US 20030176770A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2003/0176770 A1**

Merril et al. (43) **Pub. Date: Sep. 18, 2003**

(54) **SYSTEM AND METHOD FOR CONTROLLING FORCE APPLIED TO AND MANIPULATION OF MEDICAL INSTRUMENTS**

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(21) Appl. No.: **10/390,715**

(22) Filed: **Mar. 19, 2003**

Related U.S. Application Data

(62) Division of application No. 09/811,358, filed on Mar. 16, 2001.

(60) Provisional application No. 60/189,838, filed on Mar. 16, 2000.

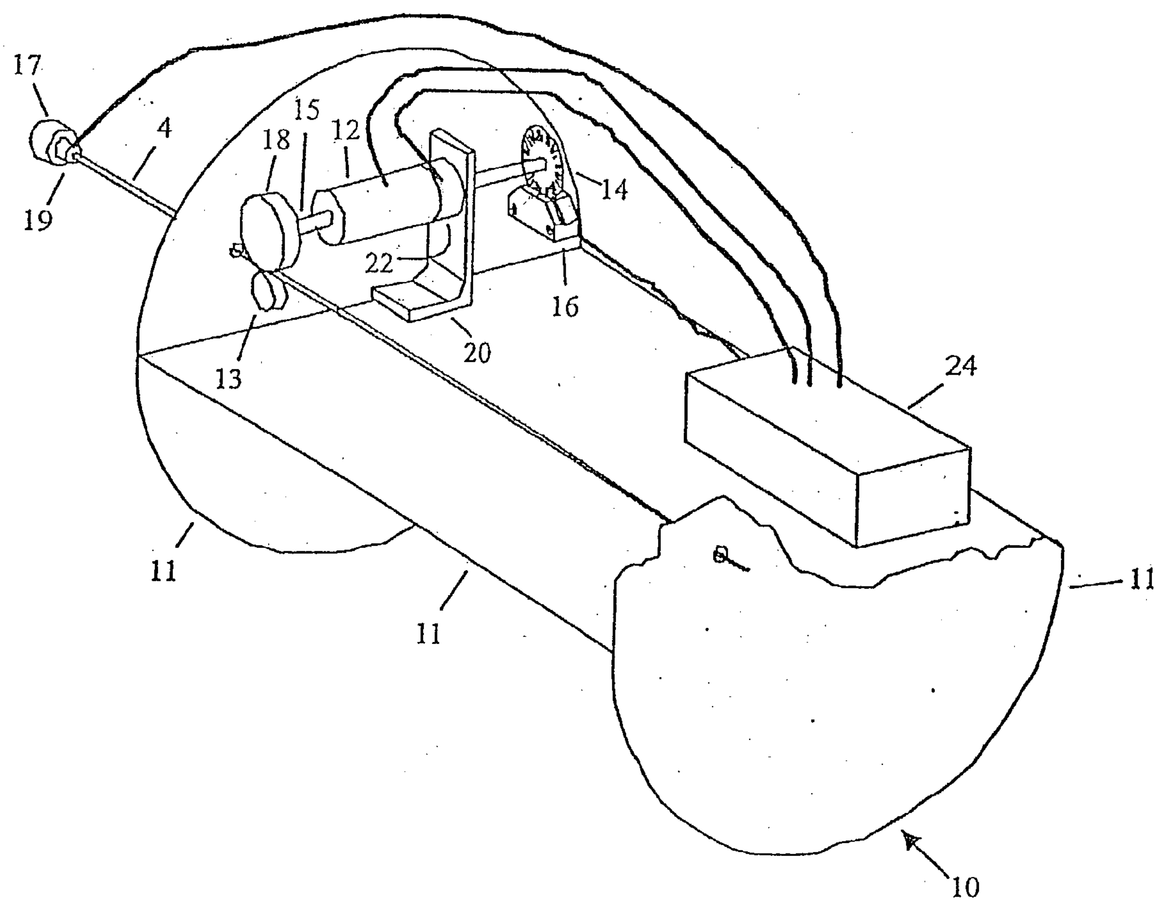
Publication Classification

(51) **Int. Cl.**[7] **A61B 1/018**

(52) **U.S. Cl.** **600/118**; 600/106

(57) **ABSTRACT**

An endoscopic assembly having and elongated member with a distal end and a haptic-feedback housing having a passageway, the elongated member being removably disposed therein, the haptic-feedback housing being configured to provide variable force feedback as the distal end of the elongated member is proximate to a distal end of the haptic-feedback housing.



