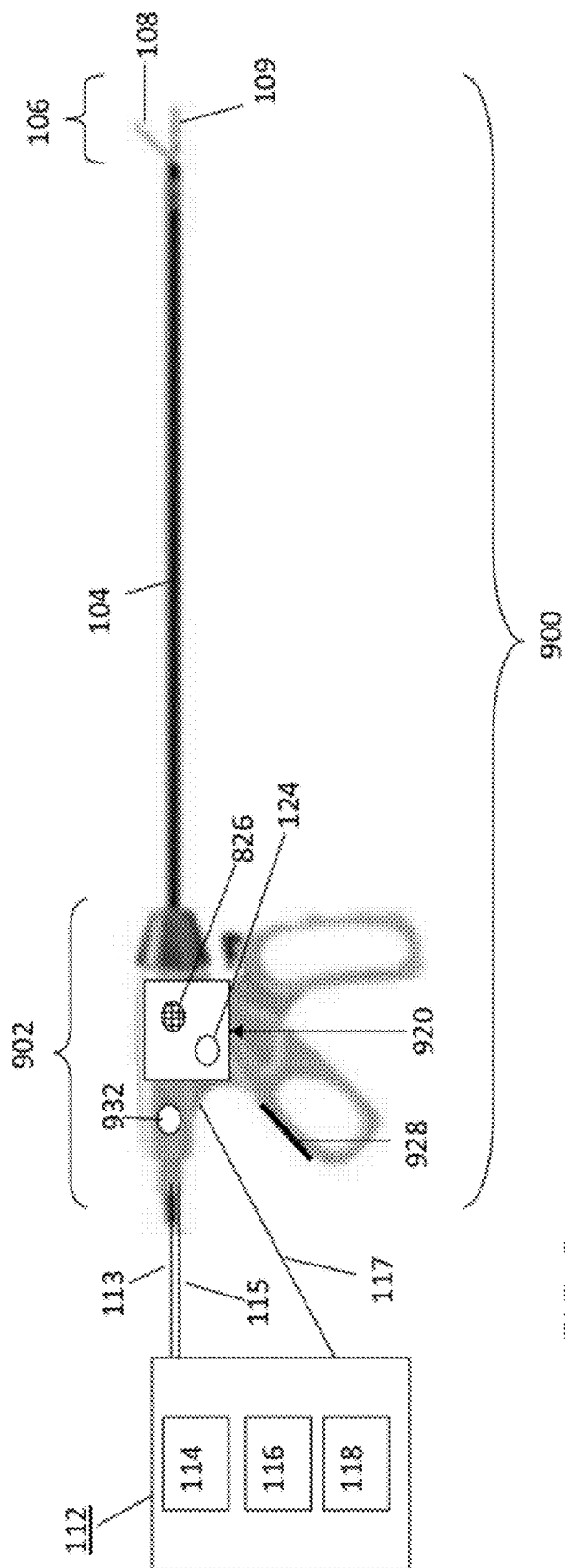


FIG. 9

ELECTROSURGICAL SEALING TOOL HAVING HAPTIC FEEDBACK

FIELD OF THE INVENTION

[0001] Embodiments hereof relate to surgical tools for treating tissue, wherein information related to the tissue treatment is processed and displayed to a user in one or more feedback modes integrated onto a handle of the tool.

BACKGROUND OF THE INVENTION

[0002] As opposed to open surgery in which a surgeon cuts a relatively large incision in the skin of a patient for accessing internal organs, minimally invasive surgical procedures are performed by making relatively small incisions and then inserting tools through the incisions to access the organs. Minimally invasive surgery usually results in shorter hospitalization times, reduced therapy requirements, less pain, less scarring, and fewer complications.

[0003] Although minimally invasive surgical procedures involving small incisions include many advantages over open surgery, minimally invasive surgery can still create challenges to a surgeon. For example, the surgeon must typically rely on a miniature camera introduced through an incision to view the patient's internal organs and see how the movement and operation of the tools affects the organs. The camera transmits images to a visual display, allowing the surgeon to see the internal organs and tissues and to see the effect of other minimally invasive tools on the organs and tissues. In this way, the surgeon is able to perform laparoscopic surgery, dissection, cauterization, endoscopy, telesurgery, and the like.

[0004] Compared to open surgery, however, minimally invasive surgery presents limitations in visual and haptic perceptions, and creates challenges unique to this type of surgery. One of the major concerns relevant to both open surgery and minimally invasive surgery is the potential for tissue damage, possibly caused by inappropriate use of force or excessive application of energy/heat. For example, electro-surgical tools operate by stimulating tissue with a high frequency electric current. The frequency of the current controls the action of the tool, which can include sealing/coagulating and/or dissecting. In both open surgery and minimally invasive surgery, the tissue being sealed is clamped within the jaws of a tissue sealing tool and is not visible to the user, and therefore direct visualization is not helpful in determining when an electrosurgical endpoint has been reached, i.e., when the clamped tissue is completely sealed. Surgeons must often rely on experience and indirect visualization to determine when the tissue is sealed, dissected or when other changes have occurred in the tissue. Based on the foregoing, there is a need for improved minimally invasive surgical tools and in particular, there is a need for minimally invasive surgical tools having improved feedback related to the surgical procedure.

BRIEF DESCRIPTION OF DRAWINGS

[0005] The foregoing and other features and advantages of the invention will be apparent from the following description of embodiments hereof as illustrated in the accompanying drawings. The accompanying drawings, which are incorporated herein and form a part of the specification, further serve to explain the principles of the invention and to enable a person skilled in the pertinent art to make and use the invention. The drawings are not to scale.

[0006] FIG. 1 is a diagram illustrating a side view of a surgical tool system including a laparoscopic surgical tool and an external control system according to an embodiment hereof.

[0007] FIG. 1A is an enlarged view of the distal end of the laparoscopic surgical tool of FIG. 1.

[0008] FIG. 2 is a block diagram of the surgical tool system of FIG. 1.

[0009] FIG. 3 is a block diagram of a surgical tool system according to an embodiment hereof in which haptic effects relating to the completeness of tissue-sealing cycle are communicated to the user.

[0010] FIG. 4 is a block diagram of a surgical tool system according to an embodiment hereof in which haptic effects relating to cutting-readiness are communicated to the user.

