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(54) **CONDUCTOR CABLES FOR USE IN STEERABLE DEVICES**

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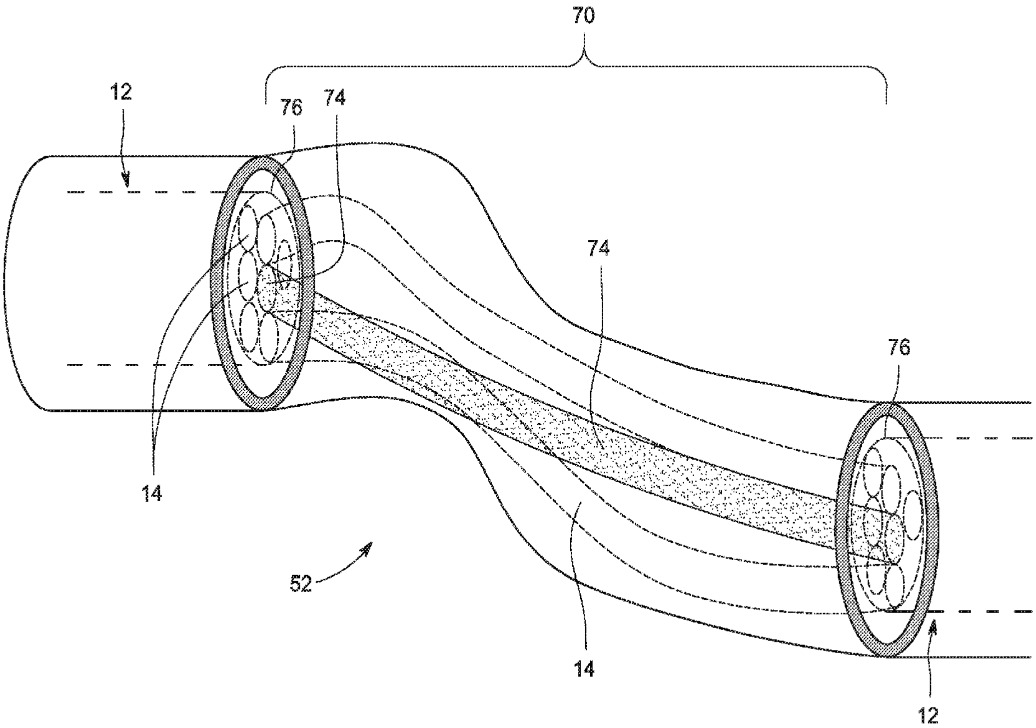
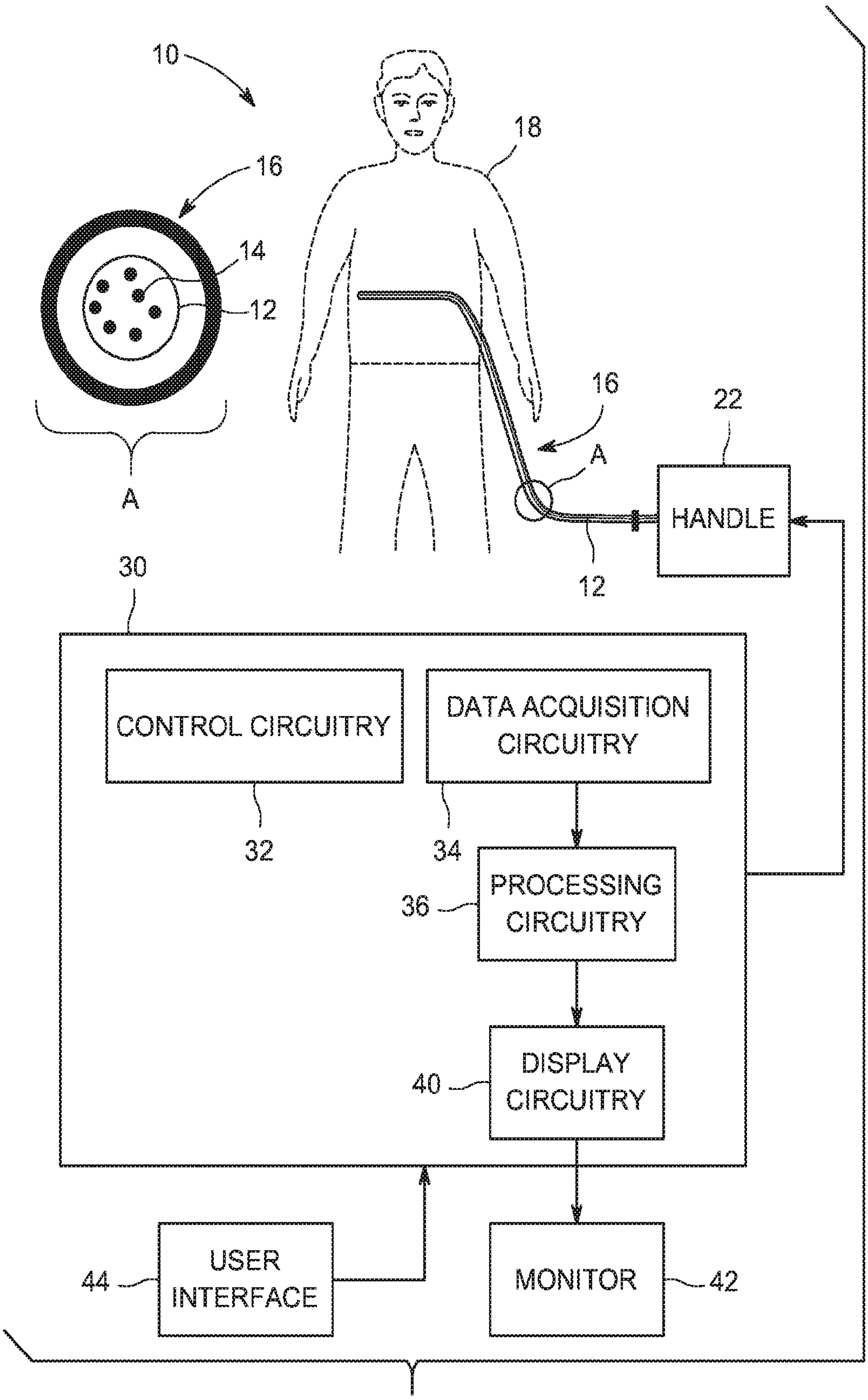
(57) **ABSTRACT**