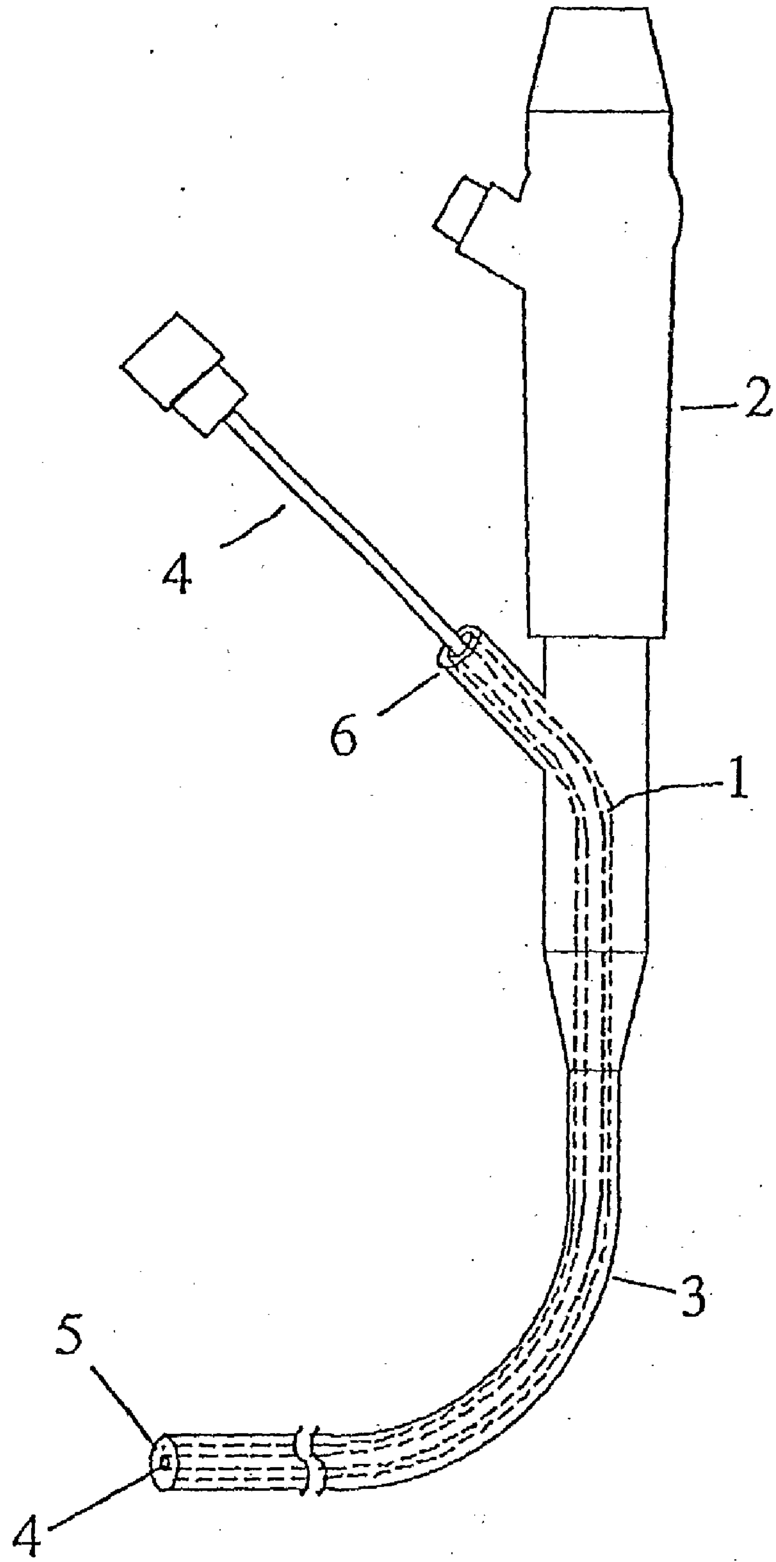


Figure 1A

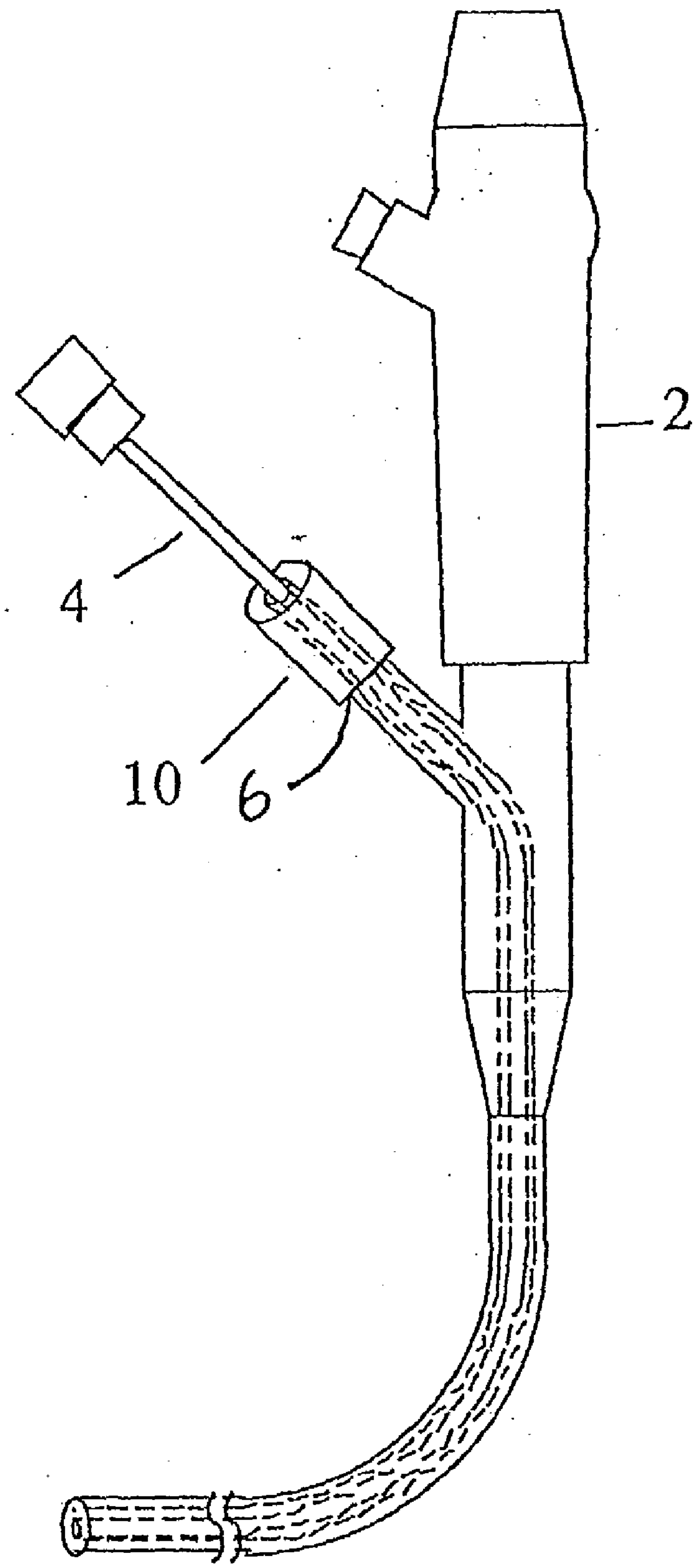


Figure 1B

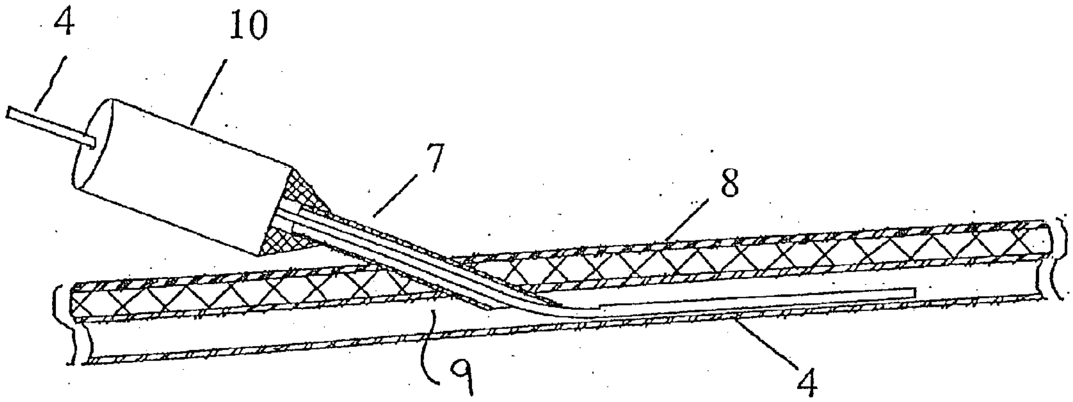


Figure 2

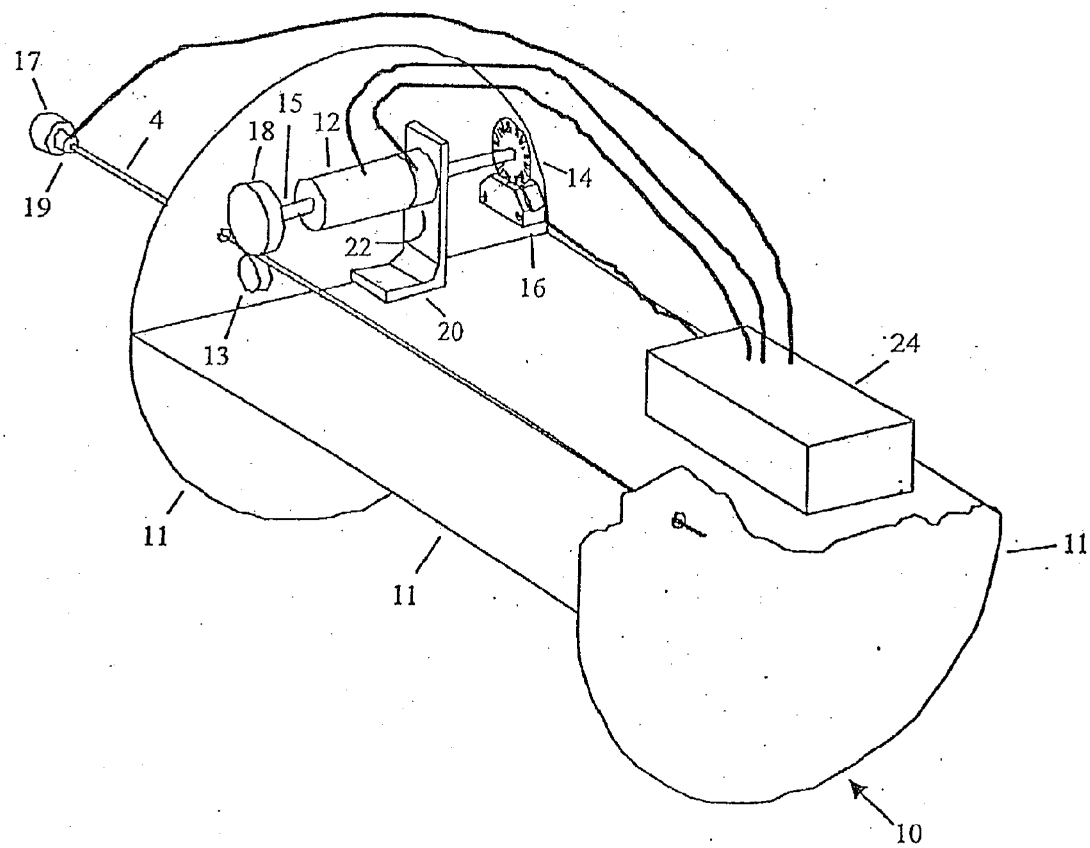


Figure 3

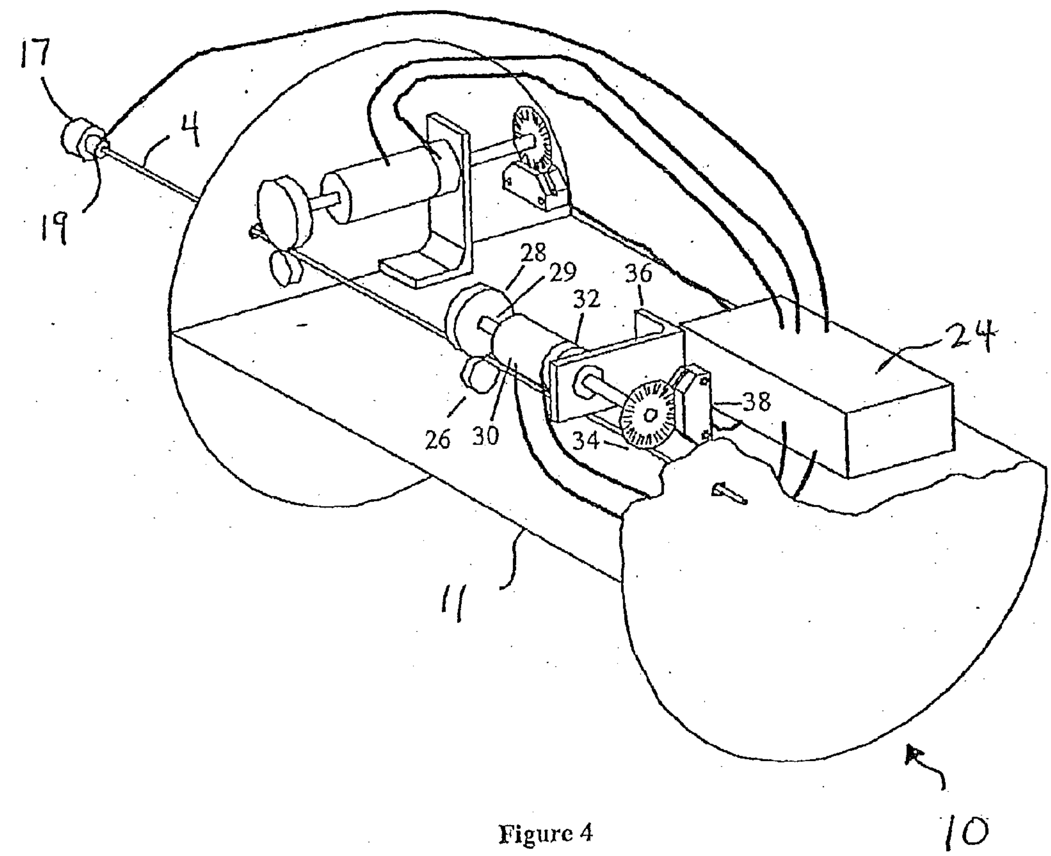


Figure 4

SYSTEM AND METHOD FOR CONTROLLING FORCE APPLIED TO AND MANIPULATION OF MEDICAL INSTRUMENTS

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application is a divisional of and claims the benefit of pending U.S. application Ser. No. 09/811,358, filed Mar. 16, 2001 and U.S. Provisional Application No. 60/189,838, filed Mar. 16, 2000 by Merril et al., both of which are entitled "System and Method for Controlling Force Applied to and Manipulation of Medical Instruments," both disclosures of which are incorporated herein by reference in their entirety.

BACKGROUND OF THE INVENTION

[0002] Minimally invasive techniques for providing medical examinations and therapies frequently employ endoscopes, such as a bronchoscope, ureteroscope, or flexible sigmoidoscope. Endoscopes such as these typically employ fiber optic or CCD imaging devices to enable the practitioner to visually inspect otherwise inaccessible