[0011] FIG. 5 is a block diagram of a surgical tool system according to an embodiment hereof in which haptic effects relating to the quantity or thickness of tissue within the jaws of the surgical tool are communicated to the user.

[0012] FIG. 6 is a block diagram of a surgical tool system according to an embodiment hereof in which haptic effects relating to vessel-sensing within the jaws of the surgical tool are communicated to the user.

[0013] FIG. 7 is a block diagram of a surgical tool system according to an embodiment hereof in which haptic effects relating to the status of energy application are communicated to the user.

[0014] FIG. 8 is a diagram illustrating a side view of a surgical tool system having haptic and audio feedback mechanisms, according to an embodiment hereof.

[0015] FIG. 9 is a diagram illustrating a side view of a surgical tool system having haptic, audio, and visual feedback mechanisms, according to another embodiment hereof.

DETAILED DESCRIPTION OF THE INVENTION

[0016] Specific embodiments of the present invention are now described with reference to the figures, wherein like reference numbers indicate identical or functionally similar elements. The terms "distal" and "proximal" are used in the following description with respect to a position or direction relative to the treating clinician. "Distal" or "distally" refer to a position distant from or in a direction away from the clinician. "Proximal" and "proximally" refer to a position near or in a direction toward the clinician.

[0017] The following detailed description is merely exemplary in nature and is not intended to limit the invention or the application and uses of the invention. Furthermore, there is no intention to be bound by any expressed or implied theory presented in the preceding technical field, background, brief summary or the following detailed description.

[0018] Embodiments hereof relate to a surgical tool system **101** that includes a laparoscopic surgical tool **100** for sealing and transecting tissue, a control system **112** for providing electrosurgical energy to tool **100**, and a tactile feedback system **120** integrated into tool **100** that generates relevant feedback in at least the form of haptic effects to the user. As will be explained in more detail herein, the tactile feedback provided by feedback system **120** alerts the tool user of tissue properties such as but not limited to when tissue located within the jaws of tool **100** has been completely sealed, when the tissue is ready to be cut, the cutting rate or speed, the quantity of tissue located within the jaws of tool **100**, and whether a blood vessel is located within the jaws of tool **100**. In addition, as will be explained in more detail herein, the

tactile feedback provided by feedback system 120 may supply information relating to the operating status of tool 100 to the user such as but not limited to the presence or absence of energy application.

[0019] FIGS. 1, 1A, and 2 illustrate an embodiment of an exemplary surgical tool system 101 that includes a surgical tool or device 100 and a control system 112. In one embodiment, surgical tool 100 is a laparoscopic tool which is configured to be inserted through a trocar or other minimally invasive access port. In another embodiment (not shown), surgical tool 100 is a surgical device adapted for an open medical tissue-sealing procedure. Surgical tool 100 includes a handle 102, a shaft 104, and a distal portion 106 having jaw members 108, 109. Jaw members 108, 109 include opposed surfaces 108A, 109A, respectively, which are arranged to close toward each other and clamp or grasp tissue therebetween. Jaw members 108, 109 include channels (not shown in FIG. 1) formed therein respectively, for receiving a deployable cutting element 119 as it is advanced through jaw members 108, 109. For illustrative purposes only, cutting element 119 is shown in FIG. 1 as partially deployed within open jaw members 108, 109. As will be understood by those of ordinary skill in the art, in operation cutting element 119 is only advanced/deployed when jaw members 108, 109 are closed toward each other with tissue clamped therein. Shaft 104 is designed to connect handle 102 to distal portion 106 and to communicate mechanical and electrical actions of handle 102 to distal portion 106. More particularly, operation of handle 102 opens and closes jaw members 108, 109 through an internal mechanical connector (not shown) that runs from handle 102 to distal portion 106. According to some examples of the embodiment of FIG. 1 in which tool 100 is a laparoscopic tool, shaft 104 may be about 20 cm to 30 cm in length and distal portion 106 may be about 10 mm to 15 mm in length. In addition the shaft 104 is typically 5 mm in diameter, although tools with 3 mm, 10 mm and 12 mm diameters are also commonly used. By manipulating handle 102, an operator can insert distal portion 106 into the abdomen of the patient and control jaw members 108, 109. In one embodiment, handle 102 may include a rotatable knob 103 for rotating jaw members 108, 109 into position to grasp and clamp tissue. After tissue is positioned between the jaw members, jaw members 108, 109 are closed toward each other to clamp tissue therebetween and electrosurgical energy is applied via control system 112 to seal the clamped tissue. After coagulation of the clamped tissue occurs, the cutting element 119 may be advanced to cut the clamped tissue. In one embodiment, handle 102 may include a deployable trigger 121 for advancing cutting member 119 and a selectable on-off switch 123 for applying electrosurgical energy therethrough. Surgical tool 100 may be for example, the ENSEAL TRIO Device by Ethicon Endo-Surgery, Inc. or other laparoscopic tools suitable for sealing and transecting tissue.

[0020] More particularly, in order to seal the clamped tissue, jaw members 108, 109 include bipolar electrodes 110, 111, respectively, on a portion of surfaces 108A, 109A respectively. In one embodiment, electrodes 110, 111 are offset from each other so that they will not contact each other if tissue is thin. Control system 112 provides electrosurgical energy to electrodes 110, 111 in order to seal or coagulate tissue located between jaw members 108, 109. In one embodiment, electrodes 110, 111 are radiofrequency (RF) electrodes, control system 112 includes a radiofrequency (RF) generator, and electrodes 110, 111 apply RF energy

from control system 112 to tissue. However, it should be understood by those of ordinary skill in the art that control system 112 may generate other types of energy for heating or ablating tissue including electrical energy, ultrasonic energy, cryoablation energy, etc., and in each case, electrodes 110, 111 would be a suitable corresponding component to apply the type of energy to tissue. Further, when utilized in conjunction with alternative types of energy, control system 112 may monitor suitable tissue, system, and/or operating properties to indicate when the treatment procedure is complete.

