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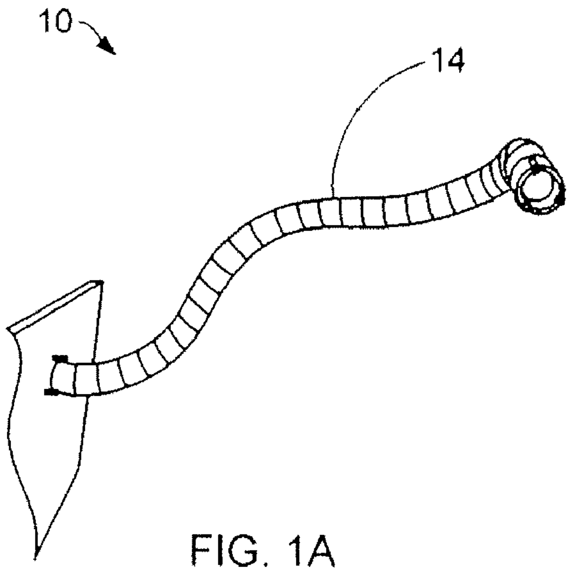

FIG. 1A

(57) Abstract: A system for controlling the movement of a steerable multi-linked device may include a steerable multi-linked device, a feeder mechanism releaseably connected to the steerable multi-linked device and a controller device. The steerable multi-linked device may include a first link, a plurality of intermediate links, and a second link movably coupled to a second one of the intermediate links. A first one of the intermediate links may be movably coupled to the first link. The controller device may be configured to control movement of the multi-linked device via the feeder mechanism.

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A. TITLE – A SYSTEM FOR CONTROLLING THE MOVEMENT OF A MULTI-LINKED DEVICE

B. CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Patent Application 60/891,881 filed February 27, 2007, the entirety of which is incorporated by reference herein. This application is related to co-pending U.S. Patent Application No. 12/038560 (attorney docket no. 132041.00401) and 12/038691 (attorney docket no. 132041.00411).

C.-E. Not Applicable

F. BACKGROUND

[0002] This application discloses an invention that is related, generally and in various embodiments, to a system for controlling the movement of a multi-linked device.

G. SUMMARY

A system for controlling the movement of a steerable multi-linked device may include a steerable multi-linked device, a feeder mechanism releaseably connected to the steerable multi-linked device and a controller device. The steerable multi-linked device may include a first link, a plurality of intermediate links, and a second link movably coupled to a second one of the intermediate links. A first one of the intermediate links may be movably coupled to the first link. The controller device may be configured to control movement of the multi-linked device via the feeder mechanism.

H. BRIEF DESCRIPTION OF DRAWINGS

[0003] Various embodiments of the invention are described herein by way of example in conjunction with the following figures.

[0004] FIGS. 1A and 1B illustrate various embodiments of a steerable multi-linked device;

[0005] FIG. 2 illustrates various embodiments of a core mechanism of the device of Figure 1;

[0006] FIGS. 3A-3C illustrate various embodiments of a proximal link of the core mechanism;

[0007] FIGS. 4A-4C illustrate various embodiments of an intermediate link of the core mechanism;

[0008] FIGS. 5A-5C illustrate various embodiments of a distal link of the core mechanism;

[0009] FIG. 6 illustrates various embodiments of a sleeve mechanism of the device of Figure 1;

[0010] FIGS. 7A-7C illustrate various embodiments of a proximal link of the sleeve mechanism;

[0011] FIGS. 8A-8C illustrate various embodiments of an intermediate link of the sleeve mechanism;

[0012] FIGS. 9A-9D illustrate various embodiments of a distal link of the sleeve mechanism;

[0013] FIG. 10 illustrates various embodiments of a motion sequence of the device of Figure 1;

[0014] FIG. 11 illustrates various embodiments of a steerable multi-linked device traversing a path having tight curvatures;

[0015] FIG. 12A illustrates various embodiments of a joystick for controlling the movement of a multi-linked device;

[0016] FIG. 12B illustrates various embodiments of a haptic controller for controlling the movement of a multi-linked device; and

[0017] FIG. 13 illustrates various embodiments of a method for controlling movement of a multi-linked device.

I. DETAILED DESCRIPTION

[0018] It is to be understood that at least some of the figures and descriptions of the invention have been simplified to focus on elements that are relevant for a clear understanding of the invention, while eliminating, for purposes of clarity, other elements that those of ordinary skill in the art will appreciate may also comprise a portion of the invention. However, because such elements are well known in the art, and because they do not necessarily facilitate a better understanding of the invention, a description of such elements is not provided herein.

[0019] According to various embodiments, the invention described herein may be utilized to control movement of a multi-linked device such as the steerable multi-linked device described herein. For ease of explanation purposes, the invention will be described in the context of its use with various embodiments of the steerable multi-linked device described herein. However, one skilled in the art will appreciate that the invention may be utilized with other types of multi-linked devices.

[0020] FIGS. 1A and 1B illustrate various embodiments of a steerable multi-linked device **10**. According to various embodiments, the steerable multi-linked device may be a snake robot, a continuum robot or the like. Various embodiments of the device **10** may be utilized for medical procedures (e.g., as a robotic bore, positioning device, ablation tool, camera or instrument support, or guidance system for minimally invasive procedures), for surveillance applications, for inspection applications, for search and rescue applications, etc. For purposes of clarity only, the utility of the device **10** will be described hereinbelow in the context of its applicability to medical procedures. However, a person skilled in the art will appreciate that the device **10** can be utilized in a variety of different applications.

[0021] The device **10** comprises a first mechanism **12** and a second mechanism **14**. According to various embodiments, a mechanism may be a snake robot, a continuum robot or the like. According to various embodiments, the second mechanism **14** is structured and arranged to receive and surround the first mechanism **12** as shown in FIG. 1B. Thus, the first mechanism and second mechanism may be concentric. For such embodiments, the first mechanism **12** may be considered the inner mechanism or the core mechanism, and the second mechanism **14** may be considered the outer mechanism or the sleeve mechanism. According to other embodiments, the first and second mechanisms **12, 14** may be structured and arranged to have a relationship other than a concentric relationship. For example, one skilled in the art will appreciate that, according to various embodiments, the first and second mechanisms **12**, **14** may be structured and arranged to operate in a side-by-side arrangement, where the first mechanism **12** operates adjacent to the second mechanism **14**. According to various embodiments, additional and/or alternate configurations may be used within the scope of this disclosure. According to various embodiments, a three-dimensional space **240** may be provided between the first and second mechanisms. This space will be described in more detail below.

[0022] As described in more detail hereinbelow, the first mechanism **12** may operate in either a rigid mode or a limp mode, the second mechanism **14** may operate in either a rigid mode or a limp mode, and the first and second mechanisms **12**, **14** may operate independent of one another. Both the first mechanism **12** and the second mechanism **14** may be steerable mechanisms. Accordingly, it will be appreciated that the device **10** may be utilized to navigate a luminal space as well as any three-dimensional path within an intracavity space. According to various embodiments, the device **10** may advance by alternating the operation of the first mechanism **12** and the second mechanism **14** between a limp mode and a rigid mode.

[0023] According to various embodiments, the device **10** may also comprise one or more cables. According to various embodiments, one or more of the cables may be steering cables and/or tensioning cables. For example, the device may include three steering cables and one tensioning cables.

[0024] FIG. 2 illustrates various embodiments of the first mechanism **12** of the device **10**. The first mechanism **12** is a multi-linked mechanism and includes a first end **24** and a second end **26**. The first end **24** may be considered the proximal end and the second end **26** may be considered the distal end. The first mechanism **12** may comprise a first link **28**, a second link **30**, and one or more intermediate links **32** between the first and second links **28**, **30**. The first link **28** may be considered the proximal link, and the second link **30** may be considered the distal link.

[0025] FIGS. 3A-3C illustrate various embodiments of the first link **28** (inner proximal link) of the first mechanism **12**. The first link **28** includes a first end **34** and a second end **36**, and defines a longitudinal axis **38** that passes through the center of the first end **34** and the center of the second end **36** as shown in FIG. 3B. The first link **28** may be fabricated from any suitable material. According to various embodiments, the first link **28** is fabricated from a fiber reinforced material such as, for example, G10/FR4 Garolite®. The first link **28** has a generally cylindrical shaped exterior and is described in more detail hereinbelow.

[0026] The first link **28** comprises a first portion **40** and a second portion **42**. The first portion **40** may be considered the proximal portion and the second portion **42** may be considered the distal portion. The first portion **40** may be fabricated integral with the second portion **42**. The first portion **40** has a cylindrical shaped exterior, and extends from the first end **34** of the first link **28** toward the second end **36** of the first link **28**. According to various embodiments, the diameter of the first portion **40** may be on the order of approximately 6.35 millimeters. Other sizes are possible.

[0027] The second portion **42** has a generally cylindrically shaped exterior, with other features described below. The second portion **42** has a cylindrically shaped exterior where it contacts the first portion **40**, and tapers toward the second end **36** of the first link **28**. The second portion **42** may be shaped in the form of a generally segmented hemisphere at the second end **36** of the first link **28**. According to various embodiments, the diameter of the second portion **42** may be on the order of approximately 4.75 millimeters where it contacts the first portion **40**. Other sizes are possible.

[0028] The second portion **42** comprises a first surface **44**. The first surface **44** may be considered the outer surface of the second portion **42**. The second portion **42** defines a first groove **46** parallel to the longitudinal axis **38** along the first surface **44**, a second groove **48** parallel to the longitudinal axis **38** along the first surface **44**, and a third groove **50** parallel to the longitudinal axis **38** along the first surface **44**. Each of the first, second and third grooves **46, 48, 50** extend along the first surface **44** toward the second end **36** of the first link **28**. The first, second and third grooves **46, 48, 50** may be semi-tubular shaped and may be evenly spaced about the first surface **44** of the second portion **42** of the first link **28** as shown in FIG. 3C. According to various embodiments, the first, second, and third grooves **46, 48, 50** may be configured in the shape of a segmented cylinder. The size of each of the grooves **46, 48, 50** may be identical to one another or may be different from one another. For example, according to various embodiments, the first and second grooves **46**, **48** may be configured as segments of a cylinder having a diameter on the order of approximately 1.25 millimeters, and the third groove **50** may be configured as a segment of a cylinder having a diameter on the order of approximately 2.50 millimeters. The length of the first link **28** may be on the order of approximately 65 millimeters. However, one skilled in the art will appreciate that the length or diameter of the first link **28** can vary based on the application.

[0029] The first link **28** also defines a passage **52** extending from the first end **34** to the second end **36** along the longitudinal axis **38** as shown in FIG. 3B. The passage **52** is of a size sufficient to allow at least one cable to pass therethrough. According to various embodiments, the passage **52** may be of a sufficient size to allow a tensioning cable to pass therethrough. According to various embodiments, the passage **52** is generally configured as a complex shape that comprises a combination of a first cylinder **54** that extends from the first end **34** toward the second end **36**, and a second cylinder **56** that extends from the first cylinder **54** toward the second end **36**. The diameter of the first cylinder **54** is larger than the diameter of the second cylinder **56**. For example, according to various embodiments, the first cylinder **54** may have a diameter on the order of approximately 3.20 millimeters and the second cylinder **56** may have a diameter on the order of approximately 1.50 millimeters. Other sizes are possible.

[0030] FIGS. 4A-4C illustrate various embodiments of one of the intermediate links **32** (inner intermediate link) of the first mechanism **12**. The intermediate link **32** is representative of the other intermediate links **32**. The intermediate link **32** includes a first end **58** and a second end **60**, and defines a longitudinal axis **62** that passes through the center of the first end **58** and the center of the second end **60** as shown in FIG. 4B. The intermediate link **32** may be fabricated from any suitable material. According to various embodiments, the intermediate link **32** is fabricated from a fiber reinforced material such as, for example, G10/FR4 Garolite®. The intermediate link **32** has a generally bullet-shaped exterior and is described in more detail hereinbelow.

[0031] The intermediate link **32** comprises a first portion **64** and a second portion **66**. The first portion **64** may be considered the proximal portion and the second portion **66** may be considered the distal portion. The first portion **64** may be fabricated integral with the second portion **66**. The first portion **64** has a generally cylindrical shaped exterior, and extends from the first end **58** of the intermediate link **32** toward the second end **60** of the intermediate link **32**. According to various embodiments, the second portion **66** has a generally cylindrically shaped exterior where it contacts the first portion **64**, and tapers toward the second end **60** of the intermediate link **32**. The exterior of the second portion **66** is configured in the form of a generally segmented hemisphere. According to various embodiments, the diameter of the intermediate link **32** may be on the order of approximately 4.75 millimeters at the first end **58** thereof. The length of the intermediate link **32** may be on the order of approximately 5.85 millimeters. However, one skilled in the art will appreciate that the length or diameter of the intermediate link **32** can vary based on the application.

[0032] The intermediate link **32** also comprises a first surface **68** that extends from the first end **58** of the intermediate link **32** to the second end **60** of the intermediate link **32**. The first surface **68** may be considered the outer surface of the intermediate link **32**. The intermediate link **32** also defines a first groove **70** parallel to the longitudinal axis **62** along the first surface **68**, a second groove **72** parallel to the longitudinal axis **62** along the first surface **68**, and a third groove **74** parallel to the longitudinal axis **62** along the first surface **68**. Each of the first, second and third grooves **70**, **72**, **74** extend along the first surface **68** from the first end **58** of the intermediate link **32** toward the second end **60** of the intermediate link **32**. The first, second and third grooves **70, 72, 74** may be semi-tubular shaped and may be evenly spaced about the first surface **68** of the intermediate link **32** as shown in FIG. 4C.

According to various embodiments, the first, second, and third grooves **70**, **72**, **74** may be configured in the shape of a segmented cylinder. The size of each of the grooves **70**, **72**, **74** may be identical to one another or may be different from one another. For example, according to various embodiments, the first and second grooves **70**, **72** are configured as segments of a cylinder having a diameter on the order of approximately 1.75 millimeters at the first end **58** of the intermediate link **32**, and the third groove **74** is configured as a segment of a cylinder having a diameter on the order of approximately 2.50 millimeters at the first end **58** of the intermediate link **32**. The first, second and third grooves **70**, **72**, **74** are each configured to receive and partially surround any of a variety of tools or instruments (e.g., ablation tools) which may pass from the first end **24** of the multi-linked device **10** to the second end **26** of the multi-linked device **10**.