areas of the anatomy such as the lungs, the ureter and kidneys, the colon, etc. These endoscopes also typically contain a tube, called the working channel, through which solutions such as anesthetics can be administered and bodily materials such as mucus can be withdrawn, typically via suction. In addition to use in administering and removing liquids or other material, the working channel of an endoscope is used to pass slender instruments to perform other functions at the distal end of the scope, under visual guidance through the endoscope.

[0003] Instruments typically used in this manner include forceps for grasping objects or for pinching and removing small tissue samples, biopsy needles for removing deep tissue samples in the lumen of a needle, snares or baskets for capturing and withdrawing objects such as an aspirated peanut from the lungs or a kidney stone from the calyxes of the kidney, and a wide variety of other tools.

[0004] Manipulation of these tools requires simultaneous manipulation or stabilization of the endoscope, along with manipulation of the working channel tool itself. The endoscope can typically be maneuvered along three, four or more degrees of freedom, including insertion and withdrawal, rotation, and tip flexion in one or two dimensions (up/down and/or left/right). The working channel tool is maneuvered along an additional two or more degrees of freedom, including insertion/withdrawal, rotation, and tool actuation, etc. Tool actuation can include, for example, opening and closing the jaws of a biopsy forceps, controlling the plunge of a biopsy needle, actuating a cauterization or ablation tool, pulsing a laser, or opening and closing a snare or basket. The tasks of manipulating and stabilizing the three or more degrees of freedom of the endoscope, while simultaneously manipulating the multiple degrees of freedom of the working channel tool are difficult to perform, and frequently the practitioner uses an assistant to manipulate one or more of the degrees of freedom, such as working channel tool actuation.

SUMMARY OF THE INVENTION

[0005] The present invention relates to a device or system that extends the functionality of the working channel of an endoscope by adding devices for sensing motion of the working channel tool and r for application of motive force to assist the practitioner in manipulation of the instrument in the working channel.

[0006] In one mode of use, the system uses drive wheels driven by a motor or other device to permit the, practitioner to quickly exchange working channel tools, by smoothly moving the current tool out of the working channel, and then quickly moving in the new tool to a point just short of exiting the working channel. At this point the practitioner takes over and performs the fine motor skills necessary to move the tool out of the endoscope and into a position to interact with the anatomy. In another mode of operation the physician manipulates tools manually and is provided with tactile guidance via a set of driven or braked drive wheels. One form of guidance is the provision of notification that the tool is approaching the end of the endoscope and is about to emerge from the endoscope. A braking or other tactile force would signal nearing the end of the working channel, enabling the user to move the tool quickly within the working channel without Manger of moving the tool too rapidly out of the working channel, thereby reducing the risk of damage or injury to tissue adjacent the distal end of the endoscope.