A multi-conductor cable for use in a catheter is described. The conductor-cable is isotropically flexible to allow catheter steering, but is also longitudinally stiff enough to push and pull the entire cable through the catheter lumen. In one implementation, the multi-conductor cable is bundled for most of its length, to provide longitudinal stiffness and support pushing and pulling the cable through a catheter lumen. However, in one such implementation, the portion of the cable within a steerable section of the catheter is unbundled and divided into individual conductors or groups that are flexible enough that they do not bias or otherwise interfere with the steering of the catheter. In one such approach, a spring wire or other stiffening element is added to the cable at that location to preserve or enhance longitudinal stiffness (tension and compression) of the cable through the unbundled flexible section.




10
16
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HANDLE
12
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CONTROL CIRCUITRY
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PROCESSING CIRCUITRY
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DISPLAY CIRCUITRY
44
USER INTERFACE
MONITOR
42

FIG. 1

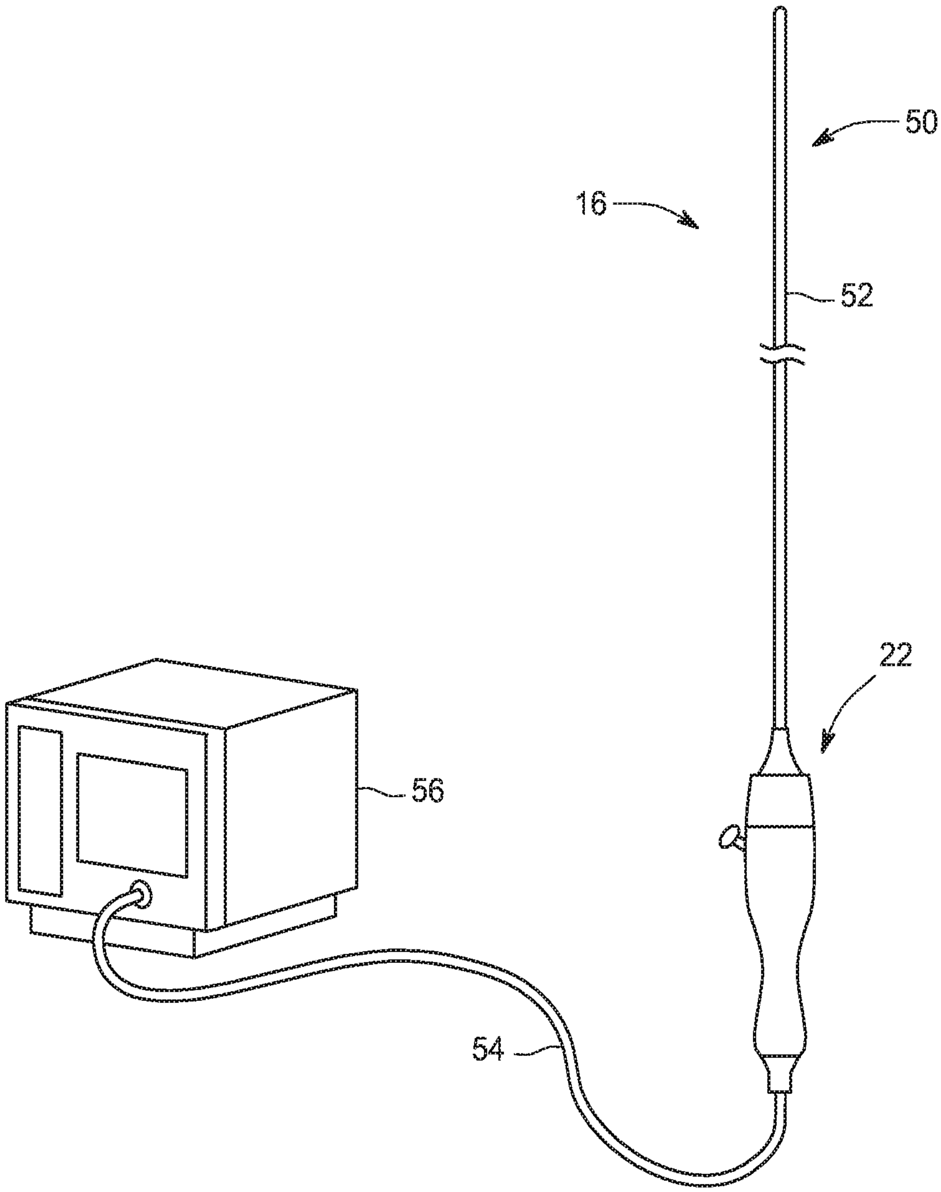

FIG. 2

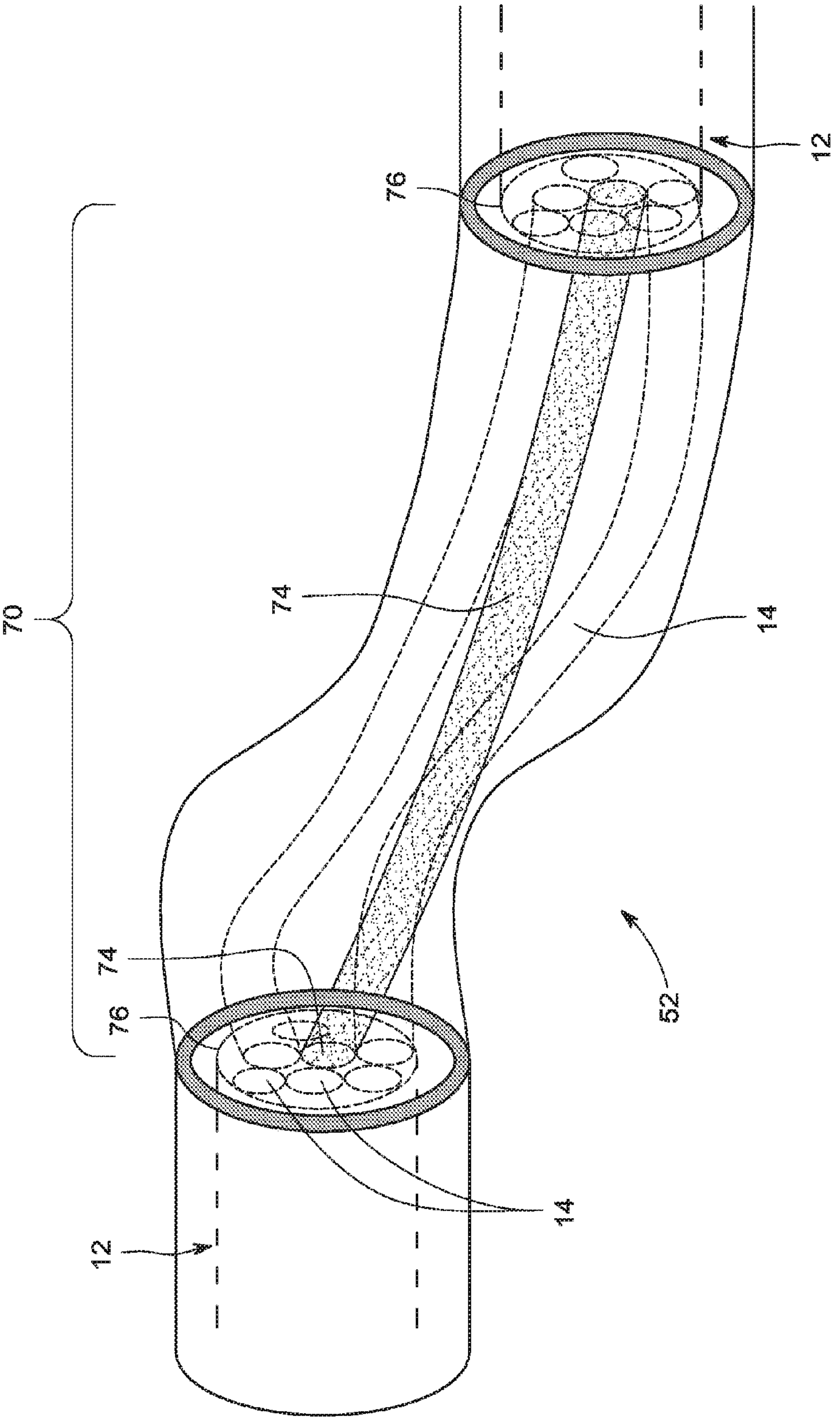

FIG. 3

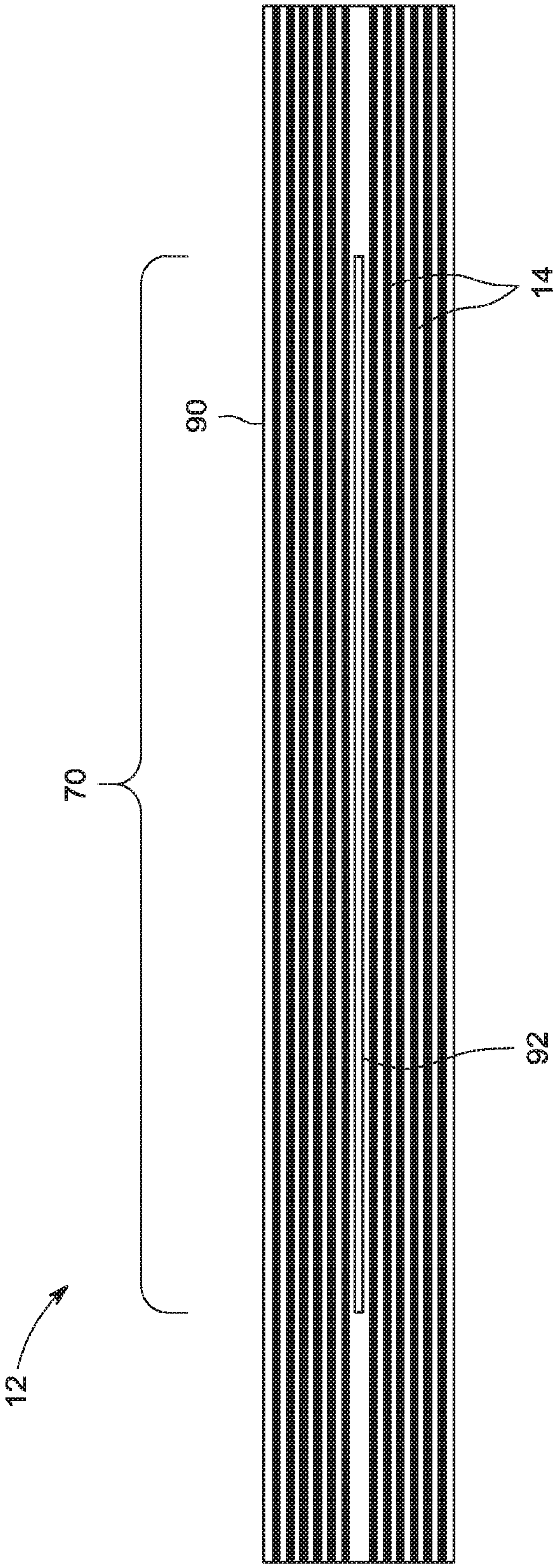

FIG. 4

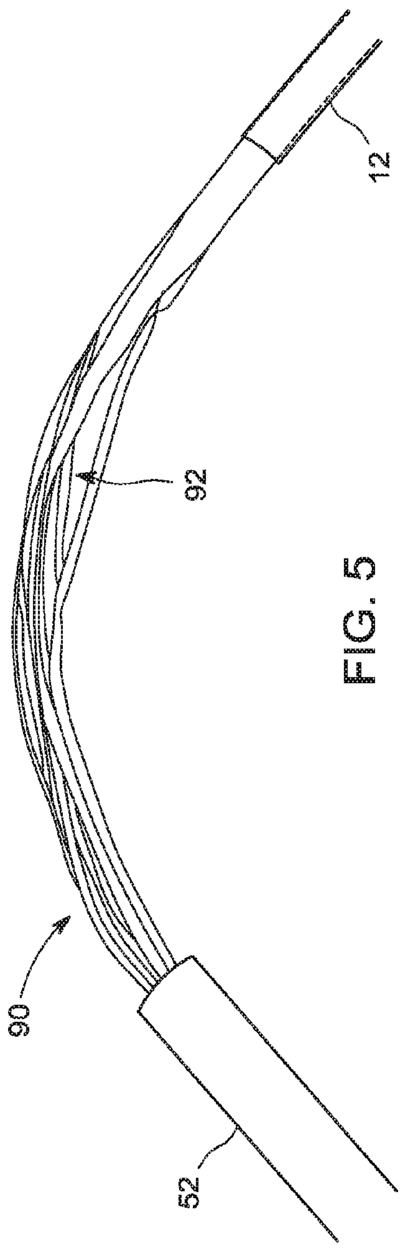

FIG. 5

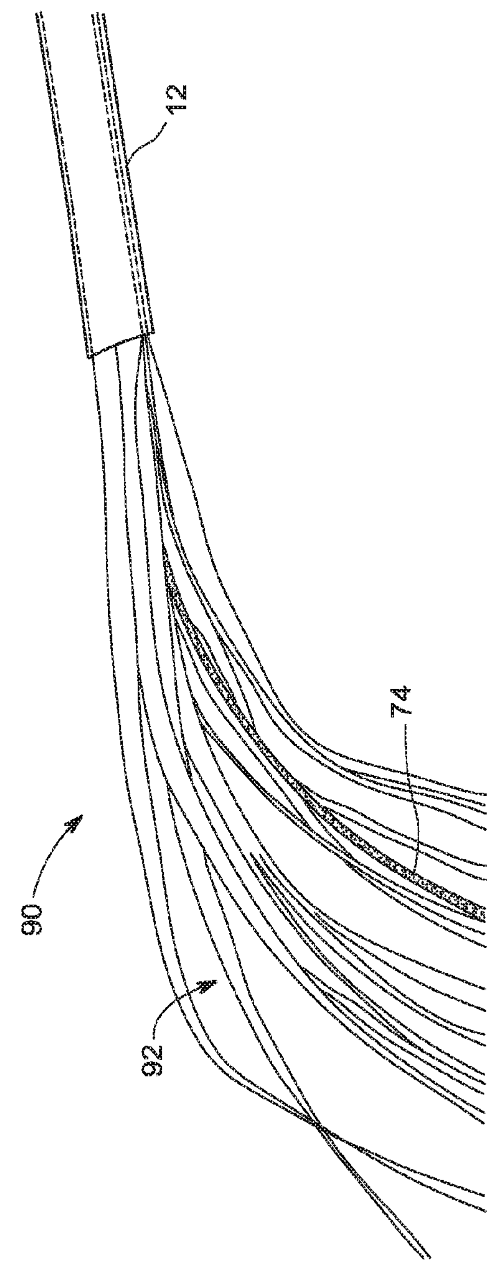

FIG. 6