[0033] The intermediate link **32** also defines a passage **76** extending from the first end **58** to the second end **60** along the longitudinal axis **62** as shown in FIG. 4B. The passage **76** may be of a size sufficient to allow one or more cables to pass therethrough. According to various embodiments, the passage **76** may be of a size sufficient to allow a tensioning cable to pass therethrough. According to various embodiments, the passage **76** is generally configured as a complex shape that comprises a combination of a first segmented hemisphere **78** that extends from the first end **58** toward the second end **60**, a second segmented hemisphere **80** that extends from the first segmented hemisphere **78** toward the second end **60**, a cylinder **82** that extends from the second segmented hemisphere **80** toward the second end **60**, and a third segmented hemisphere **84** that extends from the cylinder **82** to the second end **60** of the intermediate link **32**. According to various embodiments, the first segmented hemisphere **78** represents a portion of a sphere having a diameter on the order of approximately 4.75 millimeters, the second segmented hemisphere **80** represents a portion of a sphere having a diameter on the order of approximately 2.25 millimeters, the cylinder **82**

may have a diameter on the order of approximately 1.0 millimeter, and the third segmented hemisphere **84** represents a portion of a sphere having a diameter on the order of approximately 2.25 millimeters. Other sizes are possible.

[0034] The first segmented hemisphere **78** of the passage **76** is configured to receive the second end **36** of the first link **28** when the first link **28** is coupled to the intermediate link **32**. Similarly, for a given intermediate link **32**, the first segmented hemisphere **78** of the passage **76** is configured to receive the second end **60** of another intermediate link **32** when the other intermediate link **32** is coupled to the given intermediate link **32**. The third segmented hemisphere **84** may serve to reduce the pinching or binding a cable when one intermediate link **32** moves relative to an adjacent intermediate link **32** coupled thereto. Similarly, when the second link **30** is coupled to a given intermediate link **32**, the third segmented hemisphere **84** may serve to reduce the pinching or binding of a cable when the second link **30** moves relative to the given intermediate link **32**.

[0035] With the above described structure, the first link **28** may be coupled to the intermediate link **32** by seating the second end **36** of the first link **28** in the first segmented hemisphere **78** of the passage **76** of the intermediate link **32**. As the convex configuration of the second end **36** of the first link **28** generally corresponds with the concave configuration of the first segmented hemisphere **78** of the passage **76** of the intermediate link **32**, the first link **28** may be coupled to the intermediate link **32** such that the longitudinal axis **38** and the first, second and third grooves **46**, **48**, **50** of the first link **28** are respectively aligned with the longitudinal axis **62** and the first, second and third grooves **70**, **72**, **74** of the intermediate link **32**. The intermediate link **32** may be moved relative to the first link **28** such that the longitudinal axis **62** of the intermediate link **32** is not aligned with the longitudinal axis **38** of the first link **28**. According to various embodiments, the configuration of the first link **28** and the intermediate link **32** allows for the intermediate link **32** to be moved relative to the first link **28** coupled thereto such that the longitudinal axis **38** of the first link **28** and the longitudinal axis **62** of the intermediate link **32** are up to approximately 25° out of alignment with one another. Similarly, one intermediate link **32** may be coupled to another intermediate link **32**, and so on, by seating the second end **60** of one intermediate link **32** in the first segmented hemisphere **78** of the passage **76** of another intermediate link **32**. As the convex configuration of the second end **60** of the intermediate link **32** generally corresponds with the concave configuration of the first segmented hemisphere **78** of the passage **76** of the intermediate link **32**, the intermediate links **32** may be coupled such that the respective longitudinal axes **62** and the respective first, second and third grooves **46**, **48**, **50** of the intermediate links **32** are aligned. The coupled intermediate links **32** may be moved relative to one another such that the respective longitudinal axes **62** of the coupled intermediate links **32** are not aligned. According to various embodiments, the configuration of the coupled intermediate links **32** allows for one intermediate link **32** to be moved relative to an adjacent intermediate link **32** coupled thereto such that the respective longitudinal axes **62** are up to approximately 25° out of alignment with one another.

[0036] FIGS. 5A-5C illustrate various embodiments of the second link **30** (inner distal link) of the first mechanism **12**. The second link **30** includes a first end **86** and a second end **88**, and defines a longitudinal axis **90** that passes through the center of the first end **86** and the center of the second end **88** as shown in FIG. 5B. The second link **30** may be fabricated from any suitable material. According to various embodiments, the second link **30** is fabricated from a thermoplastic material such as, for example, Delrin®.

[0037] The second link **30** comprises a first portion **92** and a second portion **94**. The first portion **92** may be considered the proximal portion and the second portion **94** may be considered the distal portion. The first portion **92** may be fabricated integral with the second portion **94**. The first portion **92** has a generally cylindrical shaped exterior, and extends from the first end **86** of the second link **30** toward the second end **88** of the second link **30**. According to various embodiments, the second portion **94** has a generally cylindrically shaped exterior where it contacts the first portion **92**, and tapers toward the second end **88** of the second link **30**. The exterior of the second portion **64** is configured in the form of a generally segmented cone. According to various embodiments, the diameter of the second link **30** may be on the order of approximately 4.75 millimeters at the first end **86** thereof, and the taper of the second portion **94** may be at an angle of approximately 30° relative to the exterior of the first portion **92**. The length of the second link **30** may be on the order of approximately 5.90 millimeters. However, one skilled in the art will appreciate that the length or diameter of the second link **30** can vary based on the application.

[0038] The second link **30** also comprises a first surface **96** that extends from the first end **86** of the second link **30** to the second end **88** of the second link **30**. The first surface **96** may be considered the outer surface of the second link **30**. The second link **30** also defines a first groove **98** parallel to the longitudinal axis **90** along the first surface **96**, a second groove **100** parallel to the longitudinal axis **90** along the first surface **96**, and a third groove **102** parallel to the longitudinal axis **90** along the first surface **96**. Each of the first, second and third grooves **98**, **100**, **102** extend along the first surface **96** from the first end **86** of the second link **30** toward the second end **88** of the second link **30**. The first, second and third grooves **98**, **100**, **102** may be semi-tubular shaped and may be evenly spaced about the first surface **96** of the second link **30** as shown in FIG. 5C. According to various embodiments, the first, second, and third grooves **98**, **100**, **102** may be configured in the shape of a segmented cylinder. The size of each of the grooves **98**, **100**, **102** may be identical to one another or may be different from one another. For example, according to various embodiments, the first and second grooves **98**, **100** are configured as segments of a cylinder having a diameter on the order of approximately 1.25 millimeters at the first end **86** of the second link **30**, and the third groove **102** is configured as a segment of a cylinder having a diameter on the order of approximately 2.50 millimeters at the first end **86** of the second link **30**. The first, second and third grooves **98**, **100**, **102** are each configured to receive and partially surround any of a variety of tools or instruments (e.g., ablation tools) which may pass from the first end **24** of the multi-linked device **10** to the second end **26** of the multi-linked device **10**.

[0039] The second link **30** also defines a passage **104** extending from the first end **86** to the second end **88** along the longitudinal axis **90** as shown in FIG. 5B. The passage **104** may be of a size sufficient to allow at least one cable to pass therethrough. According to various embodiments, the passage **104** may be of a size sufficient to allow a tensioning cable to pass therethrough. According to various embodiments, the passage **104** is generally configured as a complex shape that comprises a combination of a first segmented hemisphere **106** that extends from the first end **86** toward the second end **88**, a second segmented hemisphere **108** that extends from the first segmented hemisphere **106** toward the second end **88**, and a cylinder **110** that extends from the second segmented hemisphere **108** to the second end **88** of the second link **30**. According to various embodiments, the first segmented hemisphere **106** represents a portion of a sphere having a diameter on the order of approximately 4.75 millimeters, the second segmented hemisphere **108** represents a portion of a sphere having a diameter on the order of approximately 2.50 millimeters, and the cylinder **110** may have a diameter on the order of approximately 1.0 millimeter. The first segmented hemisphere **106** of the passage **104** may be configured to receive the second end **60** of an intermediate link **32** when the intermediate link **32** is coupled to the second link **30**.

[0040] With the above described structure, an intermediate link **32** may be coupled to the second link **30** by seating the second end **60** of the intermediate link **32** in the first segmented hemisphere **106** of the passage **104** of the second link **30**. As the convex configuration of the second end **60** of the intermediate link **32** generally corresponds with the concave configuration of the first segmented hemisphere **106** of the passage **104** of the second link **30**, the intermediate link **32** may be coupled to the second link **30** such that the longitudinal axis **62** and the first, second and third grooves **70**, **72**, **74** of the intermediate link **32** are respectively aligned with the longitudinal axis **90** and the first, second and third grooves **98**, **100**, **102** of the second link **30**. The second link **30** may be moved relative to the intermediate link **32** coupled thereto such that the respective longitudinal axes **62**, **90** are not aligned. According to various embodiments, the configuration of the second link **30** allows for an intermediate link **32** coupled thereto to be moved relative to the second link **30** such that the respective longitudinal axes **62**, **90** are up to approximately 25° out of alignment with one another.

[0041] FIG. 6 illustrates various embodiments of the second mechanism **14** of the device **10**. The second mechanism **14** is a multi-linked mechanism and includes a first end **120** and a second end **122**. The first end **120** may be considered the proximal end and the second end **122** may be considered the distal end. The second mechanism **14** comprises a first link **124**, a second link **126**, and any number of intermediate links **128** between the first and second links **124**, **126**. The first link **124** may be considered the proximal link, and the second link **126** may be considered the distal link.

[0042] FIGS. 7A-7C illustrate various embodiments of the first link **124** (outer proximal link) of the second mechanism **14**. The first link **124** includes a first end **130** and a second end **132**, and defines a longitudinal axis **134** that passes through the center of the first end **130** and the center of the second end **132** as shown in FIG. 7B. The first link **124** may be fabricated from any suitable material. According to various embodiments, the first link **124** is fabricated from a stainless steel material such as, for example, **316** stainless steel. The first link **124** has a generally bullet-shaped exterior and is described in more detail hereinbelow.

[0043] The first link **124** comprises a first portion **136** and a second portion **138**. The first portion **136** may be considered the proximal portion and the second portion **138** may be considered the distal portion. The first portion **136** may be fabricated integral with the second portion **138**. The first portion **136** has a cylindrical shaped exterior, and extends from the first end **130** of the first link **124** toward the second end **132** of the first link **124**. According to various embodiments, the diameter of the first portion **136** may be on the order of approximately 12.70 millimeters. Other sizes are possible.

[0044] The second portion **138** has a generally cylindrically shaped exterior. The second portion **138** has a cylindrically shaped exterior where it contacts the first portion **136**, and tapers toward the second end **132** of the first link **124**. The second portion **138** may be shaped in the form of a generally segmented hemisphere at the second end **132** of the first link **124**. According to various embodiments, the diameter of the second portion **138** may be on the order of approximately 9.50 millimeters where it contacts the first portion **136**. Other sizes and shapes are possible.

[0045] The second portion **138** comprises a first surface **140**. The first surface **140** may be considered the outer surface of the second portion **138**. The second portion **138** defines a first groove **142** along the first surface **140**, a second groove **144** along the first surface **140**, and a third groove **146** along the first surface **140**. Each of the first, second and third grooves **142**, **144**, **146** are oblique relative to the longitudinal axis **134** and extend along the first surface **140** toward the second end **132** of the first link **124**. According to various embodiments, each of the grooves **142**, **144**, **146** are oriented at an angle on the order of approximately 15° relative to the longitudinal axis **134**. As shown in FIG. 7C, the first, second and third grooves **142**, **144**, **146** may be evenly spaced about the first surface **140** of the first link **124**. According to various embodiments, the first, second, and third grooves **142**, **144**, **146** may be configured in the shape of a segmented cylinder. The size of each of the grooves **142**, **144**, **146** may identical to one another or may be different from one another. For example, according to various embodiments, each of the grooves **142**, **144**, **146** are configured as segments of respective cylinders having diameters on the order of approximately 3.0 millimeters. The first, second and third grooves **142**, **144**, **146** are each configured to facilitate the introduction of various tools or instruments (e.g., ablation tools) into the multi-linked device **10**. The length of the first link **124** may be on the order of approximately 18.5 millimeters. However, one skilled in the art will appreciate that the length or diameter of the first link **124** can vary based on the application.

[0046] The first link **124** also defines a passage **148** extending from the first end **130** to the second end **132** along the longitudinal axis **134** as shown in FIG. 7B. The passage **148** is of a size sufficient to allow the first mechanism **12** to pass therethrough. According to various embodiments, the passage **148** is generally configured as a complex shape that comprises a combination of a segmented cone **150** that extends from the first end **130** toward the second end **132**, and a cylinder **152** that extends from the segmented cone **150** to the second end **132** of the first link **124**. According to various embodiments, the segmented cone **150** has a diameter on the order of approximately 7.0 millimeters at the first end **130** of the first link **124**, and may be tapered at an angle on the order of approximately 45° relative to the longitudinal axis **134**. The cylinder **152** may have a diameter on the order of approximately 5.50 millimeters. Other dimensions are possible.

[0047] The first link **124** also defines a first through-hole **154**, a second through-hole **156**, and a third through-hole **158**. (See FIG. 7C). The first through-hole **154** is substantially parallel to the longitudinal axis **134**, extends from the first portion **136** toward the second end **132**, and is positioned between the passage **148** and the first surface **140**. The second through-hole **156** is substantially parallel to the longitudinal axis **134**, extends from the first portion **136** to the second end **132**, and is positioned between the passage **148** and the first surface **140**. The third through-hole **158** is substantially parallel to the longitudinal axis **134**, extends from the first portion **136** to the second end **132**, and is positioned between the passage **148** and the first surface **140**. The first, second and third through-holes **154**, **156**, **158** are generally cylindrically shaped. According to various embodiments, the through-holes **154**, **156**, **158** are evenly spaced from one another as shown in FIG. 7C. The size of each of the through-holes **154**, **156**, **158** may be identical to one another or may be different from one another. For example, according to various embodiments, the respective diameters associated with the through-holes **154**, **156**, **158** may each be on the order of approximately 1.20 millimeters. The first through-hole **154** is configured to receive and surround a cable. The second through-hole **156** is configured to receive and surround a cable. The third through-hole **158** is configured to receive and surround a cable. The first, second and third through-holes **154**, **156**, **158** may serve as guidepaths for movement of the cables.

[0048] FIGS. 8A-8C illustrate various embodiments of one of the intermediate links **128** (outer intermediate link) of the second mechanism **14**. The intermediate link **128** is representative of the other intermediate links **128**. The intermediate link **128** includes a first end **160** and a second end **162**, and defines a longitudinal axis **164** that passes through the center of the first end **160** and the center of the second end **162** as shown in FIG. 8C. The intermediate link **128** may be fabricated from any suitable material. According to various embodiments, the intermediate link **128** is fabricated from a polymer thermosplastic material such as, for example, polysulfone. The intermediate link **128** has a generally bullet-shaped exterior and is described in more detail hereinbelow.

[0049] The intermediate link **128** comprises a first portion **166** and a second portion **168**. The first portion **166** may be considered the proximal portion and the second portion **168** may be considered the distal portion. The first portion **166** may be fabricated integral with the second portion **168**. The first portion **166** has a generally cylindrical shaped exterior, and extends from the first end **160** of the intermediate link **128** toward the second end **162** of the intermediate link **128**. According to various embodiments, the second portion **168** has a generally cylindrically shaped exterior where it contacts the first portion **166**, and tapers toward the second end **162** of the intermediate link **128**. The exterior of the second portion **168** is configured in the form of a generally segmented hemisphere. According to various embodiments, the diameter of the intermediate link **128** is on the order of approximately 9.65 millimeters at the first end **160** thereof. The length of the intermediate link **128** may be on the order of approximately 8.40 millimeters. However, one skilled in the art will appreciate that the dimensions of the intermediate link **128** can vary based on the application.