[0007] In another embodiment, the sensor and drive assembly is coupled to a catheter through which instruments and tools are passed into the vascular system. For instance, in the process of implantation of a heart pacing lead, the cardiologist must make a number of fine adjustments in the position of a guide catheter; then attempt to stabilize it while inserting an additional element through the lumen of the stabilized catheter. In one mode, the sensor/drive assembly is commanded to maintain a position using passive or active braking force. In another mode, the tip of the catheter is instrumented and an active mechanism commands insertion/retraction and roll increments to stabilize the actual position of the distal end.

[0008] In yet another embodiment, the sensor and drive assembly is instrumented with strain gauges or other devices to detect forces encountered at the distal end of the catheter or working channel tool. These forces are then amplified and displayed to the user via a motor or other motive mechanism.

[0009] In another embodiment, the sensor and drive assembly detect and modify motions, for example, detecting and filtering, out high frequency jitter caused by the user. This superstabilization mode is useful in situations where fine motor control is required.

[0010] In another embodiment, signals from a device inserted in the working channel are used to command the motive device to maintain a particular quality of electrical contact with the anatomy. In this situation, electrical impedance is changed by the force of contact. A desired quality of contact is initially attained by the physician, then the device is commanded to control contact force automatically to maintain the particular quality of contact.

[0011] The above and still further features and advantages of the present invention will become apparent upon consideration of the following detailed description of specific embodiments thereof, particularly when taken in conjunction with the accompanying drawings wherein like reference numerals in the various figures are utilized to designate like components.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] **FIG. 1***a* illustrates an unmodified endoscope with working channel and working channel tool.

[0013] **FIG. 1***b* illustrates an endoscope modified to provide a sensor and control element in accordance with the present invention.

[0014] **FIG. 2** illustrates an endovascular tool inserted into the vascular anatomy, combined with a sensor and control element in accordance with the present invention.

[0015] **FIG. 3** illustrates an axial motion sensor control element in accordance with the present invention.

[0016] **FIG. 4** illustrates addition of a rotational motion sensor and control element to the device in **FIG. 3**.

DETAILED DESCRIPTION

[0017] **FIG. 1***a* illustrates an unmodified endoscope, showing the endoscope body **2** attached to the endoscope tube assembly **3**. Working channel tool **4** is inserted into working channel orifice **6** in endoscope body **2**. Working channel tool **4** slides through working channel tube **1** and exits the distal end of endoscope tube assembly **3** through working channel orifice **5**.

[0018] **FIG. 1***b* illustrates motion sensor and control element **10** affixed to the working channel orifice **6**. Working channel tool **4** passes through motion sensor and control element **10** and through working channel orifice **6**. Normal manipulation and operation of the working channel tool is possible through the body of motion sensor and control element **10**.

[0019] **FIG. 2** illustrates an endovascular application of the motion sensor and control element of the present invention. Motion sensor and control element **10** is coupled to introducer sheath **7** which pierces skin **8** and the wall of blood vessel **9**. Elongated endovascular tool **4** passes through motion sensor and control unit **10**, through introducer sheath **7**, and into the lumen of blood vessel **9**.

[0020] In one mode of the present invention, the total distance of insertion of the working channel tool is measured and controlled by the motion sensor and control element. In **FIG. 3**, motion sensor and control element **10** contains a device for measuring translational motion of the body of working channel tool **4**. As the elongated portion of working channel tool **4**, passes between motion sensing and control wheel **18** and idler wheel **13**, it causes rotation of each wheel. Wheel **18** is affixed to shaft **15** of motor **12**. In turn, transparent optical encoder disk **14** is affixed to the opposite end of motor shaft **15**. Encoder reader **16** passes light through transparent encoder disk **14**. As transparent encoder disk **14** rotates, marks imprinted on the surface pass in front of the light source, occluding alternately light passing through the disk. A plurality of light sensors in encoder reader **16** measure the varying light and dark patterns and determine the amount and direction of rotational motion of encoder disk **14**. Control unit **24** receives motion signals from encoder reader **16** corresponding to translational motion of working channel tool **4**. Control unit **24** measures total insertion distance of working channel tool **4** and, for example, when a preset limit is approached, produces control signals transmitted to motor **12** to produce torque necessary to slow and then halt farther motion of motion sensing and control wheel **18**, thereby slowing and then halting further insertion of working channel tool **4**.