[0021] As shown, surgical tool 100 is a bipolar tool and a complete electrical circuit is formed between control system 112, electrodes 110 and 111, and the tissue extending between electrodes 110 and 111. However, as will be apparent to those of ordinary skill in the art, surgical tool 100 may be a monopolar tool including one or more electrode(s) at the distal portion of the tool and a reference electrode (i.e., skin patch electrode or grounding plate) positionable outside the patient's body (not shown). In a monopolar embodiment, current and/or voltage flows from control system 112, through the electrode at the distal portion of the tool, and into the grounding plate or reference electrode exterior to the patient. If multiple electrodes are located at the distal portion of the tool, the same current and/or voltage flows through each electrode and into the grounding plate or reference electrode exterior to the patient.

[0022] Electrodes 110, 111 are electrically connected to control system 112 via two electrically conductive leads 113, 115, respectively, that extend through at least one lumen (not shown) of shaft 104. Electrodes 110, 111 may be fixedly attached to the distal ends of the two electrically conductive leads by any suitable means. For example, the electrodes may be attached via welding, soldering, by the use of an electrically conductive adhesive, by the addition of a connecting element there between, or by another mechanical method. Although shown with two leads 113, 115 extending through shaft 104, it will be understood by those of ordinary skill in the art that two leads are only required for tools having bipolar electrodes integrated onto distal portion 106 of tool 100. Conversely in a monopolar tool, only one lead is required to run through shaft 104 for connecting control system 112 to one or more electrodes, while an external lead or ground line is connected the grounding plate or reference electrode exterior to the patient.

[0023] FIG. 2 is a block diagram of surgical tool system 101, further illustrating the relationship between the main components of surgical tool system 101. Control system 112 provides power to enable tool 100 to perform the tissue-sealing procedure and also communicates with both distal end 106 of tool 100 as well as handle 102 of tool 100 in order to provide haptic effects to the user. More particularly, control system 112 includes power source 114, a processor 116 for receiving measurements from one or more sensors 140 of tool 100 as will be described in more detail herein, and a controller or tactile mapping logic 118 configured to process sensor information from processor 116 into tactile feedback signals or commands. In one embodiment, power source 114, processor 116, and tactile mapping logic 118 are combined into an integral, external component that is separated from surgical tool 100 and is electrically connected to electrodes 110, 111 and haptic feedback system 120 via internal or external wires. Stated in another way, all of the components of control system 112 may be in the same external instrumentation unit. However, in another embodiment, power source 114, proces-

sor 116, and/or tactile mapping logic 118 may be separate external components that are electrically connected together. In yet another embodiment, one or more of power source 114, processor 116, and tactile mapping logic 118 may be mounted within or on handle 102 of surgical tool 100 and are electrically connected to electrodes 110, 111 and haptic feedback system 120 via only internal wires.

[0024] Power source 114 generates an alternating current of any suitable power level and frequency sufficient to seal/coagulate tissue. In one embodiment, power source 116 may be a RF power generator manufactured by Ethicon of Cincinnati, Ohio or by Covidien of Mansfield, Mass. which are both capable of providing a high output power with maximum output between 50 W-200 W. For example, power source 116 may generate 100 W at approximately 450 kHz for coagulation, although the frequency and power thereof may be varied during the procedure to allow for tissue specificity, etc. As described above, leads 113, 115 electrically connect power supply 114 and RF electrodes 110, 111 in order to supply RF power thereto.

[0025] As will be explained in more detail herein, sensor(s) 140 may include one or more of an impedance sensor, a force sensor, a displacement sensor, and/or a pressure sensor dependent on the desired haptic effects. Processor 116 is electrically connected to sensors 140 via one or more leads or other transmission medium (not shown). During operation of the tool, processor 116 receives data or measurements from sensor(s) 140 and accordingly processes or analyzes the sensor data/measurements as necessary in order to supply the correct type of input to tactile mapping logic 118. Processor 116 may include logic resources, such as a microprocessor, and may further include other specific sensor-dependent components required to analyze and store data/measurements from sensor(s) 140.

[0026] Processor 116 outputs the information derived from one or more sensors of tool 100 to tactile mapping logic 118 that further processes the information according to specific algorithms and operator selections. More specifically, tactile mapping logic 118 is configured to map sensed/calculated values derived from the tool sensor(s) onto tactile feedback signals or commands. Mapping may include a function or lookup table, or may include a more complex algorithm and, if necessary, a finite state machine. Tactile mapping logic 118 determines what haptic effects are to be played and the order in which the effects are played in response to the sensed/calculated values. Tactile mapping logic 118 may be a general-purpose or specific-purpose processing device or micro-controller. In one embodiment, tactile mapping logic 118 may be associated with a memory device (not shown) for storing data and/or instructions. The memory device can be any type of storage device or computer-readable medium, such as random access memory ("RAM") or read-only memory ("ROM"). The memory device stores logical instructions, commands, and/or code executed by tactile mapping logic 118. The memory device may also be located internal to control system 112, or any combination of internal and external memory. In another embodiment, logical instructions, commands, and/or code can be implemented in hardware and incorporated in tactile mapping logic 118 using discrete logic circuitry, an application specific integrated circuit ("ASIC"), a programmable gate array ("PGA"), a field programmable gate array ("FPGA"), etc., or any combination thereof. In yet another embodiment, logical instructions, commands, and/or code can be implemented in both hardware in tactile mapping

logic 118 and software/firmware stored in the memory. Although described separately from processor 116, it should be understood by those of ordinary skill in the art that such functional description is for illustrative purposes only and the same instrumentation may be utilized as processor 116 and tactile mapping logic 118.

[0027] Tactile mapping logic 118 outputs control signals to haptic feedback system 120 coupled to handle 102 of tool 100 to provide feedback information to an operator when performing a procedure. The control signals are communicated via a third lead or tether 117 (see FIG. 1) that electrically connects tactile mapping logic 118 to haptic feedback system 120. A fourth lead (not shown) may also be provided between control system 112 and handle 102 to provide an isolated ground line for a low voltage actuator circuit located in handle 102, described in more detail herein.