[0050] The intermediate link **128** also comprises a first surface **170** that extends from the first end **160** of the intermediate link **128** to the second end **162** of the intermediate link **128**, and a second surface **170** that extends from the first end **160** of the intermediate link **128** to the second end **162** of the intermediate link **128**. The first surface **170** may be considered the outer surface of the intermediate link **128**, and the second surface **172** may be considered the inner surface of the intermediate link **128**. The intermediate link **32** also defines a first groove **174** substantially parallel to the longitudinal axis **164** along the second surface **172**, a second groove **176** substantially parallel to the longitudinal axis **164** along the second surface **172**, and a third groove **178** substantially parallel to the longitudinal axis 164 along the second surface **172**. Each of the first, second and third grooves **174**, **176**, **178** extend along the second surface **172** toward the second end **162** of the intermediate link **128**. The first, second and third grooves **174**, **176**, **178** may be semi-tubular shaped and may be evenly spaced about the second surface **172** of the intermediate link **128** as shown in FIG. 8C. According to various embodiments, the first, second, and third grooves **174**, **176**, **178** may be configured in the shape of a segmented cylinder. The size of each of the grooves **174**, **176**,

178 may be identical to one another or may be different from one another. For example, according to various embodiments, the first and second grooves **174**, **176** are configured as segments of cylinders having diameters on the order of approximately 1.75 millimeters at the first end **160** of the intermediate link **128**, and the third groove **178** is configured as a segment of a cylinder having a diameter on the order of approximately 2.50 millimeters at the first end **160** of the intermediate link **128**. The first, second and third grooves **174**, **176**, **178** are each configured to receive and partially surround any of a variety of tools or instruments (e.g., ablation tools) which may pass from the first end **24** of the multi-linked device **10** to the second end **26** of the multi-linked device **10**.

[0051] The intermediate link **128** also defines a passage **180** extending from the first end **160** to the second end **162** along the longitudinal axis **164** as shown in FIG. 8B. The passage **180** is of a size sufficient to allow the first mechanism **12** to pass therethrough. According to various embodiments, the passage **180** is generally configured as a complex shape that comprises a combination of a segmented hemisphere **182** that extends from the first end **160** toward the second end **162**, a first segmented cone **184** that extends from the segmented hemisphere **182** toward the second end **162**, a cylinder **186** that extends from the first segmented cone **184** toward the second end **162**, and a second segmented cone **188** that extends from the cylinder **186** to the second end **162** of the intermediate link **128**. According to various embodiments, the segmented hemisphere **182** represents a portion of a sphere having a diameter on the order of approximately 9.65 millimeters, the first segmented cone **184** is tapered at an angle on the order of approximately 15° relative to the longitudinal axis **164**, the cylinder **186** has a diameter on the order of approximately 5.50 millimeters, and the second segmented cone **188** is tapered at an angle on the order of approximately 15° relative to the longitudinal axis **164**. The segmented hemisphere **182** of the passage **180** is configured to receive the second end **132** of the first link **124** when the first link **124** is coupled to the intermediate link **128**. Similarly, for a given intermediate link **128**, the segmented hemisphere **182** of the passage **180** is configured to receive the second end **162** of another intermediate link **128** when the other intermediate link **128** is coupled to the given intermediate link **128**.

[0052] The intermediate link **128** also defines a first through-hole **190**, a second through-hole **192**, and a third through-hole **194**. (See FIG. 8C). The first through-hole **190** is substantially parallel to the longitudinal axis **164**, extends from the first portion **166** toward the second end **162**, and is positioned between the passage **180** and the first surface **170**. The second through-hole **192** is substantially parallel to the longitudinal axis **164**, extends from the first portion **166** to the second end **162**, and is positioned between the passage **180** and the first surface **170**. The third through-hole **194** is substantially parallel to the longitudinal axis **164**, extends from the first portion **166** to the second end **162**, and is positioned between the passage **180** and the first surface **170**. The first, second and third through-holes **190**, **192**, **194** are generally cylindrically shaped. According to various embodiments, the through-holes **190**, **192**, **194** are evenly spaced from one another. The size of each of the through-holes **190**, **192**, **194** may be identical to one another or may be different from one another. For example, according to various embodiments, the respective diameters associated with the through-holes **190**, **192**, **194** may each be on the order of approximately 1.25 millimeters. The first through-hole **190** is configured to receive and surround a cable. The second through-hole **192** is configured to receive and surround a cable. The third through-hole **194** is configured to receive and surround a cable. The first, second and third through-holes **190**, **192**, **194** may serve as guidepaths for movement of the cables.

[0053] As shown in FIG. 8C, the intermediate link **128** also defines first, second and third indents **196**, **198**, **200** at the second end **162** thereof resulting, in part, from the combination of the taper associated with the second portion **168** and the configuration and orientation of the first, second, and third grooves **174**, **176**, **178**. The first, second and third indents **196**, **198**, **200** may be evenly spaced about the second end **162** of the intermediate link **128** as shown in FIG. 8C. The first, second and third indents **196**, **198**, **200** may serve to reduce the pinching or binding of various tools or instruments (e.g., ablation tools) when one intermediate link **128** of the second mechanism **14** is moved relative to another intermediate link **128** coupled thereto.

[0054] The intermediate link **128** also defines fourth, fifth and sixth indents **202**, **204**, **206** at the second end **162** thereof resulting from the combination of the taper associated with the second portion **168** and the configuration and orientation of the first, second, and third through-holes **190**, **192**, **194**. The fourth, fifth and sixth indents **202**, **204**, **206** may be evenly spaced about the second end **162** of the intermediate link **128**, and may be evenly spaced from the first, second and third indents **196**, **198**, **200** as shown in FIG. 8C. The fourth, fifth and sixth indents **202**, **204**, **206** may serve to reduce the pinching or binding of the cables when one intermediate link **128** of the second mechanism **14** is moved relative to another intermediate link **128** coupled thereto.

[0055] According to various embodiments, an intermediate link **128** may also define an opening (not shown) that extends from the second surface **172** or from one of the grooves **174**, **176**, **178** to the first surface **170** of the intermediate link **128**. The intermediate link **128** may have any number of such openings, and any number of the intermediate links **128** may have such openings. Referring to FIGs. 2 and 4, the opening may be utilized as an exit point for a tool or instrument which may pass from the first end **24** of the multi-linked device **10** toward the second end **26** of the multi-linked device **10**. For such embodiments, the respective intermediate link **128** may be positioned proximate to the second link **126** of the second mechanism **14**. The opening may be oriented at any angle relative to the longitudinal axis **134** of the intermediate link **128**. When the first mechanism **12** is removed from the second mechanism **14**, and a relatively large tool or instrument is advanced from the first end **120** of the second mechanism **14** to the second end **122** of the second mechanism **14**, sufficient room may not exist for a second tool or instrument (e.g., fiber optic cable) to pass through the second end **122** of the second mechanism **14**. For such instances, the second tool or instrument may exit through an opening of one of the intermediate links **128**.

[0056] With the above described structure, the first link **124** may be coupled to the intermediate link **128** by seating the second end **132** of the first link **124** in the segmented hemisphere **182** of the passage **180** of the intermediate link **128**. As the convex configuration of the second end **132** of the first link **124** generally corresponds with the concave configuration of the segmented hemisphere **182** of the passage **180** of the intermediate link **128**, the first link **124** may be coupled to the intermediate link **128** such that the longitudinal axis **134**, the first, second and third grooves **142**, **144**, **146**, and the first, second and third through-holes **154**, **156**, **158** of the first link **124** are respectively aligned with the longitudinal axis **164**, the first, second and third grooves **174**, **176**, **178**, and the first, second and third through-holes **190**, **192**, **194** of the intermediate link **128**. The intermediate link **128** may be moved relative to the first link **124** such that the longitudinal axis **164** of the intermediate link **128** is not aligned with the longitudinal axis **134** of the first link **124**. According to various embodiments, the configuration of the first link **124** and the intermediate link **128** allows for the intermediate link **128** to be moved relative to the first link **124** coupled thereto such that the longitudinal axis **134** of the first link **124** and the longitudinal axis **164** of the intermediate link **128** are up to approximately 10° out of alignment with one another. Similarly, one intermediate link **128** may be coupled to another intermediate link **128**, and so on, by seating the second end **162** of one intermediate link **128** in the segmented hemisphere **182** of the passage **180** of another intermediate link **128**. As the convex configuration of the second end **162** of the intermediate link **128** generally corresponds with the concave configuration of the segmented hemisphere **182** of the passage **180** of the intermediate link **128**, the intermediate links **128** may be coupled such that the respective longitudinal axes **164**, the respective first, second and third grooves **174**, **176**, **178**, and the respective first, second and third through-holes **190**, **192**, **194** of the intermediate links **128** are aligned. The coupled intermediate links **128** may be moved relative to one another such that the respective longitudinal axes **164** of the coupled intermediate links **128** are not aligned. According to various embodiments, the configuration of the coupled intermediate links **128** allows for one intermediate link **128** to be moved relative to another intermediate link **128** coupled thereto such that the respective longitudinal axes **164** are up to approximately 10° out of alignment with one another.

[0057] FIGS. 9A-9D illustrate various embodiments of the second link **126** (outer distal link) of the second mechanism **14**. The second link **126** includes a first end **208** and a second end **210**, and defines a longitudinal axis **212** that passes through the center of the first end **208** and the center of the second end **210** as shown in FIG. 9C. The second link **126** may be fabricated from any suitable material. According to various embodiments, the second link **126** is fabricated from a thermoplastic material such as, for example, Delrin®.

[0058] The second link **126** comprises a first portion **214** and a second portion **216**. The first portion **214** may be considered the proximal portion and the second portion **216** may be considered the distal portion. The first portion **214** may be fabricated integral with the second portion **216**. The first portion **214** has a generally cylindrical shaped exterior, and extends from the first end **208** of the second link **126** toward the second end **210** of the second link **126**. According to various embodiments, the diameter of the first portion **214** is on the order of approximately 4.80 millimeters. Other dimensions are possible.

[0059] According to various embodiments, the second portion **216** has a generally cylindrically shaped exterior where it contacts the first portion **214**, and tapers toward the second end **210** of the second link **126**. The exterior of the second portion **216** is configured in the form of a generally segmented cone. According to various embodiments, the exterior of the second portion **216** tapers from the first portion **214** to the second end **210** of the second link **126** at an angle on the order of approximately 20° relative to the exterior of the first portion **214**. The length of the second link **126** may be on the order of approximately 15 millimeters. However, one skilled in the art will appreciate that the length of the second link **126** can vary based on the application.

[0060] The second link **126** also comprises a first surface **218** that extends from the first end **208** of the second link **126** to the second end **210** of the second link **126**, and a second surface **220** that extends from the first end **208** of the second link **126** toward the second end **210** of the second link **126**. The first surface **218** may be considered the outer surface of the second link **126**, and the second surface **220** may be considered the inner surface of the second link **126**.

[0061] The second link **126** also defines a first port **222**, a second port **224**, and a third port **226**. (See FIG. 9B). The first port **222** extends from the second surface **220** to the first surface **218** and is substantially parallel to the longitudinal axis **212**. The second port **224** extends from the second surface **220** to the first surface **218** and is substantially parallel to the longitudinal axis **212**. The third port **226** extends from the second surface **220** to the first surface **218** and is substantially parallel to the longitudinal axis **212**. The first, second and third ports **222, 224, 226** may be cylindrical shaped and may be evenly spaced about the longitudinal axis **212** of the second link **126** as shown in FIG. 9D. The size of each of the ports **222, 224, 226** may be identical to one another or may be different from one another. For example, according to various embodiments, the first and second ports **222, 224** are configured as cylinders having diameters on the order of approximately 1.50 millimeters, and the third port **226** is configured as a cylinder having a diameter on the order of approximately 2.50 millimeters. Other dimensions are possible. The first, second and third ports **222, 224,**

226 are each configured to receive and surround any of a variety of tools or instruments (e.g., ablation tools) which may pass from the first end **24** of the multi-linked device **10** to the second end **26** of the multi-linked device **10**.

[0062] The second link **126** also defines a first through-hole **228**, a second through-hole **230**, and a third through-hole **232**. (See FIG. 9B). The first through-hole **228** extends from the second surface **220** to the first surface **218** and is substantially parallel to the longitudinal axis **212**. The second through-hole **230** extends from the second surface **220** to the first surface **218** and is substantially parallel to the longitudinal axis **212**. The third through-hole **232** extends from the second surface **220** to the first surface **218** and is substantially parallel to the longitudinal axis **212**. The first, second and third through-holes **228**, **230**, **232** are generally cylindrically shaped. According to various embodiments, the through-holes **228**, **230**, **232** are evenly spaced from one another as shown in FIG 9D. The size of each of the through-holes **228**, **230**, **232** may be identical to one another or may be different from one another. For example, according to various embodiments, the respective diameters associated with the through-holes **228**, **230**, **232** may each be on the order of approximately 1.25 millimeters. The first through-hole **228** is configured to receive and surround a cable. The second through-hole **230** is configured to receive and surround a cable. The third through-hole **232** is configured to receive and surround a cable.

[0063] The second link **126** also defines a recess **234** that extends from the first end **208** toward the second end **210** along the longitudinal axis **212** as shown in FIG. 9C. According to various embodiments, the recess **234** is generally configured as a complex shape that comprises a combination of a first segmented hemisphere **236** that extends from the first end **208** toward the second end **210**, and a second segmented hemisphere **238** that extends from the first segmented hemisphere **236** toward the second end **210** of the second link **126**. According to various embodiments, the first segmented hemisphere **236** represents a portion of a sphere having a diameter on the order of approximately 9.50 millimeters, and the second segmented hemisphere **238** represents a portion of a sphere having a diameter on the order of approximately 7.0 millimeters. The first segmented hemisphere **236** of the recess **234** is configured to receive the second end **162** of an intermediate link **128** when the intermediate link **128** is coupled to the second link **126**.

[0064] With the above described structure, an intermediate link **128** may be coupled to the second link **126** by seating the second end **162** of the intermediate link **128** in the first segmented hemisphere **236** of the recess **234** of the second link **126**. As the convex configuration of the second end **162** of the intermediate link **128** generally corresponds with the concave configuration of the first segmented hemisphere **236** of the recess **234** of the second link **126**, the intermediate link **128** may be coupled to the second link **126** such that the longitudinal axis **164**, the first, second and third grooves **174**, **176**, **178**, and the first, second and third through-holes **190**, **192**, **194** of the intermediate link **128** are respectively aligned with the longitudinal axis **212**, the first, second and third ports **222**, **224**, **226**, and the first, second and third through-holes **228**, **230**, **232** of the second link **126**. The second link **126** may be moved relative to the intermediate link **128** coupled thereto such that the respective longitudinal axes **164**, **212** are not aligned. According to various embodiments, the configuration of the second link **126** allows for an intermediate link **128** coupled thereto to be moved relative to the second link **126** such that the respective longitudinal axes **164**, **212** are up to approximately 10° out of alignment with one another.