[0021] In another mode of the invention, motion sensing and control unit **10** amplifies or reduces forces applied by the user to working channel tool **4**. In **FIG. 3**, handle **17** is disposed adjacent force-torque sensor **19** which in turn is disposed adjacent working channel tool **4** such that translational force applied by the user to working channel tool **4** via handle **17** is sensed by force-torque sensor **19**. A control algorithm described below and residing in control unit **24** receives signals resulting from applied force measured by force-torque sensor **19** and in response produces control signals which are transmitted to motor **12** to control the motion of wheel **18**. Wheel **18** can be moved either by force applied by motor **12** or by frictional forces applied via working channel tool **4**. When working channel tool **4** is held motionless by the user, force applied to wheel **18** via shaft **15** of motor **12** is opposed by, and therefore sensed by torque sensor **22** which is attached to bracket **20** which is in turn fastened to base **11** of sensing and control element **10**. Force applied to working channel tool **4** by control wheel **18** is sensed by torque sensor **22** and denoted F_W. This force is added to force applied by the user (F_U) to produce the effective force at the distal end of the working channel tool F_{WC}, as expressed in the following equation of equilibrium:

$$F_{WC}=F_U+F_W \quad \text{Equation 1}$$

[0022] The control algorithm described below and contained in controller **24** dynamically modifies the force applied by the wheel **18**, F_W, to control working channel tool force, F_{WC}, in response to force applied by the user F_U. In particular, if the desired relationship between user applied forces and working tool forces is expressed by function f( ) as:

$$F_{WC}=f(F_U) \quad \text{Equation 2}$$

[0023] Combining these equations and solving for F_W provides the following control algorithm:

$$F_W=f(F_U)-F_U \quad \text{Equation 3}$$

[0024] Control unit **24** receives signals corresponding to user applied force F_U and control wheel force F_W and adjusts control signals transmitted to motor **12** to implement the control algorithm of equation 3.

[0025] The sensing and control unit of **FIG. 3** can be extended to sense and control rotation and torque as well as translation and axial force. In **FIG. 4**, as the elongated portion of working channel tool **4** rotates between motion sensing and control wheel **28** and idler wheel **26**, it causes rotation of each wheel. Wheel **28** is affixed to shaft **29** of motor **30**. In turn, transparent optical encoder disk **34**, is affixed to the opposite end of motor shaft **29**. Encoder reader **38** passes light through transparent encoder disk **34**. As transparent encoder disk **34** rotates, marks imprinted on the surface pass in front of the light source, occluding alternately light passing through the disk. A plurality of light sensors in encoder reader **38** measure the varying light and dark patterns and determine the amount and direction of rotational motion of encoder disk **34**. Control unit **24** receives motion signals from encoder reader **38** corresponding to rotational motion of working channel tool **4**. Control unit **24** measures total rotation of working channel tool **4** and, for example, when a preset limit is approached, produces control signals transmitted to motor **30** to produce torque necessary to slow and then halt further motion of motion sensing and control wheel **28**, thereby slowing and then halting further rotation of working channel tool **4**.

[**0026**] Likewise, motion sensing and control unit **10** in **FIG. 4** amplifies or reduces torques applied by the user to working channel tool **4**. In **FIG. 4**, handle **17** is disposed adjacent force-torque sensor **19** which in turn is disposed adjacent working channel tool **4** such that rotational force applied by the user to working channel tool **4** via handle **17** is sensed by force-torque sensor **19**. A control algorithm described below and residing in control unit **24** receives signals resulting from applied force measured by force-torque sensor **19** and in response produces control signals which are transmitted to motor **30** to control the motion of wheel **28**. Wheel **28** can be moved either by force applied by motor **12** or by frictional forces applied via working channel tool **4**. When working channel tool **4** is held motionless by the user, force applied to wheel **28** via shaft **29** of motor **30**,is opposed by, and therefore sensed by torque sensor **32** which is attached to bracket **36** which is in turn fastened to base **11** of sensing and control element **10**. Torque applied to working channel tool **4** by control wheel **28** is sensed by torque sensor **32** and denoted T_W. This torque is added to torque applied by the user (T_U) to produce the effective torque at the distal end of the working channel tool T_{WC}, as expressed in the following equation of equilibrium:

$$T_{WC}=T_U+T_W \quad \text{Equation 4}$$

[**0027**] The control algorithm described below and contained in controller **24** dynamically modifies the torque applied by the wheel **28**, T_W, to control working channel tool torque, T_{WC}, in response to force applied by the user T_u. In particular, if the desired relationship between user applied torque **10** and working tool torque is expressed by function q( ) as:

$$T_{WC}=q(T_U) \quad \text{Equation 5}$$

[**0028**] Combining these equations and solving for T_W provides the following control algorithm:

$$T_W=q(T_U)=T_U \quad \text{Equation 6}$$

[**0029**] Control unit **24** receives signals corresponding to user applied torque T_U and control wheel torque T_W and adjusts control signals transmitted to motor **30** to implement the control algorithm of equation 6.

[**0030**] Thus, sensing and control unit **10** as shown in **FIG. 4** can provide rotational or translational position control, as well as translational force and rotational torque control to working channel tools. As shown in **FIG. 2**, sensing and control unit **10** can be used to control any elongated medical instrument, such as a catheter used in interventional radiology.