CONDUCTOR CABLES FOR USE IN STEERABLE DEVICES

BACKGROUND

[0001] The subject matter disclosed herein relates to the use of cables and conductive components within tools or instruments designed to be navigated through a patient or object during a procedure or inspection (e.g., steerable tools or instruments, such as catheters, endoscopes, laparoscopes, etc.).

[0002] As medical imaging technologies have matured, it has become possible to combine the use of medical imaging techniques with interventional procedures or techniques. For example, such technologies may be employed when performing minimally invasive procedures, guiding or employing catheters for cardiac or surgical procedures, or otherwise steering a tool to a desired location within the patient. In some instances, imaging functionality, such as ultrasound imaging functionality, may be provided on the tool itself and this imaging functionality may be used to facilitate another procedure or may be the focus of the procedure itself, e.g., to obtain localized images from within the patient.

[0003] In many instances, steerable tools, such as steerable catheters, may be employed to position the tool or instrument, including ultrasound imagers, within the patient. In such instances, the catheters are typically steered by pulling on, and thereby compressing, one side of the catheter tube using pull wires internal to the tube or a secondary tube internal to the primary tube. As a catheter is repeatedly steered and straightened, the length of the catheter repeatedly changes. Cable running through the lumen of the catheter (such as cables or conductors associated with the operation of the tool or imager at the tip of the catheter) must accommodate that change, typically by sliding back and forth through the lumen.

[0004] However, as the number of electrical conductors, optical fibers, capillary tubes, and other conductive elements through the lumen increases and/or the diameter of the catheter decreases, it may become more difficult to move or position these elements within the catheter lumen. For example, in some instances the individual conductors are not stiff enough to push the associated cable through the catheter shaft when the tip section is steered and compressed.

[0005] One conventional solution is to tightly bundle the conductors so that the bundle is stiff enough to push through the lumen. However, the stiff bundle in turn reduces the steerability (i.e., flexibility) of the catheter. That is, there is an inherent conflict between a cable that is loose enough for easy bending but stiff enough to push itself through lumen. Further, if the bundle is not cylindrical and isotropic (e.g., if the cable is a stack of flat flex circuits), then it bends more easily in some directions than in others, which biases the steering of the catheter. Further, if the fine conductors are not bundled, then as the catheter is steered and compressed, the conductors tend to bunch together and kink. Over repeated cycles, the kinks become cracks and the conductors fail.

[0006] The preceding examples are provided in a medical context so as to give a useful frame-of-reference and useful example. However, it should be appreciated that such issues may be present in non-medical contexts as well, such as in equipment inspection (optical or ultrasound-based) as well as other industrial or commercial contexts.

BRIEF DESCRIPTION

[0007] In one implementation, a steerable device is provided. In accordance with this implementation, the steerable device includes one or more deflection regions and a lumen running through the steerable device. The steerable device also includes a multi-conductor cable configured to move within the lumen. Portions of the multi-conductor cable configured to be positioned in the deflection regions of the steerable device include one or more stiffening elements and two or more conductor elements unbound from one another and moving at least partially independent of one another.

[0008] In another implementation a steerable device is provided. In accordance with this implementation, the steerable device includes one or more deflection regions. The steerable device also includes a flexible circuit within a lumen of the steerable device. The flexible circuit, within the deflection regions, includes at least one slit running substantially parallel to conductive elements within the flexible circuit. The steerable device also includes at least one stiffening element disposed within each deflection region.