[0065] When the first mechanism **12** is inserted into the second mechanism **14**, the first second and third grooves **70**, **72**, **74** of the intermediate links **32** of the first mechanism **12** may be substantially aligned with the first, second and third grooves **174**, **176**, **178** of the intermediate links **128** of the second mechanism **14**, and the first, second and third grooves **98**, **100**, **102** of the second link **30** of the first mechanism **12** may be substantially aligned with the first, second and third ports **222**, **224**, **226** of the second link **126** of the second mechanism **14**. The combination of the first grooves **70** of the intermediate links **32** of the first mechanism **12** aligned with the first grooves **174** of the intermediate links **128** of the second mechanism **14** allows the respective first grooves **70**, **174** to collectively serve as a first working port that is substantially aligned with the first port **222** of the second link **126** of the second mechanism **14**. The first groove **70** may be considered the inner portion of the first working port and the first groove **174** may be considered the outer portion of the first working port.

[0066] Similarly, the combination of the second grooves **72** of the intermediate links **32** of the first mechanism **12** aligned with the second grooves **176** of the intermediate links **128** of the second mechanism **14** allows the respective second grooves **72**, **176** to collectively serve as a second working port that is substantially aligned with the second port **224** of the second link **126** of the second mechanism **14**, and the combination of the third grooves **74** of the intermediate links **32** of the first mechanism **12** aligned with the third grooves **178** of the intermediate links **128** of the second mechanism **14** allows the respective third grooves **74**, **178** to collectively serve as a third working port that is substantially aligned with the third port **226** of the second link **126** of the second mechanism **14**. The second groove **72** may be considered the inner portion of the second working port and the second groove **176** may be considered the outer portion of the second working port. The third groove **74** may be considered the inner portion of the third working port and the third groove **178** may be considered the outer portion of the third working port. The first, second and third working ports may be utilized to pass various tools or instruments (e.g., ablation tools) from the first end **24** of the multi-linked device **10** to the second end **26** of the multi-linked device **10**. For the exemplary sizes described hereinabove, the third working port is larger than the first and second working ports. Accordingly, the third working port may be utilized to carry a particular tool or instrument that is too large to be carried by the first or second working ports.

[0067] When the respective grooves **70**, **72**, **74**, **174**, **176**, **178** of the respective intermediate links **32**, **128** are aligned and collectively surround the various tools and instruments, the combination of the grooves **70**, **72**, **74**, **174**, **176**, **178** and the tools and instruments may serve to limit or prevent the rotation of the first mechanism **12** relative to the second mechanism **14**.

[0068] As the diameter of the passage **180** of the intermediate link **128** of the second mechanism **14** is larger than the diameter of any portion of the first mechanism **12**, a three-dimensional space **240** exists between the first mechanism **12** and the second mechanism **14** when the first mechanism **12** is received by the second mechanism **14** (See FIG. 1B). According to various embodiments, the space **240** may be utilized to carry wiring, tools, instruments, etc. from the first end **24** of the multi-linked device **10** toward the second end **26** of the multi-linked device **10**.

[0069] According to various embodiments, one or more steering cables may be fabricated from any suitable material. For example, according to various embodiments, the steering cables may be fabricated from a polyethylene fiber cable such as, for example, Spectra®. The steering cables may be utilized to control the movement of the multi-linked device **10**. For example, by applying a substantially equal tension to each of the steering cables, the first mechanism **12** and/or second mechanism **14** may be steered in a direction such that the respective longitudinal axes **38**, **62**, **90**, **134**, **164**, **212** of each of the links **28**, **30**, **32**, **124**, **126**, **128** are all aligned. By applying a different tension to one or more of the steering cables, the first mechanism **12** and/or the second mechanism **14** may be steered in a direction such that the respective longitudinal axes **38**, **62**, **90**, **134**, **164**, **212** of each of the links **28**, **30**, **32**, **124**, **126**, **128** are not all aligned. The cables **16**, **18**, **20** may also be utilized to control the relative state of the second mechanism **14**. For example, when a uniform tension is applied to the steering cables, the second mechanism **14** may be placed in a "rigid" state, and when a tension is removed from the steering cables, the second mechanism **14** may be placed in a "limp" state. According to various embodiments, one or more of the steering cables may be attached at the first end **130** of the first link **124** of the second mechanism **14** to respective pullies (not shown) by, for example, respective stopper knots. The steering cables may be attached to the second end **132** of the second link **126** of the second mechanism **14** by, for example, respective stopper knots. One skilled in the art will appreciate that, according to other embodiments, the "rigid" and "limp" states may be achieved by subjecting the first and/or second mechanisms **12**, **14** to a twisting force, or by any other manner known in the art.

[0070] According to various embodiments, one or more tensioning cables may be fabricated from any suitable material. For example, according to various embodiments, the tensioning cables may be fabricated from a polyethylene fiber cable such as, for example, Spectra®. The tensioning cables may be utilized to control the relative state of the first mechanism **12**. For example, when the tensioning cable is drawn tight, the first mechanism **12** may be placed in a "rigid" state, whereas when the tensioning cable is let loose, the first mechanism **12** may be placed in a "limp" state. According to various embodiments, the tensioning cable may be attached at the first end **34** of the first link **28** of the first mechanism **12** to a pully (not shown) by, for example, a stopper knot. The tensioning cable may be attached to the second end **88** of the second link **30** of the first mechanism **12** by, for example, a stopper knot.

[0071] FIG. 10 illustrates various embodiments of a motion sequence of the steerable multi-linked device **10**. At the start of the sequence, the second mechanism **14** surrounds the first mechanism **12** as shown in step "a" of FIG. 10, the longitudinal axes **38**, **62**, **90** of the links **28**, **30**, **32** of the first mechanism **12** are substantially aligned with the respective longitudinal axes **134**, **164**, **212** of the links **124**, **126**, **128** of the second mechanism, and the second end **26** of the first mechanism **12** is at substantially the same position as the second end **122** of the second mechanism **14**. A tensioning cable is pulled tight, thereby placing the first mechanism **12** in the rigid mode. The steering cables are not pulled tight, thereby placing the second mechanism **14** in the limp mode.

[0072] The second mechanism **14** is then advanced so that its second link **126** is positioned approximately one link ahead of the second end **24** of the first mechanism **12** as shown in step "b" of FIG. 10. The cables **16**, **18**, **20** may be utilized to orient the second link **126** to a particular orientation, where the longitudinal axis **134** of the first link **124** is no longer aligned with the longitudinal axes **164** of the intermediate links **128** of the second mechanism **14** or the longitudinal axis **90** of the second link **30** of the first mechanism **12**. After the second link **126** is in the desired position and orientation, the steering cables are pulled with identical force in order to place the second mechanism **14** in the rigid mode, thereby preserving the position and orientation of the second mechanism **14**.

[0073] The pulling force of the tensioning cable is then released to place the first mechanism **12** in the limp mode. After the first mechanism **12** is placed in the limp mode, the first mechanism **12** is advanced so that its second link **30** is at substantially the same position as the second end **122** of the second mechanism **14** as shown in step "c" of FIG. 10. After the second link **30** of the first mechanism **12** is in the desired position and orientation, the tensioning cable is pulled tight to place the first mechanism **12** back in the rigid mode, thereby preserving the position and orientation of the first mechanism **12**.

[0074] The pulling forces of the steering cables are then released to place the second mechanism **14** back in the limp mode. After the second mechanism **14** is placed back in the limp mode, the second mechanism **14** is advanced so that its second link **126** is once again positioned approximately one link ahead of the second end **26** of the first mechanism **12** as shown in step "d" of FIG. 10. After the second link **126** is in the desired position and orientation, the steering cables are pulled with identical force in order to place the second mechanism **14** in the rigid mode, thereby preserving the position and orientation of the second mechanism **14**.

[0075] The pulling force of the tensioning cable is then released to place the first mechanism **12** back in the limp mode. After the first mechanism **12** is placed back in the limp mode, the first mechanism **12** is advanced so that its second link **30** is once again at substantially the same position as the second end **122** of the second mechanism **14** as shown in step "e" of FIG. 10. After the second link **30** of the first mechanism **12** is in the desired position and orientation, the tensioning cable is pulled tight to place the first mechanism **12** back in the rigid mode, thereby preserving the position and orientation of the first mechanism **12**. The general motion sequence described hereinabove, may be repeated any number of times, and the second link **126** of the second mechanism **14** may be advancing in any direction and orientation. One skilled in the art will appreciate that any number of motion sequences may be utilized with the multi-linked device **10**. For example, according to various embodiments, the second mechanism **14** may advance any number of links ahead of the first mechanism **12**.

[0076] The exemplary sizes described hereinabove are generally relative to each other, and one skilled in the art will appreciate that the multi-linked device **10** can be scaled up or scaled down. For example, although the diameter at the largest portion of the intermediate link **128** of the multi-linked device **10** is on the order of approximately 9.65 millimeters for the embodiments described hereinabove, one skilled in the art will appreciate that, for other embodiments, the intermediate link **128** can be scaled down such that the diameter at the largest portion of the intermediate link **128** of the multi-linked device **10** is on the order of approximately 1.0 millimeter. For such embodiments, each of the other components of the multi-linked device **10** would also be proportionally scaled down.

[0077] The combination of the unique configuration of the respective links **28**, **30**, **32** which comprise the first mechanism **12** and the unique configuration of the respective links **124**, **126**, **128** which comprise the second mechanism **14** provides the multi-linked device **10** with the ability to traverse a path defined by the circumference of a circle having a relatively small radius. For example, for the exemplary sizes described hereinabove, the multi-linked device **10** can traverse a path defined by the circumference of a circle having a radius on the order of approximately 45 millimeters. An example of the multi-linked device **10** navigating such tight curvatures is shown in FIG. 11. For embodiments, where the largest portion of the intermediate link **128** of the multi-linked device **10** is on the order of approximately 1.0 millimeter, the multi-linked device **10** can traverse a path defined by the circumference of a circle having a radius significantly smaller than 45 millimeters. One skilled in the art will appreciate that the ability to navigate such tight curvatures makes the multi-linked device **10** suitable for use in a number of different minimally invasive procedures, both in luminal spaces and in intracavity spaces.

[0078] A controller device may control the movement of a multi-linked device such as, for example, the multi-linked device **10**. According to various embodiments, the controller device may comprise one or more electromechanical devices that may receive input from a user. Exemplary electromechanical devices may include buttons, sliders, knobs, toggles, dials, handles or the like.

[0079] According to various embodiments, the controller device may be embodied as a joystick, and the joystick may be similar to joysticks known in the art. FIG. 12A illustrates an exemplary joystick according to an embodiment. For such embodiments, the controller device **500** comprises a handle **502** and a base **504**. In operation, movement of the handle

502 relative to the base **504** signals the feeder mechanism **400** to move the multi-linked device **10** in a desired direction.

[0080] According to various embodiments, a controller device may be associated with two or more independent degrees of freedom (DOF). For example, a joystick 500 may have two DOF, where one DOF is associated with a pitch of the multi-linked device and one DOF is associated with a yaw of the multi-linked device. According to various embodiments, a three DOF controller may use a modified Stewart platform to accept input representative of motion from a user. The third degree of freedom may be controlled simultaneously with steering of the device. This may allow the device to operate with continuous motion.

[0081] The controller device may be in electrical and/or mechanical communication with the feeder mechanism **400** and/or the multi-linked device 10. According to various embodiments, the controller device may be utilized to control the movement of the multi-linked device **10**.

[0082] A common problem associated with remotely controlling target devices, such as the multi-linked device **10**, is the dissociation that may occur between the controller device's motion and the device's motion. For example, a large target device may move very slowly, whereas a controller device controlling the motion of the target device may move very quickly, or vice versa. As such, the motion capabilities between a controller device and a target device may be mismatched. The use of a haptic controller may mitigate this problem.

[0083] According to various embodiments, a controller device may be a haptic controller, such as that illustrated by FIG. 12B. A haptic controller may be a device that tactilely interacts with a user. A haptic controller may receive input having a plurality of degrees of freedom. According to various embodiments, the haptic controller may exert a force output that may be associated with one or more of the degrees of freedom. For example, if a user moves the haptic controller faster than the device that is being controlled, the haptic controller may output a force against the user's motion. According to various embodiments, the magnitude of the force output may be related to a difference between a command signal from the haptic controller and feedback received from the target device and/or the feeder.

[0084] According to various embodiments, a relationship may exist between the location of the controller device and the target device, between the velocity and/or acceleration of the controller device and the target device, and the like.

[0085] According to various embodiments, the haptic controller may convey information to a user by exerting one or more force outputs. For example, the haptic controller may cause an electromechanical device, such as a handle of the haptic controller, to pull toward a predetermined position, such as a home position. This may help orient the user as to the direction of the home position from a current position. According to various embodiments, the magnitude of the force associated with the force output may be proportional to a relationship between the handle and the home position. For example, a haptic controller may exert a greater force on the handle in the direction of the home position the further the handle is from the home position. According to various embodiments, the home position may be dynamically changed and its new location may be communicated to the user by one or more force outputs.

[0086] According to various embodiments, one or more force outputs may be used to alert the user as to undesirable configurations and/or positions. As a result, the haptic controller may resist user motion into areas of the haptic controller's workspace that may result in undesirable configurations. For example, if the user is controlling the target device in such a way that may damage the area through which the target device is maneuvering or the target device itself, the haptic controller may exert one or more force outputs that may resist the user's motion. According to various embodiments, the magnitude of the force output may be proportional to a relationship between the target device and the undesirable area. For example, if, during a medical procedure, there is an area that the target device should avoid, such as the aorta, the haptic controller may resist the user's motion when the target device approaches the vicinity of the transverse sinuses. As the target device moves closer to the transverse sinuses, the magnitude of the force output exerted by the haptic controller may increase.

[0087] According to various embodiments, the target device may comprise one or more force sensors. The force sensors may measure the force associated with contact between the target device and a surrounding structure, area or the like. According to various embodiments, the feeder device **400** may receive information associated with the deformation of a surrounding external structure, area or the like caused by the target device. The deformation information, in conjunction with the measured force, may be used to estimate the compliance of the surrounding structure, area or the like. For example, if the target device is maneuvering through a portion of the body, a force sensor may measure the force with which the target device contacts an organ. This information may be used with deformation information to estimate the compliance of the organ.

[0088] According to various embodiments, the type of force output exerted by the haptic controller may vary. For example, the haptic controller may exert a constant force, pulsating force, a vibrating force or the like. The type of force output may vary depending on the information being conveyed to a user. For example, the haptic controller may exert a constant force output to indicate the device is near an area that may be damaged by the device, but the haptic controller may exert a vibrating force output to indicate that the device is near an area that may cause damage to the device. According to various embodiments, the haptic controller may discontinue force output to inform the user that communication between the haptic controller and the target device has been lost.