[**0031**] While this invention has been described in terms of several preferred embodiments, it is contemplated that alterations, permutations, and equivalents thereof will become apparent to those skilled in the art upon a reading of the specification and study of the drawings. For example, many different types of sensors and actuators can be used to sense tool position or motion and to output tactile sensations to the user. Furthermore, many of the features described in one embodiment can be used interchangeably with other embodiments. Furthermore, certain terminology has been used for the purposes of descriptive clarity, and not to limit the present invention.

What is claimed is:

1. An apparatus, comprising:

an endoscope body having a channel portion including a channel;

an elongated member moveably disposed in the channel;

an actuator disposed in contact with the elongated member; and

a sensor positioned to detect a first force being applied to the elongated member, the actuator being adapted to apply a second force to the elongated member based on the first force applied to the elongated member.

2. The apparatus of claim 1, further comprising a controller in communication with the actuator and the sensor, the controller being configured to control the second force applied to the elongated member in response to the first force applied to the elongated member.

3. The apparatus of claim 2, wherein the controller is at least partially disposed within the channel, the controller being programmable.

4. The apparatus of claim 1, wherein the sensor is positioned to detect a longitudinally directed force applied to the elongated member.

5. The apparatus of claim 1, wherein the actuator resists undesired motions associated with the first force applied to the elongated member.

6. The apparatus of claim 1, further comprising a second sensor.

7. The apparatus of claim 6, wherein the second sensor is configured to detect torque applied to an elongated member.

8. The apparatus of claim 6, wherein the second sensor is located on a distal end of the elongated member.

9. The apparatus of claim 8, wherein the second sensor is configured to detect a soft tissue upon contact.

10. The apparatus of claim 8, wherein the actuator modifies the movements of the elongated member based on a predefined control characteristic.

11. An apparatus, comprising:

an endoscope body having a channel portion including a channel;

an elongated member moveably disposed in the channel;

an actuator disposed in contact with the elongated member; and

a sensor positioned to detect a movement of the elongated member, the actuator being adapted to apply force to the elongated member based on the movement of the elongated member.

12. The apparatus of claim 11, further comprising a controller in communication with the actuator and the sensor, the controller being configured to control the force applied to the elongated member in response to the movement of the elongated member.

13. The apparatus of claim 12, wherein the controller is at least partially disposed within the channel, the controller being programmable.

14. The apparatus of claim 12, wherein the sensor is an optical sensor, the elongated member has marks detectable by the optical sensor, and the marks are placed at predetermined distances along the elongated member.

15. The apparatus of claim 11, further comprising a second sensor.

16. The apparatus of claim 15, wherein the second sensor is configured to detect a torque applied to an elongated member.

17. The apparatus of claim 16, wherein the second sensor is located on a distal end of the elongated member.

18. The apparatus of claim 16, wherein the second sensor is configured to detect a soft tissue upon contact.

19. The apparatus of claim 16, wherein the actuator modifies the movements of the elongated member based on a predefined control characteristic.

20. An apparatus, comprising:

an endoscope body including a channel along at least a portion of the endoscope body;

a first actuator disposed within the channel and a second actuator disposed within the channel;

a first sensor positioned in the channel; and

a second sensor.

21. The apparatus of claim 20, further comprising a controller in communication with the first actuator, second actuator, first sensor and the second sensor, the controller being programmable and located at least partially within the channel.

22. The apparatus of claim 20, further comprising an elongated member, the first actuator being configured to apply a longitudinally directed force to the elongated member, the second actuator being configured to apply torque to the elongated member, the controller being configured to control the first actuator based the force detected in the first sensor, and the controller being configured to control the second actuator based on the force detected the second sensor.

23. The apparatus of claim 20, wherein the second sensor is disposed on a distal end of the endoscope body.

24. The apparatus of claim 20, further comprising an elongated member moveably disposed within the channel, the second sensor being disposed proximate to a distal end of the elongated member and configured to detect a soft tissue upon contact.

25. An endoscopic assembly, comprising:

an elongated member having a distal end; and

a haptic-feedback housing having a passageway, the elongated member being removably disposed therein, the haptic-feedback housing being configured to provide variable force feedback as the distal end of the elongated member is proximate to a distal end of the haptic-feedback housing.

26. The endoscopic assembly of claim 25, wherein the haptic-feedback housing is configured to limit the transmission of unwanted movements to the elongated member.

27. The endoscopic assembly of claim 25, wherein the haptic-feedback housing is configured to modify the movements of the elongated member based on an input force.

28. The endoscopic assembly of claim 25, wherein the haptic-feedback housing is configured to provide variable force feedback for longitudinal and torsional inputs to the elongated member.

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