[0009] In a further implementation, a method for improving steerability of a steerable device is provided. In accordance with this implementation, for one or more deflection regions of a steerable device, two or more conductive elements of a multi-conductor structure running through the respective deflection region are physically separated. One or more stiffening elements are provided along with the multi-conductor structure in the one or more deflection regions.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] These and other features, aspects, and advantages of the present invention will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:

[0011] FIG. **1** is a schematic view of an implementation of components of a diagnostic or therapy system, in accordance with aspects of the present disclosure;

[0012] FIG. **2** depicts an example of a steerable device (e.g., a catheter) suitable for use with a present multi-conductor cable, in accordance with aspects of the present disclosure;

[0013] FIG. **3** depicts a deflection region of a catheter shaft having unbundled conductive elements, in accordance with aspects of the present disclosure;

[0014] FIG. **4** depicts a slitted flex circuit, in accordance with aspects of the present disclosure;

[0015] FIG. **5** depicts a picture of a prototype slitted flex circuit, in accordance with aspects of the present disclosure; and

[0016] FIG. **6** depicts another view of the slitted flex circuit of FIG. **5** outside the catheter tubing.

DETAILED DESCRIPTION

[0017] One or more specific implementations will be described below. In an effort to provide a concise description of these implementations, not all features of an actual implementation are described in the specification. It should be appreciated that in the development of any such actual implementation, as in any engineering or design project, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which may vary from one implementation to another. Moreover, it should be appreciated that such a development effort might be complex and time consuming, but would nevertheless be a routine undertaking of design, fabrication, and manufacture for those of ordinary skill having the benefit of this disclosure.

[0018] When introducing elements of various embodiments of the present subject matter, the articles "a," "an," "the," and "said" are intended to mean that there are one or more of the elements. The terms "comprising," "including," and "having" are intended to be inclusive and mean that there may be additional elements other than the listed elements.

[0019] A multi-conductor cable for use in a steerable or interventional device (e.g., a catheter, endoscope, laparoscope, and so forth) is described herein. The multi-conductor cable is isotropically flexible to allow steering of the device, but is also longitudinally stiff enough to push and pull the entire cable through a lumen of the device. In one implementation, the multi-conductor cable is bundled for most of its length, to provide longitudinal stiffness and support pushing and pulling the cable through the lumen. However, in one such implementation, the portion of the cable within a steerable section of the steerable device is unbundled and divided into individual conductors or groups that are flexible enough that they do not bias or otherwise interfere with the steering of the device. In one such approach, a spring wire or other stiffening element is added to the cable at that location to preserve or enhance longitudinal stiffness (tension and compression) of the cable through the unbundled flexible section. In such an approach, the spring wire is anchored in the bundled cable both proximal and distal to the unbundled section. When employed in a catheter (or other steerable device), the result is a catheter that that has omnidirectional steering (e.g., is steerable in multiple directions) and is not biased in certain directions due to the effects of the internal conductive elements.

[0020] Though certain of the following examples are provided in a medical context so as to provide a useful frame-of reference, it should be appreciated that these examples are not intended to be limiting and are provided merely to facilitate explanation of the present approaches. Indeed, the present approaches may be useful in other contexts including, but not limited industrial inspection and quality control, security inspection and observation, and other industrial, commercial, or security applications where a device may be employed that is steered within or through an object or subject, such as for optical or ultrasound inspection.

[0021] With the preceding in mind, FIG. **1** depicts an interventional (e.g., minimally invasive diagnostic or therapy) system **10** employing a steerable device in the form of a catheter **16** in which the cable described herein may be employed. In the depicted example, a cable **12** is shown schematically in part as being a multi-conductor cable **12** having multiple, separate and distinct conductor elements **14** that run within the catheter **16** and an operator interface **22** (e.g., a probe, handle, or other user-manipulated aspects) used to operate the catheter **16** and/or the cable **12** within the catheter **16**. As used herein, the conductive elements **14** may include, but are not limited to: wires, coax cables (coax), optical fibers, flex circuits, and so forth. In some instances the cable **12** may include lumens or tubing (e.g., capillary tubes) suitable for the passage of fluids or gases that may be utilized in a given procedure.

[0022] In one implementation, the interventional system **10** provides imaging functionality using the conductor elements **14**, such as a phased-array ultrasound imager (e.g., transducer elements and circuitry) that can be positioned and moved at the tip of the catheter **16** that is inserted and navigated within a patient **18**. It should be appreciated though that other functionality, including surgical functionality (e.g., remote operation of surgical instrumentation) and/or treatment functionality (e.g., application of heat, cold, ablative radiation or energy, and so forth) may be provided using the conductive elements **14** in addition to or instead of such imaging functionality.

[0023] In an imaging implementation, as shown in FIG. **1**, other components that may be present in the overall system **10**, typically include some type of imaging transducer (e.g., a phased-array ultrasound transducer array or other elements) within or affixed to the catheter **16** which generates signals that can be converted to image data. The transducer, when present, may be operated by system control circuitry **30** which controls various aspects of the imager operation and acquisition and processing of the image data. In the depicted generalized example, the system control circuitry **30** includes control circuitry **32** useful in operating the imaging transducer when present in the catheter. For example, the control circuitry **32** may include circuitry for transmitting ultrasound, receiving and amplifying ultrasound, and/or otherwise operating the imaging transducer within the catheter **16**. Acquisition of the image data or signals may be facilitated by data acquisition circuitry **34**. For digital systems, the data acquisition circuitry **34** may perform a wide range of initial processing functions. The data may then be transferred to data processing circuitry **36** where additional processing, analysis, and or image generation are performed. For the various digital imaging systems available, the data processing circuitry **36** may perform substantial reconstruction and/or analyses of data, ordering of data, sharpening, smoothing, feature recognition, and so forth.