[0089] According to various embodiments, the controller device may provide for pause functionality. When pause functionality is invoked, the position of the multi-linked device **10** may not change, regardless of whether or not the position of the handle changes relative to the base. The pause functionality may be invoked at any time. For example, the pause functionality may be invoked while controlling the movement of the first or second mechanisms **12**, **14** of the multi-linked device **10**. When a user is controlling the position of the multi-linked device **10** via the controller device, the user may invoke the pause functionality by keeping the handle in the same position relative to the base. The user may also accomplish this by simply removing his/her hand from the controller device. According to various embodiments, the controller device further comprises a pause button, which when pressed, invokes the pause functionality. The pause functionality may be toggled on/off via the pause button. The pause functionality allows the user to reorient and continue in a manner generally not available with typical medical devices. The pause functionality may also be utilized to allow a switch from one user to another user.

[0090] FIG. 13 illustrates various embodiments of a method **600** for controlling movement of a multi-linked device such as, for example, the multi-linked device **10**. According to various embodiments, the method **600** may correspond to the use of a two DOF controller, such as the joystick illustrated in FIG. 12A. The method **600** begins at block **602**, where the handle **502** of the device **500** is moved relative to the base **504** of the device **500** to advance the second end **122** of the second mechanism **14** of the multi-linked device **10** away from the feeder mechanism **400**. From block **602**, the process advances to block **604**, where the handle **502** of the device **500** is moved relative to the base **504** of the device **500** to advance the second end **26** of the first mechanism **12** of the multi-linked device **10** away from the feeder mechanism **400**. The process described at blocks **602-604** may be repeated any number of times, and the movement of the second ends **26**, **122** away from the feeder mechanism **400** may be in a variety of directions.

[0091] From block **604**, the process advances to block **606**, where the device **500** is placed in the pause mode. From block **606**, the process advances to block **608**, where the device **500** is removed from the pause mode. From block **608**, the process may return to either block **602** or block **604**, or the process may advance to block **610**, depending on how the handle **502** is moved relative to the base **504**. At block **610**, the handle **502** is moved relative to the base **504** to retract the first mechanism **12** toward the feeder mechanism **400**. According to various embodiments, the handle **502** may be moved relative to the base **504** in a manner which results in the full retraction of the first mechanism **12**. From block **610**, the process may return to block **604**, or advance to block **612** depending on how the handle **502** is moved relative to the base **504**. At block **612**, the handle **502** is moved relative to the base **504** to retract the second mechanism **14** toward the feeder mechanism **400**. From block **610**, the process may return to block **602**. According to various embodiments, the handle **502** may be moved relative to the base **504** in a manner which results in the full retraction of the second mechanism **14**.

[0092] According to various embodiments, a three DOF controller may be used to advance a target device, such as, for example, the multi-linked device **10**, in a continuous manner. For example, a handle of a three DOF controller may operate in a three-dimensional coordinate system. The x-direction may correspond to the horizontal direction, the y-direction may correspond to the vertical direction and the z-direction may correspond to forward(positive)/backward(negative). The home position may be zero for one or more directions. For a motion of the three DOF controller's handle, the x-component of position may be related to the yaw angle of the distal link relative to an adjacent link, the y-component of position may be related to the pitch angle of the distal link relative to an adjacent link, and the z-component of position may be related to the advancement and/or retraction of the target device. According to various embodiments, the relationship between motion of the target device may be related to the position of the handle of the target device relative to the base of the target device, the velocity of the handle relative to the base, the acceleration of the handle relative to the base and/or the like.

[0093] In various embodiments, the controller device may be used to activate one or more modes of movement associated with the device **10**. Exemplary modes may include a homing mode, an advancing mode, a steering mode, a retract mode, a retract inner mode, and/or the like.

[0094] In various embodiments, the homing mode may reset one or more settings associated with the device **10**. While operating in the advancing mode, the device **10** may advance forward from one location to a next location. In various embodiments, this advancement may be repeated a plurality of times. While operating in the steering mode, the second mechanism **14** may alternate between operating in a rigid mode and a limp mode. In various embodiments, the direction of the second link **126** of the second mechanism **14** may change direction while the device **10** operates in the steering mode.

[0095] While operating in a retract mode, the device **10** may move backward from one location to a next location. In various embodiments, this retraction may be repeated a plurality of times. In various embodiment, while operating in retract mode, the device **10** may automatically retract along the same path it had advanced. For example, if the device **10** advanced along a path represented by the sequence of points $\{x_1, x_2, x_3, x_4, x_5\}$, the device may automatically retract along a path represented by the sequence of points $\{x_5, x_4, x_3, x_2, x_1\}$ if the mode is switched to retract mode. While operating in a retract inner mode, the first mechanism **16** may retract.

[0096] In various embodiments, a movement of the controller device may correspond to a mode of movement associated with the device **10**. For example, moving the controller device forward may signal the feeder mechanism **400** to operate the device **10** in an advancing mode. In various alternate embodiments, the controller device may include one or more controls such as a button, a switch, a toggle a dial or the like. Each control may correspond to one or more modes. For example, a controller device may include a button corresponding to one or modes. To operate the device in a given mode, a user may enable a control, such as pressing a button corresponding to the desired mode. According to various embodiments, a user may cycle through the modes by repeatedly pressing a button. For example, pressing the button while in homing mode may trigger a change to advancing mode.

[0097] While several embodiments of the invention have been described herein by way of example, those skilled in the art will appreciate that various modifications, alterations, and adaptations to the described embodiments may be realized without departing from the spirit and scope of the invention defined by the appended claims.

J. CLAIMS

What Is Claimed Is:

1. A system for controlling the movement of a steerable multi-linked device, the system comprising:

a feeder mechanism;

a steerable multi-linked device releaseably connected to the feeder mechanism, wherein the steerable multi-linked device comprises:

a first link,

a plurality of intermediate links, wherein a first one of the intermediate links is movably coupled to the first link, and

a second link movably coupled to a second one of the intermediate links; and

a controller device configured to select a mode of movement associated with the multi-linked device.

2. The system of claim 1, wherein the controller device is a joystick.

3. The system of claim 1, wherein the controller device is a haptic controller.

4. The system of claim 1, wherein the controller device is configured to provide one or more output forces when the steerable multi-linked device is a certain distance from a predetermined area.

5. The system of claim 4, wherein a magnitude of the one or more output forces is related to a difference in motion between the controller device and the steerable multi-linked device.

6. The system of claim 1, wherein the controller device is configured to provide one or more output forces when the steerable multi-linked device is a certain distance from an area that may be damaged by the steerable multi-linked device.

7. The system of claim 1, wherein the controller device is configured to provide one or more output forces when the steerable multi-linked device is a certain distance from an area that may damage the steerable multi-linked device.

8. The system of claim 1, wherein:

the steerable multi-linked device comprises one or more force sensors configured to measure a force associated with a contact between the steerable multi-linked device and a surrounding area;

the feeder mechanism is configured to receive information associated with a deformation of the surrounding area; and

the controller device is configured to:

estimate a compliance associated with the surrounding area, and

provide one or more output forces based on the estimation.

9. The system of claim 1, wherein the controller device comprises one or more buttons, wherein each button is associated with a mode of movement of the multi-linked device.

10. The system of claim 1, wherein the controller device is configured to pause movement of the multi-linked device.

11. The system of claim 1, wherein the controller device is configured to select one or more of the following modes:

a homing mode;

an advancing mode;

a steering mode;

a retract mode; and

a retract inner mode.

12. The system of claim 1, wherein the steerable multi-linked device comprises:

a first multi-linked mechanism, wherein the first mechanism defines a first plurality of grooves;

a second multi-linked mechanism, wherein the second mechanism defines a second plurality of grooves, and wherein:

the first and second pluralities of grooves cooperate to define at least two working ports along a length of the device steerable multi-linked device; and

at least one of the first and second mechanisms are steerable.

13. The system of claim 12, wherein the second mechanism surrounds the first mechanism.

14. The system of claim 1, wherein the first link defines a passage extending from a first end of the first link to a second end of the first link along a longitudinal axis which passes through a center of the first end and a center of the second end.

15. The system of claim 1, wherein at least one of the intermediate links defines a passage extending from a first end of the at least one of the intermediate links to a second end of the at least one of the intermediate links along a longitudinal axis which passes through a center of the first end and a center of the second end.

16. The system of claim 1, wherein the controller device is in communication with one or more of the feeder mechanism and the steerable multi-linked device.

17. The system of claim 1, wherein the controller device comprises a base and a handle, wherein the controller device is configured to control movement of the steerable multi-linked device based on a relationship between one or more of the following:

position of a handle of the controller device relative to a base of the controller device,

a velocity associated with the handle of the controller device relative to the base of the controller device, and

an acceleration associated with the handle of the controller device relative to the based of the controller device.