[0028] Haptic feedback system 120 includes at least an actuator drive circuit 122 (shown in FIG. 2) which is coupled to a haptic actuator 124 (also shown as FIG. 2) for providing haptic feedback to the operator. In order to provide feedback to the operator, haptic feedback system 120 is electrically connected to control system 112. In one embodiment, in order to communicate commands from tactile mapping logic 118 to haptic actuator 124, control system 112 provides a motor voltage along lead or tether 117 to handle 102 of tool 100. As will be explained in more detail herein, haptic actuator 124 may include but is not limited to one or more vibrotactile or kinesthetic actuators that utilize any suitable instrumentation such as but not limited to a friction brake or a dynamic motor coupled to tool 100 for providing the desired haptic effects. As such, tactile mapping logic 118 outputs control signals to drive circuit 122 which includes electronic components and circuitry used to supply haptic actuator 124 with the required electrical current and voltage to cause the desired haptic effects. As mentioned above, a fourth lead (not shown) may also be provided between control system 112 and handle 102 to provide an isolated ground line for a drive circuit 122 in handle 102 such that tactile mapping logic 118 communicates with haptic feedback system 120 via an isolated DC voltage line having two conductors.

[0029] Haptic feedback may be generated and provided to the user, including vibrotactile, kinesthetic, handle deformation and/or other types of tactile feedback such as texture and heat. Haptic actuators 124 may include electromagnetic motors, eccentric rotating mass ("ERM") actuators in which an eccentric mass is moved by a motor, linear resonant actuators ("LRAs") in which a mass attached to a spring is driven back and forth, shape memory alloys, electro-active polymers that deform in response to signals, mechanisms for changing stiffness, vibrotactile actuators, inertial actuators, piezoelectric actuators, or other suitable types of actuating devices. In one embodiment, haptic actuator 124 can be implemented as an inertial actuator to provide vibrotactile feedback to the operator. In another embodiment, kinesthetic haptic feedback may utilize, for example, solenoids to change the stiffness/damping of handle 102, small air bags that change size in handle 102, or shape changing materials. A detailed description of drive circuits and haptic actuators suitable for use herein may be found in U.S. patent application Ser. No. 11/862,639 (attorney docket IMM274), filed Sep. 28, 2007, herein incorporated by reference in its entirety.

[0030] In one embodiment, haptic actuator 124 is a vibrotactile device that generates vibrations on handle 102 for haptic feedback. For example, in one embodiment, one or

more vibrotactile actuators may be incorporated in handle **102** at several locations corresponding to the fingers and thumb of a hand of the surgeon for providing high bandwidth vibrotactile feedback over the entire handle. A target acceleration of between 4-5 G's at resonance is desirable, along with response greater than 2.5 G's from 100-250 Hz. In one embodiment, all moving mass components relating to actuation of haptic actuator **124** are internal to tool **100**.

[0031] In another embodiment, haptic actuator **124** is a kinesthetic device such as a friction brake or a motor that enables variable resistance to motion, lock-out, barrier and detent display on handle **102** for haptic feedback. For example, in one embodiment, trigger **121** for cutting element **119** may be fitted with a kinesthetic actuation means to enable kinesthetic haptic effects. In addition, one or more kinesthetic actuators may be incorporated in handle **102** at several locations corresponding to the fingers and thumb of a hand of the surgeon for providing resistance of motion to the entire grasper portion of the handle. The kinesthetic actuators must be capable of at least significantly impeding motion. For example, in one embodiment, the kinesthetic actuators may have a resistance of between 20% and 30% of the maximum applied force in order to display effective impeding forces. In another embodiment, the kinesthetic actuators may be capable of impeding all user motion to communicate a "lock-out" mode.

[0032] As previously mentioned, the type of tool sensor(s) as well as the operation of processor **116** depends on desired haptic effects. In one embodiment, the sensor is an impedance sensor and the processor continuously measures impedance of the tissue clamped between jaws **108**, **109** of tool **100** to provide an indication of when the tissue-sealing cycle or treatment is complete. Specifically, electrosurgical energy aims to seal cells at a treatment site while leaving the basic structure of the tissue intact. It is essential for the user to know when the sealing cycle is complete because the user should not cut the tissue prior to adequate sealing. Although some sealing tools include a predetermined audible alert at the end of a predetermined amount of time that is assumed to be the end of the sealing cycle (i.e., fifteen seconds), audible alerts are easily confused with other audible alerts and may not be heard in noisy operating room environments. In addition, the use of time alone is not a good indication of seal quality. Real-time impedance measurement permits the user to gauge the completeness, i.e., degree of tissue sealing, of the coagulation treatment. Sealed tissue blocks electrical signals, which may be accurately indicated by simultaneously monitoring the impedance of tissue. Accordingly, impedance may be monitored to indicate when tissue sealing is complete and haptic effects may be provided to the handle of the tool to alert that user that the sealing cycle is complete.

[0033] More particularly, as shown in FIG. 3, surgical tool **300** includes a secondary pair of electrodes **340A** and **340B** which are capable of measuring tissue impedance and the control system includes sealing-cycle processor **316**. Electrodes **340A**, **340B** may be located on opposed surfaces **108A**, **109A** of jaw members **108**, **109**, respectively, adjacent electrodes **110**, **111**. Electrode **340A** is electrically connected to power source **114** via a lead (not shown), and electrode **340B** is electrically connected to sealing-cycle processor **316** via a lead (not shown). Power source **114** and sealing-cycle processor **316** work together in order to continuously measure impedance of the target tissue in real time. Power source **114** is capable of generating a harmless alternating current in

the range of 1 kHz to 500 kHz or other suitable frequencies known to those of skill in the art of bioelectric impedance to allow for the measurement of impedance. For example, a current of 2 microamperes at 50 KHz may be used. While current is flowing, sealing-cycle processor **316** measures a corresponding resistance between electrodes **340A**, **340B**. Sealing-cycle processor **316** then arithmetically converts the resistance to an impedance measurement. In order to measure impedance, sealing-cycle processor **316** may include logic resources, such as a microprocessor, a voltage-current converting circuit, an amplifying circuit, an A/D converting circuit, and an impedance arithmetic operation section. In order to determine adequate tissue sealing, sealing-cycle processor **316** may record and/or calculate various parameters including current, voltage, power, impedance, and rates of change of these parameters. Although described herein as measuring impedance via secondary pair of electrodes **340A**, **340B**, it will be understood by those of ordinary skill in the art that the configuration of tool **100** may be adjusted such that impedance is alternatively monitored between electrodes **110**, **111**, thus eliminating the need for the secondary pair of electrodes.