[0024] The processed image data may be forwarded to display circuitry **40** for display at a monitor **42** for viewing and analysis. While operations may be performed on the image data prior to viewing, the monitor **42** is at some point useful for viewing reconstructed images derived from the image data collected. The images may also be stored in short or long-term storage devices which may be local to the system **10**, such as within the system control circuitry **30**, or remote from the system **10**, such as in picture archiving communication systems. The image data can also be transferred to remote locations, such as via a network.

[0025] For simplicity, certain of the circuitry discussed above, such as the control circuitry **32**, the data acquisition circuitry **34**, the processing circuitry **36**, and the display circuitry **40**, are depicted and discussed as being part of the system control circuitry **30**. Such a depiction and discussion is for the purpose of illustration only, however, and is intended to merely exemplify one possible arrangement of this circuitry in a manner that is readily understandable. Those skilled in the art will readily appreciate that in other implementations the depicted circuitry may be provided in different arrangements and/or locations. For example, certain circuits may be provided in different processor-based systems or workstations or as integral to different structures, such as imaging workstations, system control panels, and so forth, which functionally communicate to accomplish the techniques described herein.

[0026] The operation of the interventional system **10** may be controlled by an operator via a user interface **44** which may include various user input devices, such as a mouse, keyboard, touch screen, and so forth. Such a user interface **44** may be configured to provide inputs and commands to the system control circuitry **30**, as depicted. Moreover, it should also be noted that more than a single user interface **44** may be provided.

[0027] While the preceding description has generally been in the context of providing some form of imaging functionality with respect to the diagnostic or therapy system **10**, as noted above the system **10** may instead of, or in addition to, provide treatment (e.g., ablation) and/or surgical functionality. In such implementations, the system **10** may include additional or alternative circuitry to provide the needed functionality and/or the described circuitry may support the additional functions. Similarly, in non-medical contexts (e.g., industrial or security contexts) the system **10** may provide appropriate imaging or other functionality in the context of a suitable application.

[0028] While FIG. **1** is primarily a schematic or block-type view of a diagnostic or therapy system **10** suitable for use of the cable **12** discussed herein, FIG. **2** depicts one example of a catheter-based system as it may appear in a real-world setting. In this example, the catheter **16** is suitable for insertion into and navigation through the vasculature of a patient. The depicted catheter **16** includes a distal end or tip **50** in which one or more instruments or devices may be positioned or moved and which, during operation, utilize conductors **14** (FIG. **1**) to receive control signals and/or transmit data. The instrumentation and conductors **14** may be moved within a shaft **52** which connects the tip **50** with a handle assembly **22** that may be used to manipulate and operate the catheter **16**. As discussed herein, the shaft **52** may be flexible to facilitate being steered within the patient and the handle **22**, via one or more control structures, may operate one or more pull wires in the shaft **52** to bend the shaft in various directions in response to the commands of a user. In certain instances, the handle **22** may communicate, such as via a cable **54**, with an operator console **56** that allows a user to control certain aspects of the catheter function and operation, as described more generally with respect to FIG. **1**.

[0029] As discussed herein, to facilitate flexing of the shaft **52** and movement of the conductive elements **14**, various approaches are contemplated. For example, turning to FIG. **3**, in one implementation, the conductive elements **14**, bundled as a multi-conductor cable **12**, run through the shaft **52** of the catheter. In those regions of the shaft **52** where flexion is not an issue (e.g., straight or non-flexing portions of the shaft **52**), the conductive elements **14** may be bunched or bound together (i.e., move as a unit) in the cable **12**, such as in a fitted inner tubing **76** (e.g., heat shrink tubing). Bundling of the conductive elements **14** in this manner provides longitudinal stiffness, which allows the cable **12** to be easily pushed and pulled within the catheter lumen.

[0030] However, as depicted in FIG. **3**, the shaft **52** may also include flexible deflection regions **70** through which the conductive elements **14** pass but through which bundling of these conductive elements **14** may be undesirable or infeasible due to the need to flex the shaft **52** at the deflection region **70** to allow the catheter **16** to be steered. As shown in the depicted example, the sheath (fitted inner tubing) **76** or other bundling mechanism may be released or removed in this deflection region **70** (i.e., the conductive elements **14** are unbundled) so as to allow the conductive elements **14** to move freely and independently relative to one another in this region, thus reducing the forces that might otherwise inhibit flexing of the shaft **52** at deflection region **70**. In particular, when unbundled, the conductive elements **14** are flexible enough that they do not bias or otherwise interfere with the steering of the catheter **16**. As a result of this unbundling of the conductive wires in the deflection region **70**, the catheter **16** is steerable in multiple directions (i.e., omnidirectional steering) without bias from the conductive wires interfering.