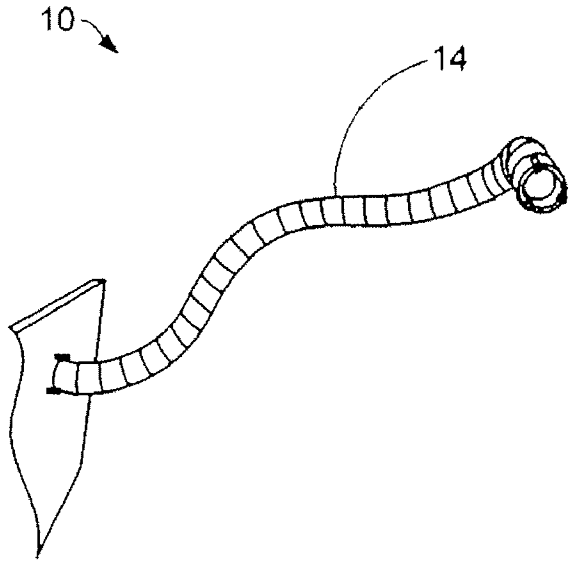

FIG. 1A

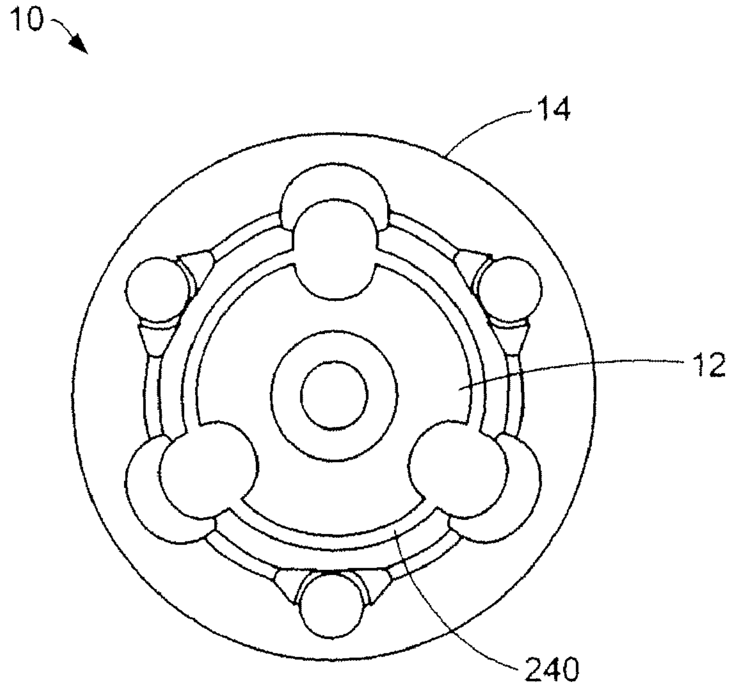

FIG. 1B

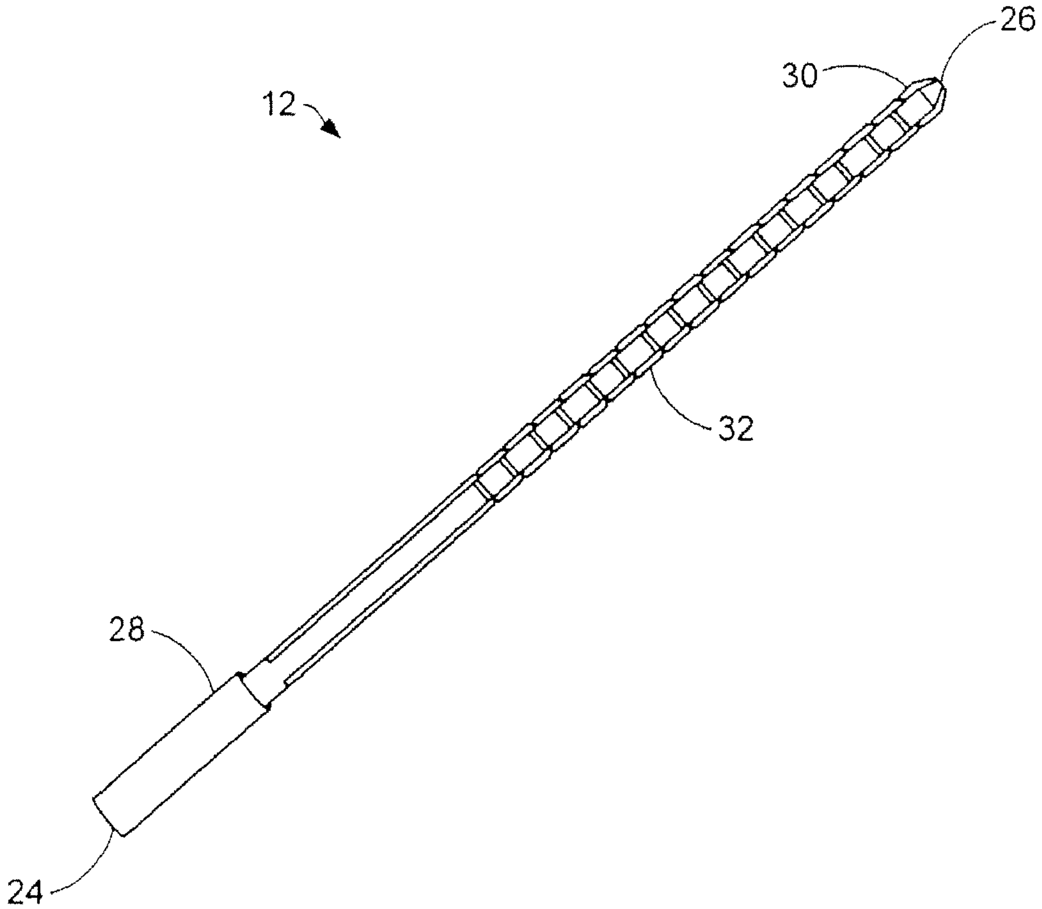

FIG. 2

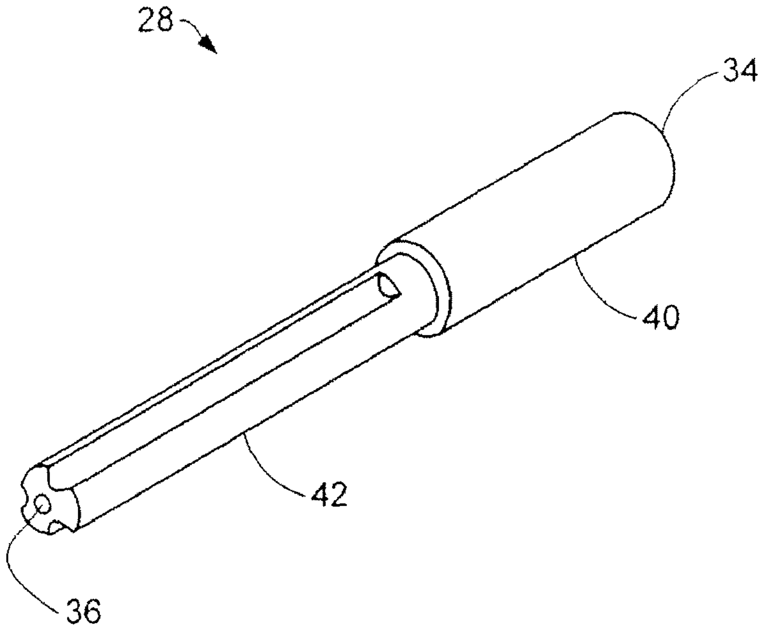

FIG. 3A

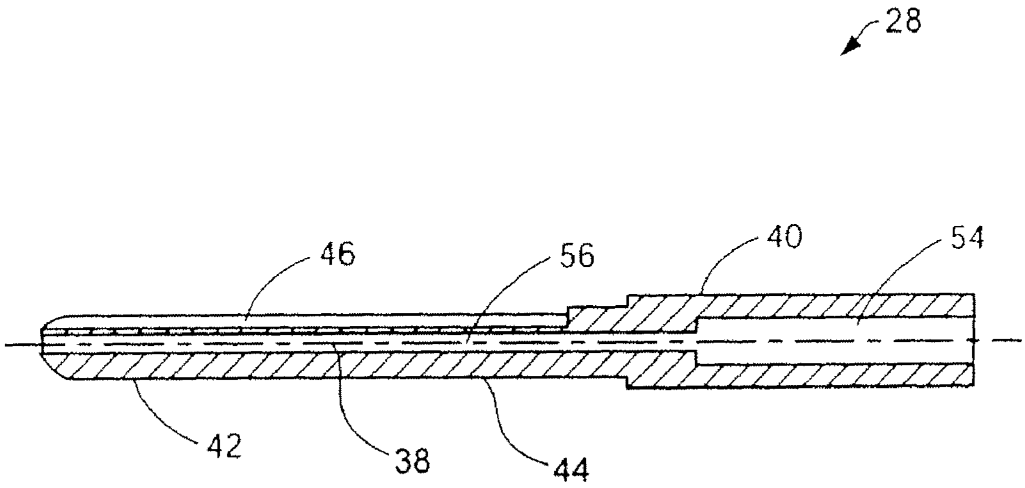

FIG. 3B

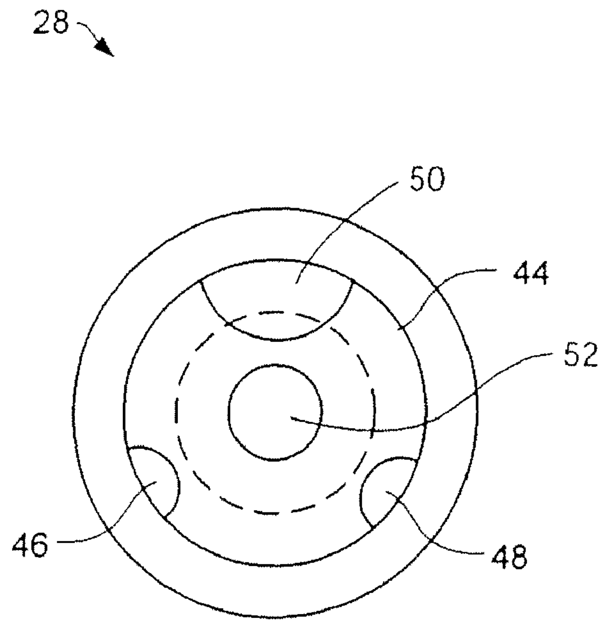

FIG. 3C

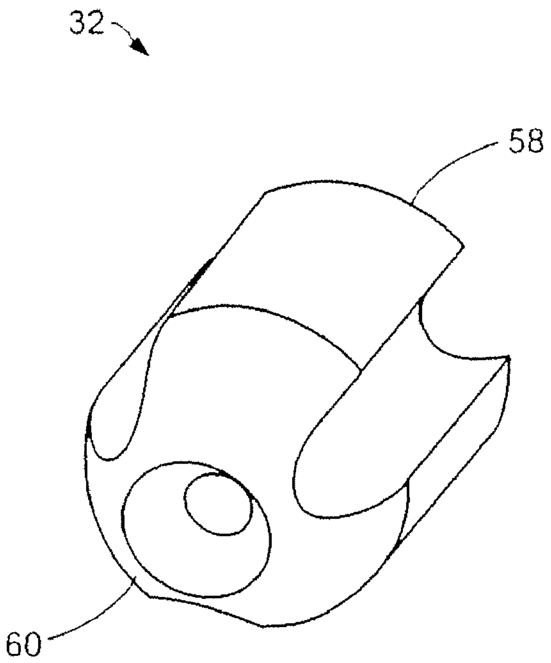

FIG. 4A

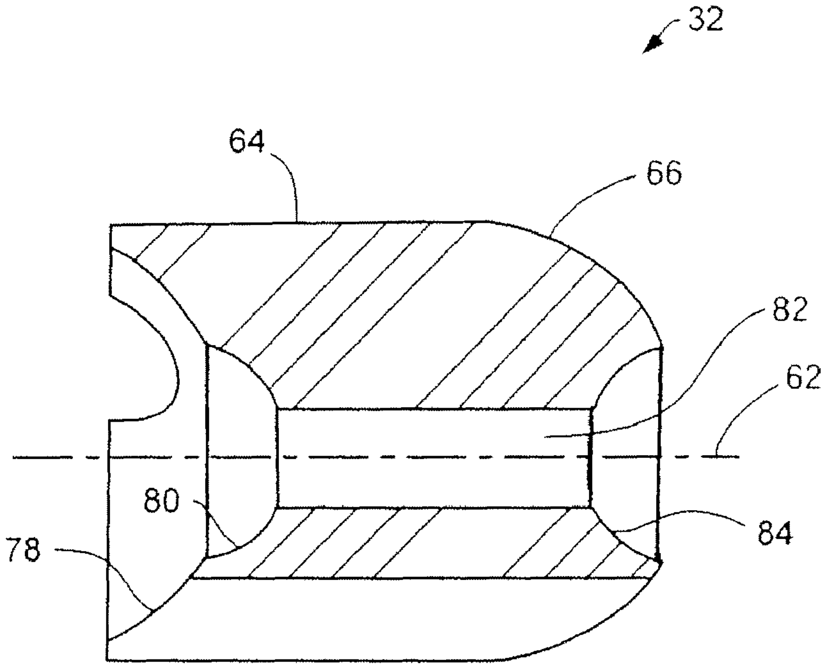

FIG. 4B

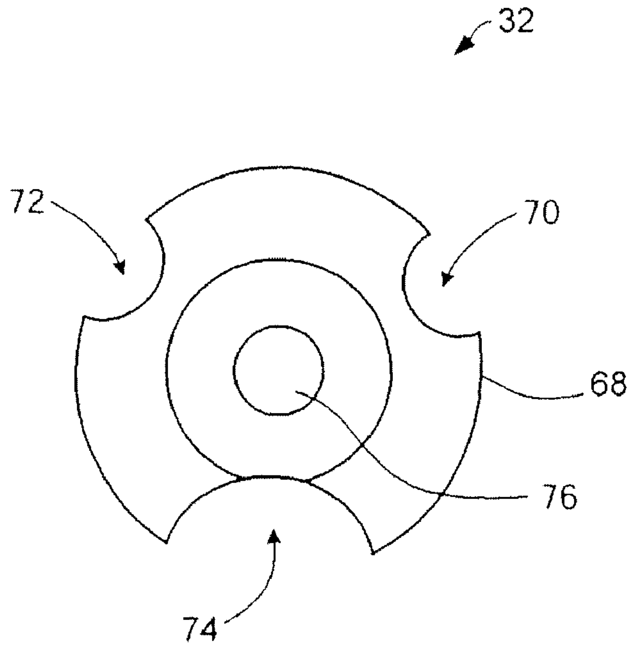

FIG. 4C

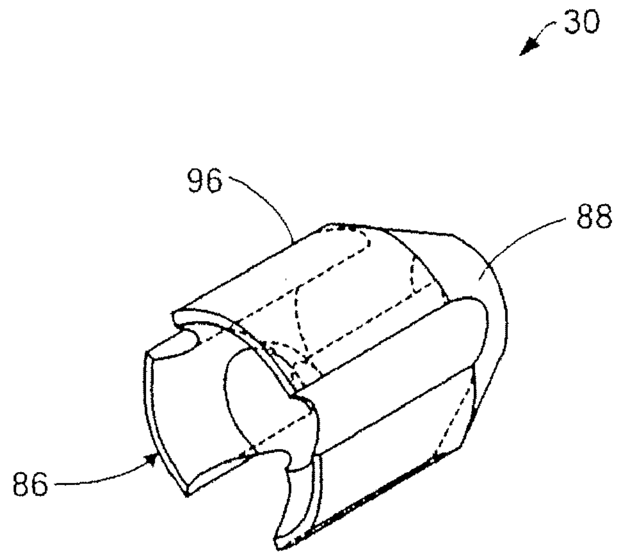

FIG. 5A

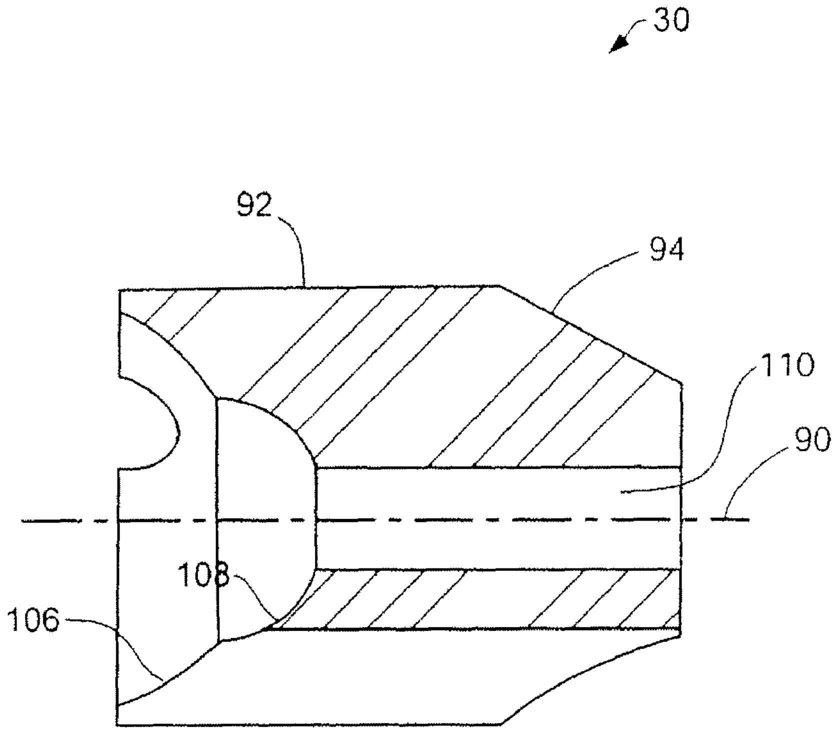

FIG. 5B

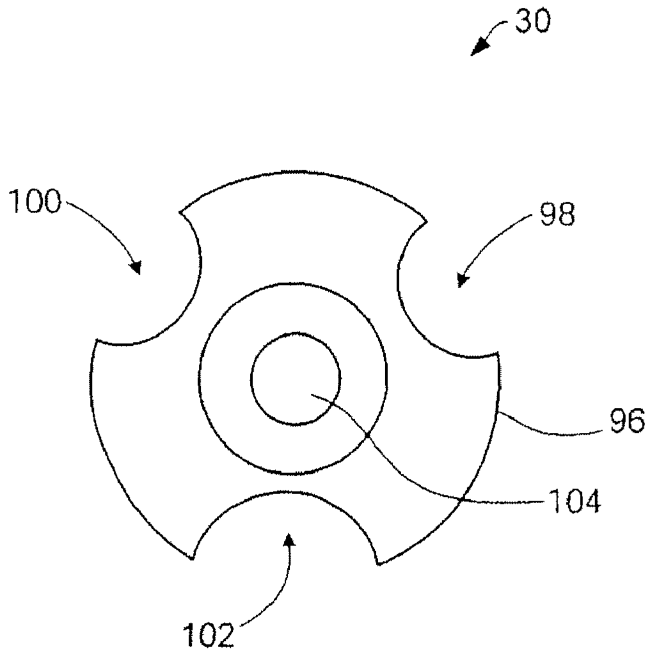

FIG. 5C

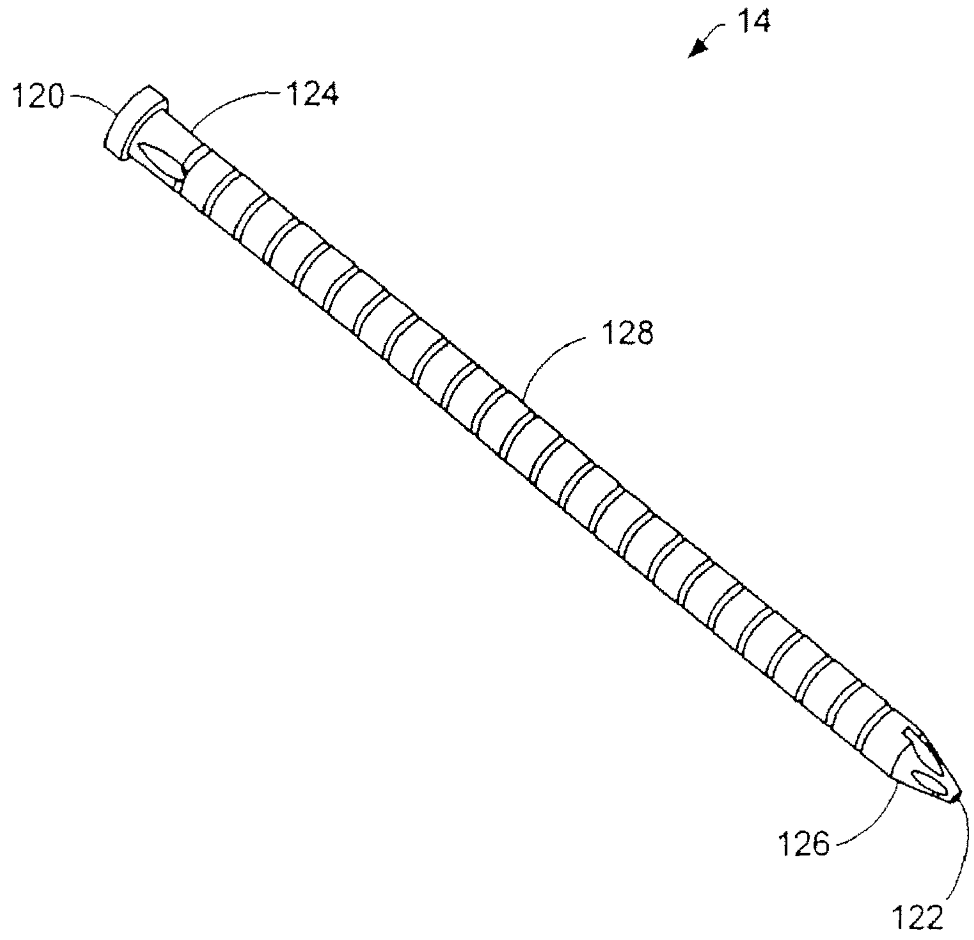

FIG. 6

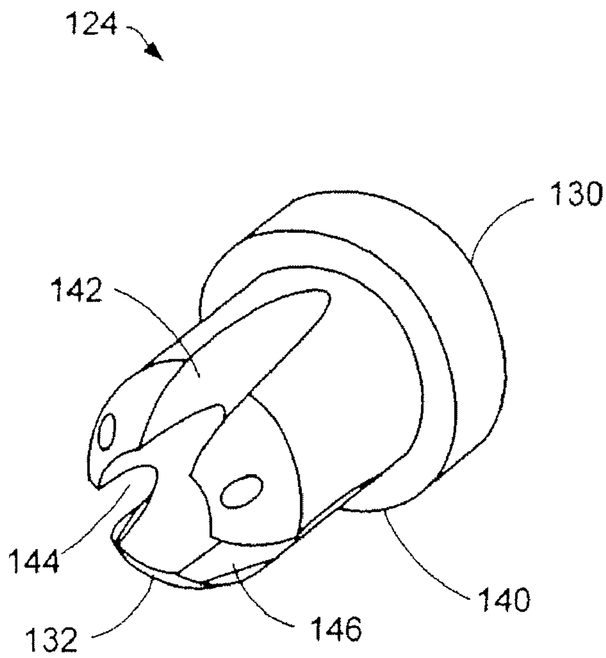

FIG. 7A

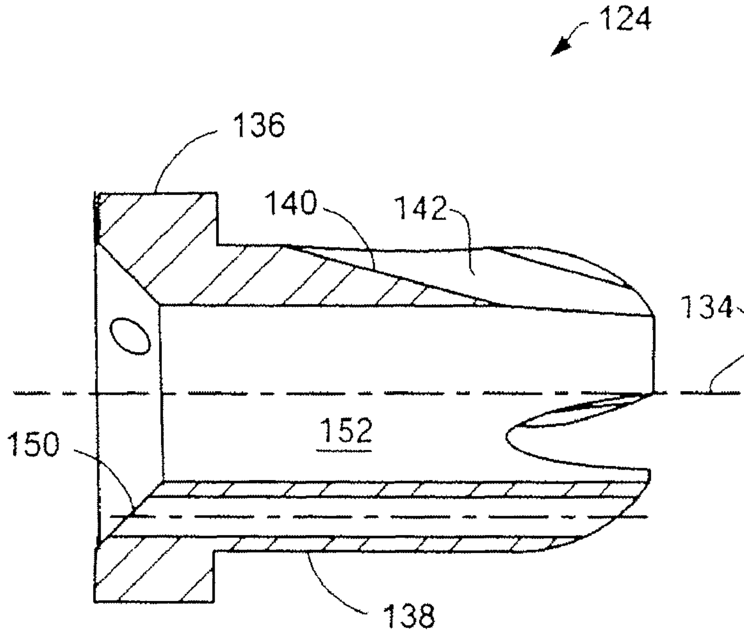

FIG. 7B

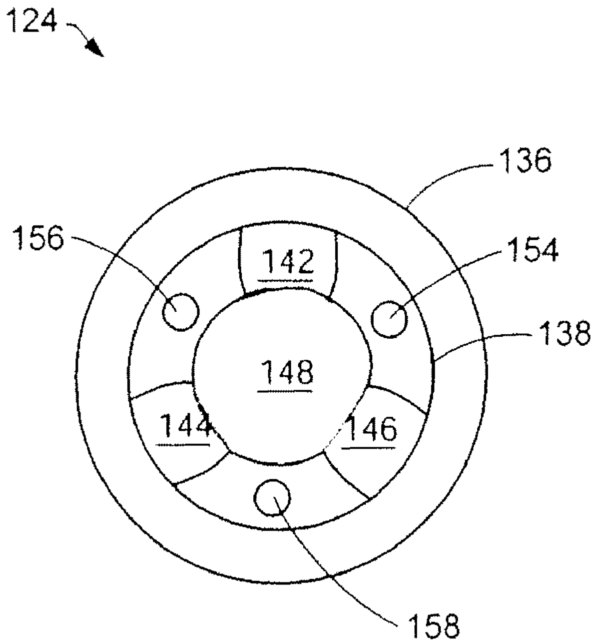

FIG. 7C

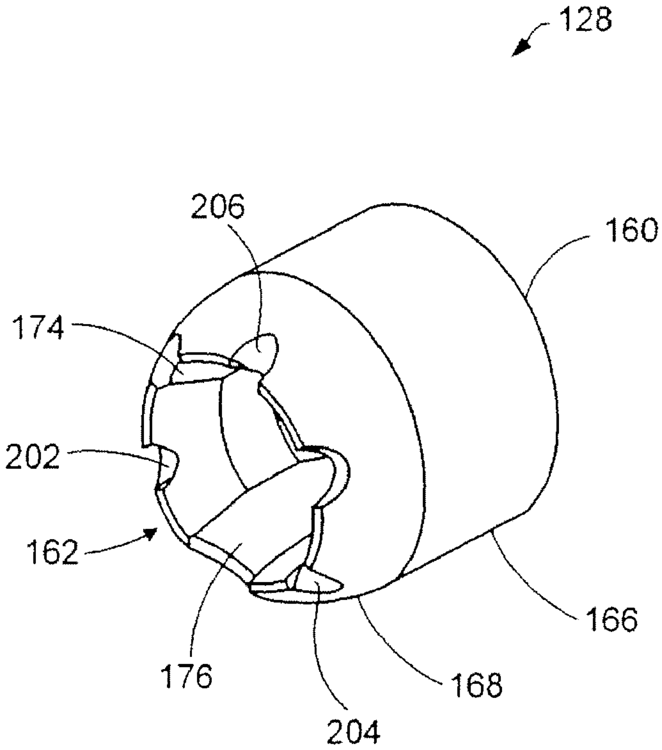

FIG. 8A

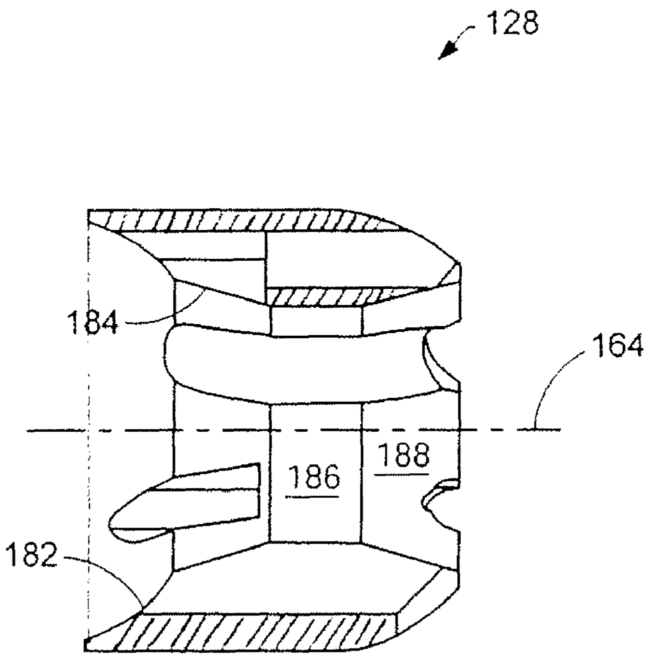

FIG. 8B

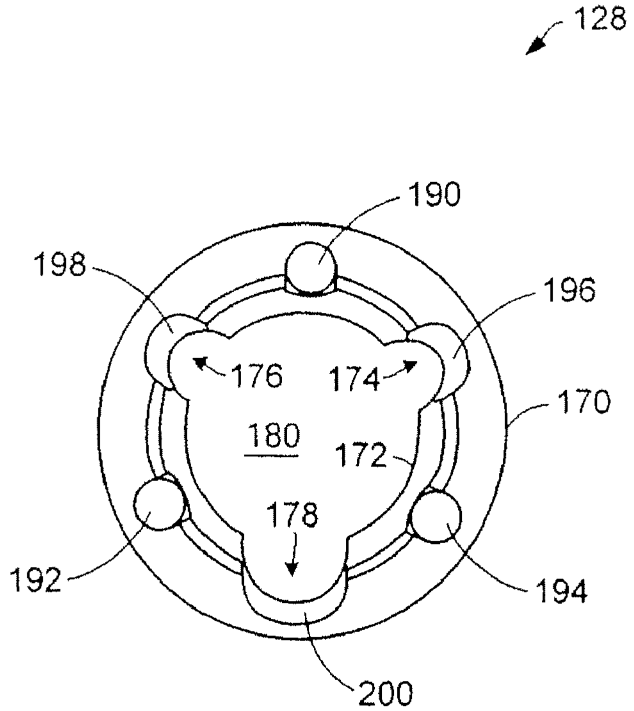

FIG. 8C