[0034] When impedance or other measured/calculated system parameter(s) signifies that tissue sealing is complete, tactile feedback system **120** provides haptic effects to the user. The completion of the tissue-sealing cycle needs to be indicated to the user to enable them to proceed with the surgery. In one embodiment, the haptic effects may be a single haptic alert such as a vibrotactile alert to indicate completion of the tissue-sealing cycle. In another embodiment, the haptic effects may include continuous feedback based on live impedance values as the tissue impedance approaches completion of the tissue-sealing cycle such as a vibrotactile feedback with a sequence of increasing amplitudes and/or a kinesthetic barrier or resistance on trigger **121** of handle **102**. It will be understood by those of ordinary skill in the art that haptic effects may include both alerts and continuous feedback, and may include both vibrotactile and kinesthetic effects.

[0035] Monitoring impedance at or adjacent to the treatment site and determining completeness of the treatment can be determined according to any criteria. For example, adequate tissue sealing may be determined via the detection of a particular value of electrical impedance (i.e., when impedance reaches 450 ohms, the tissue is assumed to be sealed) or via the detection of a series of impedance measurements that are relatively constant over a desired period of time or over a defined number of successive impedance measurements. In one embodiment, a complete tissue seal may be associated with an impedance change of 10 ohms. A lookup or function table may be utilized to map sensed/calculated impedance values onto tactile feedback signals or commands to provide increasing feedback to the surgeon as tissue sealing occurs. Other lookup functions are possible and may be user-selectable. In another embodiment, a complete tissue seal may be a function of various observed quantities such as impedance, impedance change, current, voltage, power, and the like or may be mapped from the output of a tissue model.

[0036] In one embodiment, application of energy for sealing tissue continues for a predetermined time period that is assumed to be the end of the sealing cycle. For example, the application of energy may occur for a sealing cycle of fifteen seconds. A negative valence vibrotactile alert may be provided at the end of the predetermined time period if the impedance information does not indicate that sealing is com-

plete, and a positive valence vibrotactile alert may be provided at the end of the predetermined time period if the impedance information indicates that sealing is complete. Accordingly, the user may utilize the haptic alert when deciding whether an additional sealing cycle needs to be applied to the target site in order to completely seal the tissue.

[0037] In yet another embodiment, tactile mapping logic **118** may output command signals to power source **114**. For example, when the impedance of the tissue indicates that tissue sealing is complete, tactile mapping logic **118** may output a command signal to shut down power source **114**, thereby preventing delivery of additional energy to the tissue and controlling the behavior of tool **100**.

[0038] In another embodiment shown in FIG. 4, the impedance measurements may be utilized to provide feedback related to cutting readiness and/or rate. Laparoscopic sealing tools may rely on the operator to control advancement of the cutting element during the sealing process. In addition to performing dissection, cutting element **119** also plays an important role in the sealing portion of the procedure because blade advancement controls the compression force exerted on the tissue clamped between the jaws of the tool. Adequate compression is critical in achieving complete sealing, especially with thick tissue and/or blood vessels. Thus, the user often wants to advance the cutting element just proximal to tissue to achieve maximum compression for sealing the tissue, but wants to defer advancement of the cutting element into the tissue until it is adequately sealed. A cutting-readiness processor **416** makes impedance or other electrical parameter calculations that may be utilized to provide the user with guidance as to the readiness of tissue for cutting and as to the appropriate rate or speed of cutting. In order to assure adequate tissue sealing, it is important to limit or control advancement of the cutting element and therefore feedback as to the appropriate cutting speed is useful. As shown in FIG. 4, in this embodiment tool **400** includes secondary pair of electrodes **340A** and **340B** for monitoring impedance, a displacement sensor **440** which is capable of measuring displacement of cutting element **119**, and a cutting-readiness processor **416**. Displacement sensor **440** is coupled to cutting element **119** to provide information relating to the position of cutting element **119**, and electrodes **340A**, **340B**, and displacement sensor **440** are all electrically connected to cutting-readiness processor **416** via one or more leads (not shown). Jaw displacement may be measured with a potentiometer or other suitable position encoder on the hinge of the jaw members. Displacement sensor **440** continuously monitors the position of cutting element **119** to provide information to processor **416** regarding when cutting element **119** is located just proximal to the tissue such that further advancement thereof would result in cutting of the tissue, i.e., when cutting element **119** is in the cutting position. Cutting-readiness processor **416** also continuously receives impedance measurements from electrodes **340A**, **340B** and calculates impedance as described above with respect to processor **316**.

[0039] Based on the displacement measurements from sensor **440** and the impedance measurements from electrodes **340A**, **340B**, cutting-readiness and/or cutting speed feedback may be provided to the user. Cutting feedback may be provided in different modes such as a training mode and an experienced mode in order to accommodate the needs of users having varying degrees of experience with the tool. In the training mode, haptic effects may include continuous active resistance feedback on trigger **121** of handle **102** based on live

impedance values in order to prevent premature and/or too rapid cutting. For example, after the measurements from displacement sensor **440** indicate that cutting element **119** is in the cutting position, maximum resistance will be provided during impedance values less than 100 ohms and zero resistance will be provided for impedance values greater than 450 ohms. During impedance values between 100 and 450 ohms, the resistance on trigger **121** will gradually decrease in a continuous or stepwise fashion from maximum to zero. In experienced mode, haptic effects may include a relatively small detent on trigger **121** of handle **102** at the beginning of the cutting portion of the stroke if the measurements from displacement sensor **440** indicate that cutting element **119** is in the cutting position and the impedance is less than 450 ohms. In addition, experienced mode may include continuous vibrotactile feedback with a sequence of increasing amplitudes for impedance values between 100 and 450 ohms. In another embodiment, the amplitude of the detents is a function of the tissue impedance, so that a rough texture or sequence of barriers is present when the tissue is in a low impedance state and is progressively reduced as tissue impedance rises. This feedback may be displayed in a continuous time fashion or only during motion of the cutting element.

[0040] In addition to haptic effects relating to cutting-readiness and/or cutting rate, haptic feedback relating to the type of tissue being cut may also be provided during the cutting procedure. For example, passive kinesthetic resistance may be provided on trigger **121** and/or on handle **102** at several locations corresponding to the fingers and thumb of a hand of the surgeon. The kinesthetic resistance during motion of cutting element **119** may be a function of sensed tissue properties. For example, the kinesthetic resistance may be varied according to stiffness of the tissue being cut, which may be sensed via a strain gauge or other suitable sensor at the distal tip of the tool. A more detailed description of monitoring tissue properties such as stiffness and providing haptic effects relating thereto may be found in U.S. patent application Ser. No. 11/955,563 (attorney docket IMM273), filed Dec. 13, 2007, herein incorporated by reference in its entirety.

[0041] In another embodiment shown in FIG. 5, tactile feedback system **120** alerts the tool user of the quantity of tissue located within the jaws of tool **100** to alert the user if too much tissue is being sealed. Sealing tools are typically rated for a maximum tissue and/or blood vessel thickness and users should be alerted when the amount of tissue clamped within jaw members **108**, **109** exceeds this limit. In addition, the quantity of tissue in the jaws affects the quality of the seal. Tool **500** includes at least a force sensor **540A** coupled to handle **102** of tool **500** and a tissue-quantity processor **516** in the control system. Force sensor **540A** may be any type of force sensor that is capable of measuring the force exerted by the user to close the grasper handle of tool **500**, such as a foil strain gauge, piezo strain gauge, force sensing resistor, a pressure transducer, or other suitable sensor. Exemplary products that may be utilized for force sensor **540A** include Tekscan force sensing resistors and Omega foil strain gauges. Tool **500** may also include a displacement sensor **540B** coupled to the distal end of the tool for monitoring the space between the jaw members. Jaw displacement may be measured with a potentiometer or other suitable position encoder on the hinge of the jaw members or the shaft of the tool. Displacement sensor **540B** may be used to complement signals from force sensor **540A** because high force signals when the jaw members are nearly closed is less significant than high

force signals when the jaw members are just beginning to close. Thus, in one embodiment, force sensor **540A** and displacement sensor **540B** are utilized in conjunction to determine when an excessive amount of tissue is located within the jaw members. Tissue-quantity processor **516** continuously monitors force measurements received from force sensor **540A** and displacement sensor **540B**, if present, and calculates/estimates the amount of tissue located within the jaws of tool **500** from the force measurements. In one embodiment, the best indicator of tissue thickness, and thus the parameter monitored by tissue-quantity processor **516**, is the rate of change of force with respect to jaw gap displacement. In addition, in one embodiment, the user may input a force state (i.e., high, medium, low) into a graphic user interface so that the calculations performed by processor **516** are consistent with the level/type of tissue that it being grasped by the tool.

[0042] Based on the force measurements from sensor **540**, tissue quantity/thickness feedback may be provided to the user. Haptic feedback will be provided to users as force measurements pass through several thresholds. For example, in order to warn the user that there might be too much tissue in the jaws, the feedback may include vibrotactile alerts of increasing amplitude as the force measurements pass through the thresholds and/or kinesthetic feedback of increasing magnitude on the graspers of handle **102** as the force measurements pass through the thresholds. In another embodiment, a negative valence vibrotactile alert may be given if the amount of tissue within the device is outside of the device specification range, and a positive valence vibrotactile alert may be given if the amount of tissue within the device is within the device specification range. In addition, haptic feedback may be provided in different modes such as a training mode and an experienced mode in order to accommodate the needs of users having varying degrees of experience with the tool. In the training or beginner mode when the force exceeds a present maximum force (i.e., 4500 mNm), haptic effects may include a kinesthetic lock on trigger **121** to prevent cutting of the tissue and/or the graspers of handle **102** to prevent the user from clamping down onto the tissue. In addition, a pulsing vibrotactile alert or error may be communicated to the user. In the experienced mode when the force exceeds a present maximum force (i.e., 4500 mNm), haptic effects may include a negative valence vibrotactile alert if the user begins to cut and/or a high-magnitude kinesthetic barrier on trigger **121**.

[0043] In yet another embodiment, tactile feedback system **120** alerts the tool user of the orientation of vascular tissue located within the jaws of the surgical tool. The user is notified if there are vascular structures beyond a threshold diameter within the jaws, and more importantly, the user is notified if there is vascular tissue that is not completely within the jaws or not well oriented in the jaws. Tool **600** includes one or more pressure sensors **640A** and one or more displacement sensors **640B** coupled to the distal end **106** of the tool, and a vessel-sensing processor **616** in the control system. Jaw displacement may be measured with a potentiometer or other suitable position encoder on the hinge of the jaw members. Pressure sensing is most effectively achieved with a capacitive pressure sensor array such as those made by Pressure Profile Systems. In one embodiment, an array of microensors is coupled to the distal end **106** of the tool for sensing pressure and displacement of the jaw members. Vessel-sensing processor **616** continuously monitors pressure and displacement measurements received from sensors **640A**, **640B**, respectively, and interprets pressure/pulsation data to determine if a

blood vessel extends beyond distal tip of device. Detailed description of possibly suitable sensors and methods for detection of a blood vessel with a minimally invasive tool suitable for use herein may be found in U.S. Patent Publication 2010/0179423, filed Jan. 15, 2009; U.S. Patent Publication 2010/0137845, filed Dec. 3, 2008; U.S. Patent Publication 2010/0152586, filed Dec. 12, 2008; U.S. Patent Publication 2010/0179587, filed Jan. 15, 2009, each of which is herein incorporated by reference in its entirety. Haptic feedback for vessel-sensing may include both vibrotactile and kinesthetic effects. For example, in order to warn a user that a blood vessel is only partially within the jaws of tool **600**, haptic effects may include a kinesthetic lock on trigger **121** to prevent cutting of the tissue and/or the graspers of handle **102** to prevent the user from clamping down onto the tissue or engaging the cutting member. In addition, a pulsing vibrotactile alert or error may be communicated to the user.

[0044] In another embodiment, pressure sensors **640A**, displacement sensors **640B**, and vessel-sensing processor **616** may also be utilized to alert the tool user of whether the sealing process has successfully sealed the tissue located within the jaws of the surgical tool. It is essential for the user to know if the tissue has been sealed by the electrosurgical process because the user should not release the clamped tissue from the jaws of the surgical tool prior to adequate sealing. Detection of adequate sealing can prevent a catastrophic bleed which can occur if a less than adequately sealed vessel is unclamped. More particularly, vessel-sensing processor **616** may utilize measurement signals from pressure sensor(s) **640A** and displacement sensor(s) **640B** to determine if vessel pulsatility, i.e., a patent lumen, still exists on both sides of the seal prior to releasing the clamped tissue. If tissue is sealed after the electrosurgical process is completed, there is no blood flow/pulsation through the blood vessel. Haptic feedback for sealing completeness may include both vibrotactile and kinesthetic effects. For example, in order to warn a user that the tissue is not completely sealed, haptic effects may include a kinesthetic lock-out or high-magnitude barrier on trigger **121** to prevent cutting of the tissue. In another embodiment, a negative valence vibrotactile alert may be given if the tissue is not completely sealed.