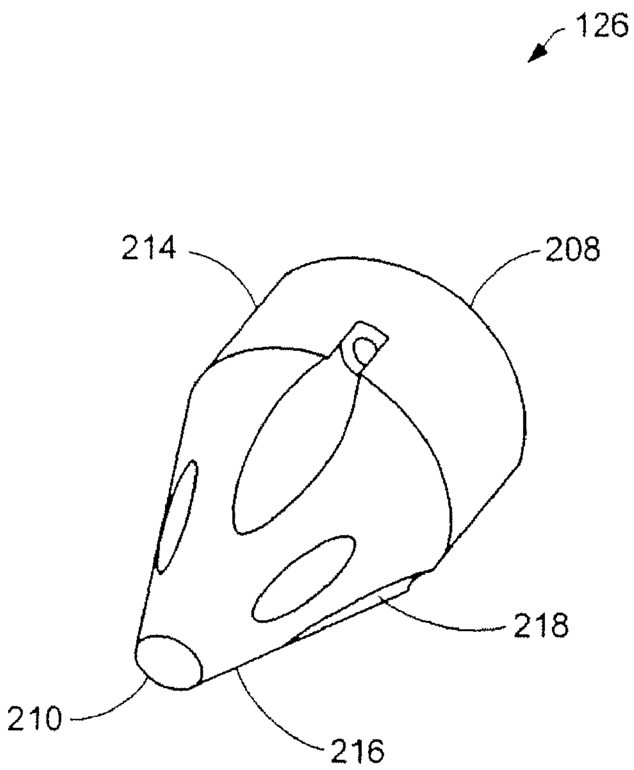

FIG. 9A

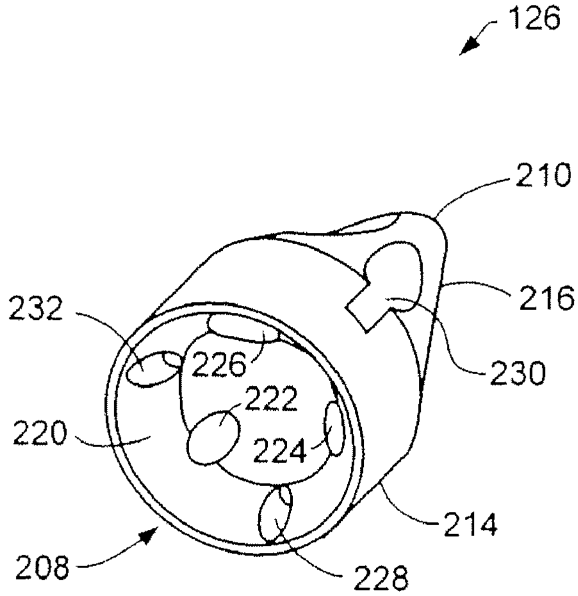

FIG. 9B

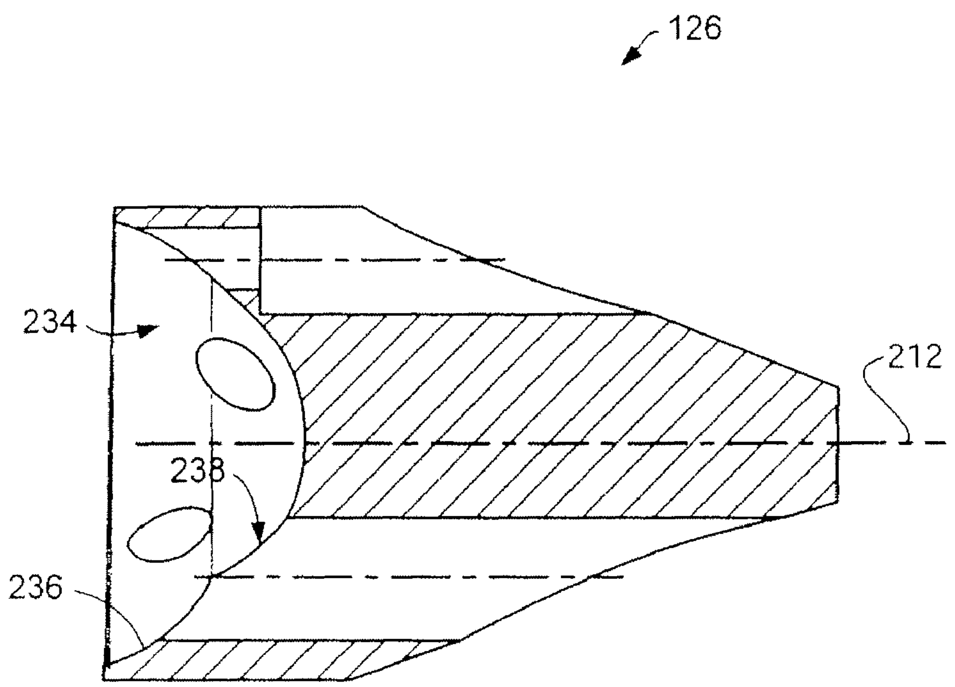

FIG. 9C

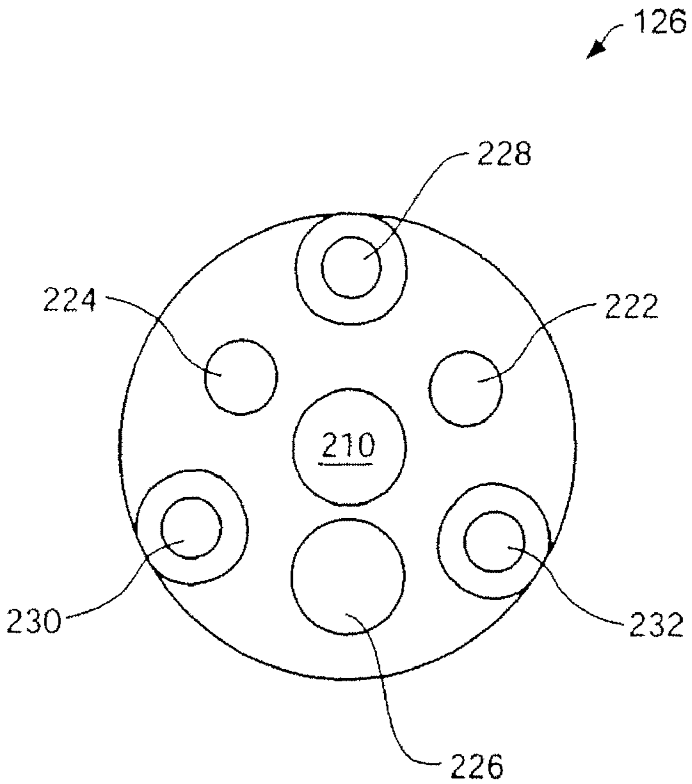

FIG. 9D

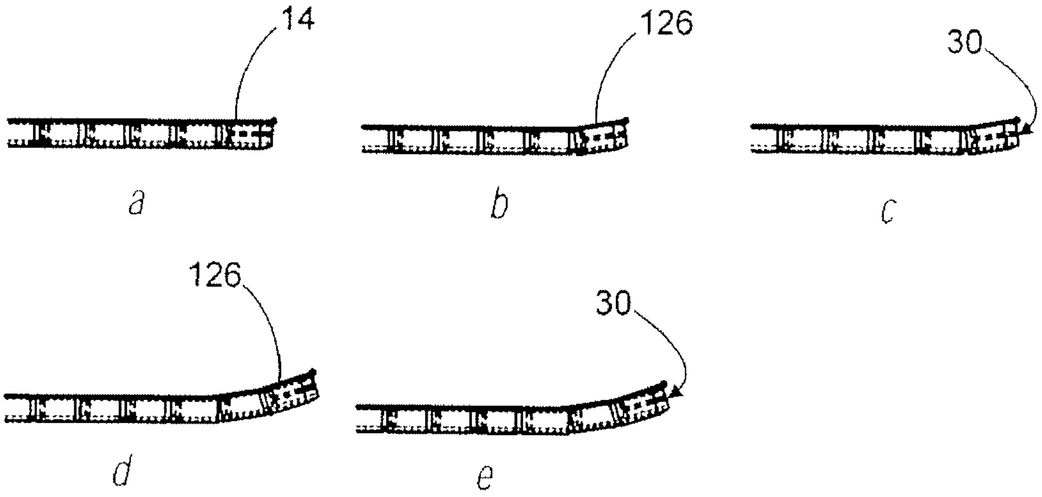

FIG. 10

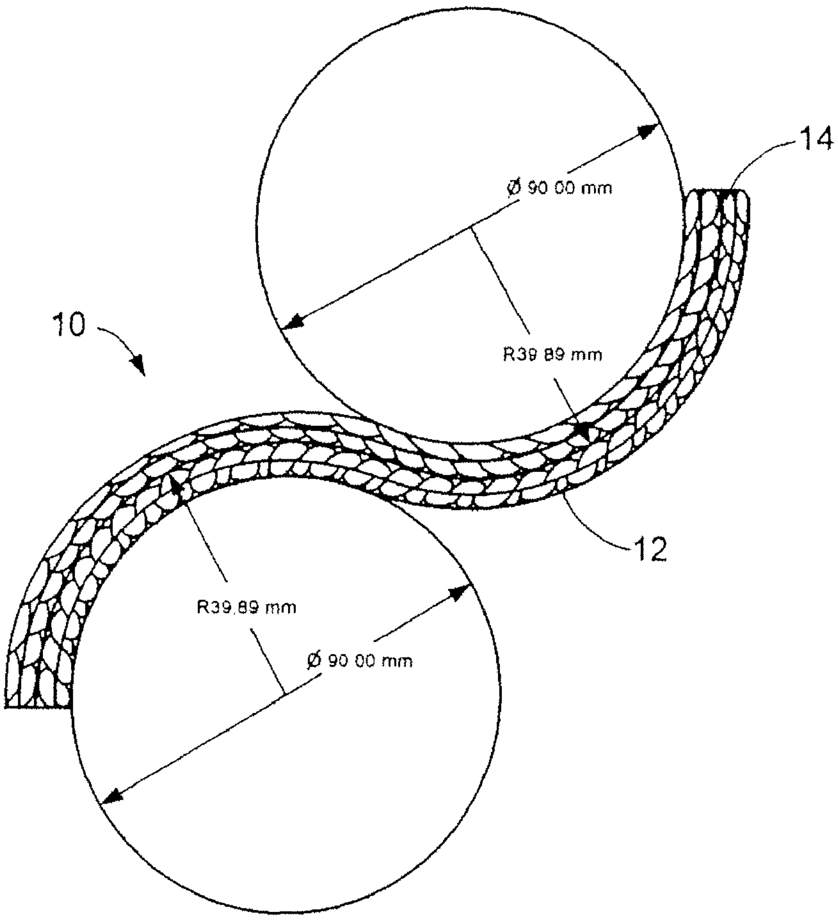

FIG. 11

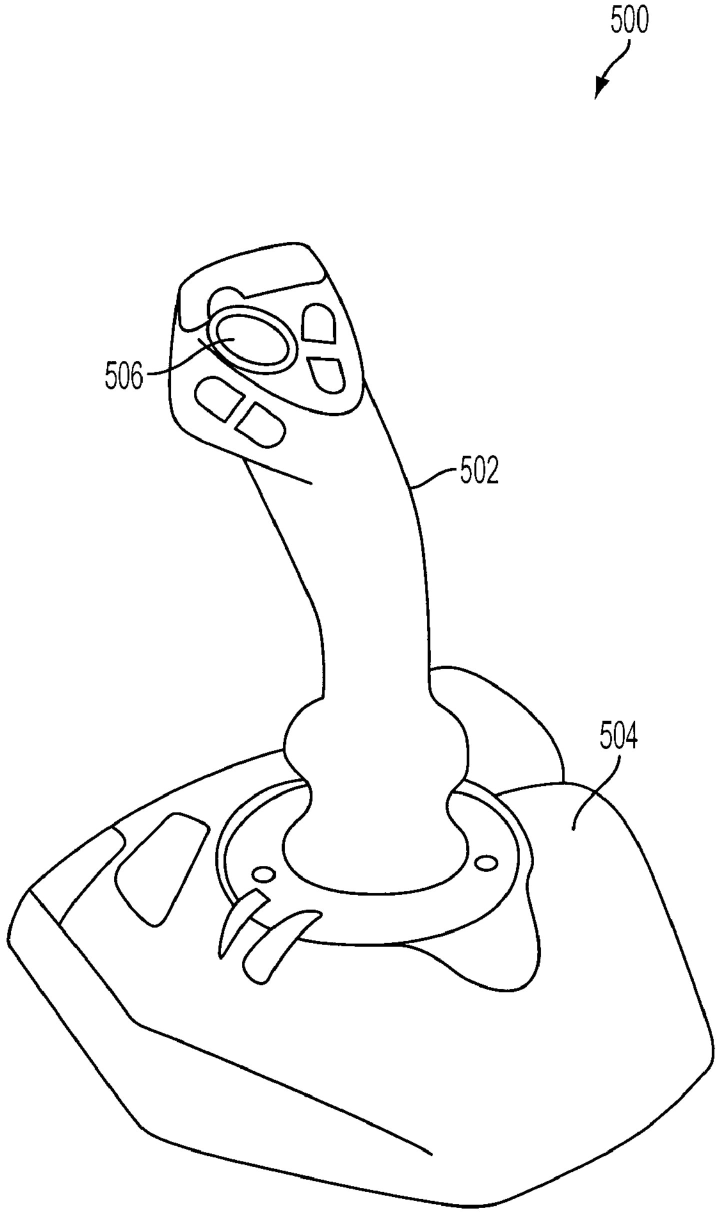

FIG. 12A

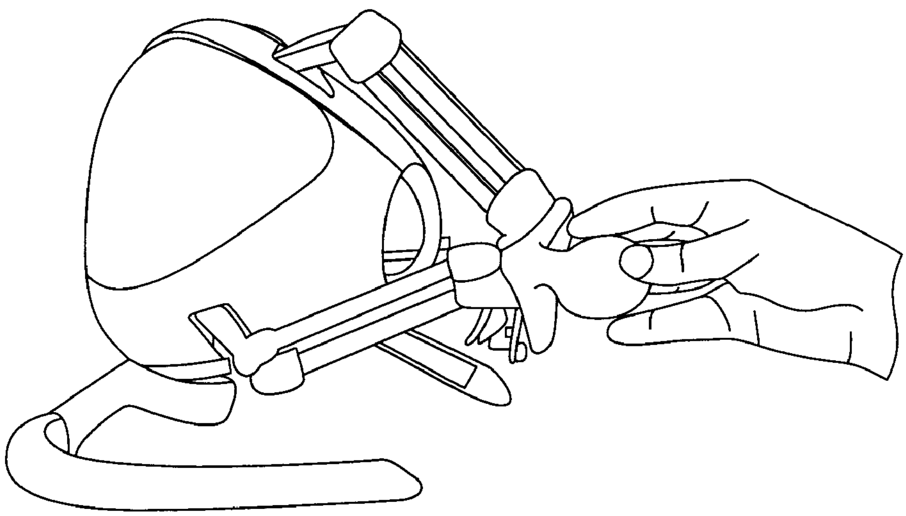

FIG. 12B

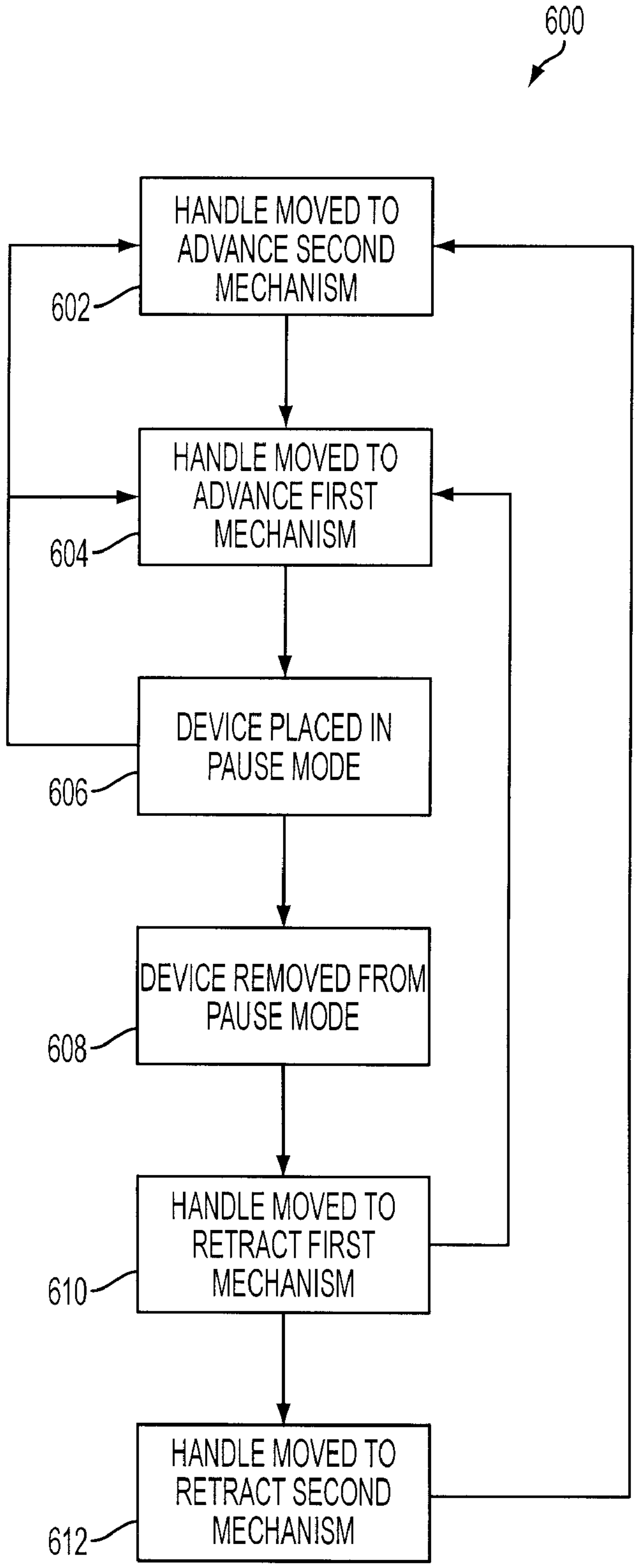
600
HANDLE MOVED TO ADVANCE SECOND MECHANISM
602
HANDLE MOVED TO ADVANCE FIRST MECHANISM
604
DEVICE PLACED IN PAUSE MODE
606
DEVICE REMOVED FROM PAUSE MODE
608
HANDLE MOVED TO RETRACT FIRST MECHANISM
610
HANDLE MOVED TO RETRACT SECOND MECHANISM
612

FIG. 13

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 08/55183

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - A61B 17/00 (2008.04)
USPC - 606/1
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC (8) - A61B 17/00 (2008.04)
USPC - 606/1

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC - 600/920 search terms below

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PubWEST (USPT,USOC,EPAB,JPAB); Google Patents; Google Scholar; DialogWeb
Search Terms Used: multi, multiple, linked, controller, link, steerable, movement, motion, joystick, damage, force, sensor, links, guidance, wire, cable, through

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 6,341,201 B1 (ISHIGURO et al.) 22 January 2002 (22.01. 2002) col 1, ln 46-52; col 5, ln 40-44	1-17
Y	US 2002/0108644 A1 (HOADLEY et al.) 15 August 2002 (15.08.2002) para [0019], [0020]	1-17
Y	US 5,907,487 A (ROSENBERG et al.) 25 May 1999 (25.05.1999) col 2, ln 14-16, ln 30-32; col 3, ln 30-43; col 4, ln 12-16, ln 61-63; col 14, ln 35-38; col 16, ln 55-59; col 19, ln 41-48; col 37, ln 46-51; col 49, ln 28-33	1-17

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
02 June 2008 (02.06.2008)	27 JUN 2008

Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774