[0045] Another area in which haptic feedback is useful for the user includes various operating conditions of control system **112** and/or tool **100**. In another embodiment of surgical tool **700** shown in FIG. 7, tactile feedback system **120** supplies information relating to the operating status of power source **114** to the user, i.e., to indicate when electrosurgical energy is being applied through the tool. Generators used with sealing tools such as those described herein are required to provide at least an audible alert when electrosurgical energy is activated on the sealing tool. However in noisy operating room environments, the audible indicator is not necessarily clearly communicated to the user. In this embodiment, switch **123** for applying electrosurgical energy is instrumented to enable an energy-status processor **716** to monitor the operating state thereof. When energy is enabled and switch **123** is in the "on" position, the user feels a haptic effect such as a subtle, transformer-type vibratory hum or sensation to indicate that there is energy flowing in tool **700**. In addition, a kinesthetic mechanical detent may be felt by the user when energy is enabled. A pulsing vibrotactile alert or error may be communicated to the user if energy is halted during cutting. In addition, vibrotactile alerts may be utilized in conjunction with the audio alerts provided by the generator,

and a distinct vibrotactile alert of higher amplitude or frequency may be utilized when a predetermined amount of time such as fifteen seconds is approaching and/or reached. This predetermined amount of time may correspond to an average or estimated time required for complete tissue sealing to occur.

[0046] Embodiments described above relate to various conditions that may be monitored and communicated to the user in the form of haptic effects. Although haptic effects for impedance monitoring, cutting-readiness, tissue-quantity, vessel-sensing, and energy-status are each described separately herein, it will be understood by those of ordinary skill in the art that a surgical sealing tool may incorporate any combination of the above-described embodiments. In particular, haptic feedback may include combinations of signals in the form of a spatial haptic texture or a combined kinesthetic-vibrotactile stimulus. In addition, a single processor of a surgical sealing tool including one or more of the above-described embodiments may be configured to receive input/measurements from various sensor devices and perform the required tasks or calculations thereon.

[0047] As described herein, a pulsing vibrotactile alert or error may be utilized in various situations to indicate improper use of tool **100**. The vibrotactile error alert may be utilized to ensure compliance with all proper instructions for use of tool **100**, including sensed improper uses as described herein or other programmable improper uses such as time periods or sequence of steps. In one embodiment, the vibrotactile error haptic effect may be the same for all error states but may include a follow-on haptic, audible, or visual effect that will provide more information about the specific error state to users. These follow on effects could include additional haptic pulses with user discernable envelopes to indicate different conditions. Alternately, the error effect could be displayed with different temporal spacing depending on the severity of the condition. In another embodiment, the positive or negative valence alerts may be played for a fixed duration following the alert condition, which in some circumstances may continue past the time when the knife has returned to its resting position.

[0048] For example, referring to FIG. **8**, an embodiment incorporating two types or modes of feedback for the operator is shown. Specifically, haptic feedback system **820** provides both haptic and audio feedback via haptic actuator **124** and an audio device or speaker **826**. Tactile mapping logic **118** communicates the processed information to one or more of haptic actuator **124** and audio device **826** according to which ones of these feedback mechanisms are enabled and how they are controlled to provide their respective outputs. In one embodiment, feedback may be provided to the operator in a continuous manner as the operator performs the surgery. In another embodiment, feedback may be provided to the operator as an alert to notify or warn the operator when a particular condition is satisfied. Further, one type of feedback (i.e., haptic or audio) may be provided in a continuous manner while another type of feedback is provided as an alert. In addition, haptic feedback alerts may augment continuous haptic feedback. In one embodiment, innocuous audible feedback may be utilized to indicate normal operation, tactile/haptic feedback may be utilized as an alert or warning to indicate to the user when a particular condition or state exists, and audible and/or visual feedback such as a beep and a flashing light may be utilized as an alarm to indicate to the user when a serious condition or state exists.

[0049] Referring to FIG. **9**, an embodiment incorporating three types or modes of feedback for the operator is shown. Specifically, haptic feedback system **920** provides haptic, audio, and visual feedback via haptic actuator **124**, audio device or speaker **826**, and visual display **928**, respectively. Tactile mapping logic **118** communicates the processed information to one or more of haptic actuator **124**, audio device **826**, visual display **928** according to which ones of these feedback mechanisms are enabled and how they are controlled to provide their respective outputs. In this embodiment, visual display **928** is a liquid crystal display (LCD) screen on a back region of handle **102**. In another embodiment, visual display **1128** may be incorporated into the camera monitor display of the laparoscope so that the visual feedback is always within the user's line of sight. Visual display **928** may be used to display impedance information and/or the operating status of RF power source **114**. In one embodiment, an ultrasound transducer (not shown) may be coupled to distal portion **106** of tool **100** and visual display **928** may be configured to show ultrasound image information to assist the surgeon to position the tool as needed. Visual display **928** can include a touch screen, which can be configured to present information to the operator and can also be configured to sense when the operator presses certain portions of the touch screen. In this way, the touch screen can act as a touchable user interface with graphical presentation capabilities. Visual display **928** may include a graphical user device that enables the surgeon to select different feedback profiles, adjust sensor behavior, modify supplemental information, and the like.

[0050] According to the embodiment of FIG. **9**, handle portion **902** of surgical tool **900** may further include one or more buttons **932**. Buttons **932** can be configured using any suitable mechanism for allowing an operator to control the nature of the feedback that is provided to the operator. Buttons **932** may include devices for allowing certain levels, intensities, or amplitudes to be adjusted or certain selections to be made regarding the output presented to the operator. In some embodiments, buttons **932** may be configured as switches, such as momentary toggle switches, allowing an operator to select different ways in which sensor information is mapped or provided to respective output devices. Buttons **932** can be implemented as a rocker switch or as a one-dimensional control surface. According to one function of buttons **932**, the operator can enable or disable one or more output mechanisms by controlling whether or not output signals based on the sensed signals are provided to the respective output devices. Another function of buttons **932** includes the ability to enable one or more output mechanisms. In this regard, the operator can control if and how feedback is presented in a visual, auditory, and/or haptic fashion. With feedback tailored to the surgeon's preferences, the tool can provide feedback to supplement the operator experience for better operation and performance.

[0051] It will be apparent to those of ordinary skill in the art that embodiments hereof relate to any type of tools that can be manipulated by an operator. More particularly, the tools described in the present disclosure include a handle portion that mechanically controls a distal portion of the tool. According to embodiments hereof, one or more sensor(s) located on the surgical tool and a haptic feedback system may collectively function to extract pertinent information regarding the operating status of the tool that is subsequently communicated to the operator as haptic, audio, and/or visual feedback.

Although embodiments disclosed are tools for laparoscopic surgery, other embodiments can be used for non-laparoscopic surgeries such as in vascular or other catheterization where information detected from a sensor on the tool-tip can be communicated back to the catheter handle. Further, for endoscopy procedures, information detected from a sensor on a flexible endoscope can be communicated back to the endoscope handle. Other embodiments can be used for telesurgery or telepresence in order to, for example, perform routine external examinations and/or utilize open surgical tools by a remote doctor. Another embodiment is the inclusion of this type of feedback in robotic surgical systems, such as the da Vinci® Surgical System of Intuitive Surgical, Inc., to enable operators to have direct tactile feedback.

[0052] While various embodiments according to the present invention have been described above, it should be understood that they have been presented by way of illustration and example only, and not limitation. It will be apparent to persons skilled in the relevant art that various changes in form and detail can be made therein without departing from the spirit and scope of the invention. Thus, the breadth and scope of the present invention should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the appended claims and their equivalents. It will also be understood that each feature of each embodiment discussed herein, and of each reference cited herein, can be used in combination with the features of any other embodiment. All patents and publications discussed herein are incorporated by reference herein in their entirety.

What is claimed is:

1. A surgical tool system comprising:
 - an electrosurgical tool configured to seal tissue, the tool including a distal portion including a tissue sealing mechanism connected to a handle via a shaft;
 - a sensor coupled to the electrosurgical tool, wherein the sensor is configured to monitor a tissue property;
 - a control system electrically connected to sensor, wherein the control system calculates sensor information from signals received from the sensor and processes the sensor information into signal commands; and
 - a feedback system including one or more haptic actuators coupled to the handle and electrically connected to the control system, wherein the control system communicates the signal commands to the feedback system and the feedback system uses the signal commands to generate haptic feedback relating to the sensor information to the handle.
2. The surgical tool system of claim 1, wherein the sensor is configured to monitor an electrical tissue property and the haptic feedback generated by the feedback system informs a user that tissue is completely sealed.
3. The surgical tool system of claim 2, wherein the sensor is an impedance sensor coupled to the distal portion of the electrosurgical tool.
4. The surgical tool system of claim 3, further comprising a deployable cutting element on the distal portion of the tool and a displacement sensor coupled to the cutting element, wherein the haptic feedback generated by the feedback system also informs the user of whether the tissue is ready to be cut by the cutting element or the cutting speed of the cutting element.
5. The surgical tool system of claim 4, wherein a trigger is coupled to the deployable cutting element and the one or more

haptic actuators include a kinesthetic actuator coupled to the trigger to enable variable resistance to motion as the haptic feedback.

6. The surgical tool system of claim 1, wherein the sensor includes a first force sensor coupled to the handle and a second displacement sensor coupled to two opposing jaw members coupled to the distal portion of the tool and the haptic feedback generated by the feedback system informs a user of the thickness of tissue located within the two opposing jaw members coupled to the distal portion of the tool.

7. The surgical tool system of claim 1, wherein the sensor is coupled to the distal portion of the tool and is selected from the group consisting of a pressure sensor and a displacement sensor, and the haptic feedback generated by the feedback system informs a user that a vessel is only partially located within two opposing jaw members coupled to the distal portion of the tool.

8. The surgical tool system of claim 1, wherein the sensor is coupled to the distal portion of the tool and is selected from the group consisting of a pressure sensor and a displacement sensor, and wherein the haptic feedback generated by the feedback system informs a user that tissue is completely sealed by detecting that there is no pulsation through a blood vessel.

9. The surgical tool system of claim 1, wherein the haptic feedback generated by the feedback system also informs a user to the operating status of a power source that is electrically coupled to the electrosurgical tool.

10. The surgical tool system of claim 1, wherein the haptic feedback generated by the feedback system includes at least vibratory or kinesthetic feedback.

11. The surgical tool system of claim 1, wherein the signal commands for generating haptic feedback are dependent upon a user's level of experience.

12. A method of providing feedback to a user during a tissue sealing surgical procedure, the method comprising the steps of:

- monitoring a tissue property during the tissue sealing surgical procedure via at least one sensor mounted on a distal portion of an electrosurgical tool;
- processing the sensor information; and
- communicating haptic feedback to a handle of the electrosurgical tool, wherein the haptic feedback relates to the sensor information.

13. The method of claim 12, wherein the tissue property is an electrical tissue property and the haptic feedback informs a user that the tissue is completely sealed.

14. The method of claim 13, wherein the electrical tissue property is impedance.

15. The method of claim 13, further comprising the steps of monitoring displacement of a deployable cutting element on the distal portion of the tool and communicating haptic feedback relating to whether the tissue is ready to be cut by the deployable cutting element or the cutting speed of the cutting element.

16. The method of claim 12, wherein the tissue property is thickness and the haptic feedback informs a user that too much tissue is located within two opposing jaw members coupled to the distal portion of the tool thereby limiting the ability to achieve an acceptable seal.

17. The method of claim 12, wherein the tissue property is vessel sensing and the haptic feedback informs a user that a vessel is only partially within two opposing jaw members coupled to the distal portion of the tool.

18. The method of claim **12**, wherein the tissue property is pulsation and the haptic feedback informs a user that tissue is completely sealed by detecting that there is no pulsation through a blood vessel.

19. The method of claim **12**, further comprising the step of communicating haptic feedback that informs a user of the

operating status of a power source that is electrically connected to the electrosurgical tool.

20. The method of claim **12**, wherein the haptic feedback includes at least one of vibratory feedback and kinesthetic feedback.

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