[0031] However, as will be appreciated, longitudinal stiffness may be reduced or lost within the deflection regions **70** where the conductive elements **14** are unbundled. Therefore, in certain implementations a spring wire(s) **74** or other longitudinal stiffening element(s) is added to the cable **12** in these regions to preserve longitudinal stiffness (tension and compression) of the cable **12** through the unbundled deflection region **70**. The spring wire **74** is stiff enough to push the cable **12** through the catheter lumen, but flexible enough to allow easy steering. In such an implementation, the spring wire **74** may be anchored in the bundled cable **12** both proximal and distal to the unbundled deflection region **70**. As will be appreciated, though longitudinally stiff, the spring wire (or other stiffening element) is laterally flexible so as to accommodate deflection within the region **70**. In general, the stiffening element (in the various embodiments discussed herein) is stiffer than the unbundled regions of the multi-conductor cable in the longitudinal direction, but is more flexible (in the lateral direction) than the bundled (i.e., stiff) regions of the multi-conductor cable. The stiffening element may or may not be more flexible in the lateral direction than the unbundled portions of the cable. In one implementation, the stiffening element **74** is a 0.2 mm-0.4 mm (e.g., 0.25 mm diameter) diameter spring-tempered stainless steel element (e.g., a wire) that transfers longitudinal forces (e.g., tension and compression) across unbundled deflection region **70** without buckling and without allowing the conductive elements **14** to kink or become damaged. Depending on the implementations, stiffening elements of other diameters, sizes, and/or stiffness, may be employed.

[0032] While FIG. **3** describes one implementation, in other implementations the conductive elements **14** may be provided as part of an existing flexible cable or flexible circuit (e.g., a flex circuit). For example, turning to FIG. **4** if the conductors **14** are flex circuits **90** or flat ribbonized wires, coax, or optical fibers, they will tend to be flexible for out-of-plane bending but very stiff for in-plane bending. If omnidirectional bending (i.e., omnidirectional catheter steering) is needed, the flex circuits **90** or ribbonized conductor groups are slit (slit **92**) into two or more strips of reduced in-plane width and lateral stiffness for the unbundled length (i.e., in deflection region **70**) of the cable **12**. The reduced-width strips will be more flexible in-plane and will be more able to move and reorient within the catheter lumen to allow steering to large angles with minimum resistance.

[0033] With this in mind, FIGS. **5** and **6** depict pictures of a prototype implementation of one such flex circuit approach. With respect to these prototypes, a scalpel was used to slit each of a set of ~1.2 m long flex circuits **90** for a distance of ~8.5 cm near one end. A ~13 cm length of a 0.25 mm diameter spring-tempered stainless steel wire **74** was flattened for a distance of ~1 cm at each end, and the ends were attached (with epoxy) to ~2 mm wide strips of flex circuit material **90**. In other implementations for greater reliability the ends could instead be welded to strips of thin metal. The non-slitted portions of the long flex circuits **90** were aligned and bundled together with heat-shrink tubing to form the cable **12**. The spring wire **74** was included in the middle of the stack of flex circuits **90**, aligned with the slits **92**, with the flex material attached to the ends of the spring wire **74** included in and thereby anchored to the bundled stack of flex circuits at both ends of the slits **92**.

[0034] The resulting cable **12** was pulled through a length of 2.5 mm ID plastic tubing (equivalent to a catheter shaft **52** and lumen). Manual (non-quantitative) experiments verified that the entire cable **12** could be pushed and pulled through the catheter shaft **52** by pushing and pulling on the end nearest the slits **92**, with no bunching or kinking of the flex circuits **90**, even with moderate friction between the cable **12** and the catheter shaft **52**. Omnidirectional flexibility of the slitted cable, and of the catheter shaft **52** in the region containing the slitted cable, was verified. In this manner loose (i.e., not bundled) strips of slitted flex circuit **90** in the deflection region **70** of a catheter shaft **52** may be employed to allow omnidirectional flexibility of the deflection region **70**. To facilitate movement of the slitted flex-circuit where unbundled, a spring wire or other stiffening element **74** provides tensile and compressive strength.

[0035] Technical effects of the invention include a catheter having unbundled conductive elements, including in the form of a slitted flex circuit, within a deflection region. Within the deflection region, a stiffening element **74** may be included to provide longitudinal stiffness.

[0036] This written description uses examples to disclose the invention, including the best mode, and also to enable any person skilled in the art to practice the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims.

1. A steerable device, comprising:
- one or more deflection regions of the steerable device;
- a lumen running through the steerable device;
- a multi-conductor cable configured to move within the lumen, wherein portions of the multi-conductor cable configured to be positioned in the deflection regions of the steerable device comprise:
  - one or more stiffening elements; and
  - two or more conductor elements unbound from one another and moving at least partially independent of one another.

2. The steerable device of claim **1**, wherein, outside the deflection regions, the two or more conductor elements of the multi-conductor cable are bound together.

3. The steerable device of claim **1**, wherein the multi-conductor cable is isotropically flexible within the deflection regions.

4. The steerable device of claim **1**, wherein the steerable device comprises one of a catheter, an endoscope, or a laparoscope.

5. The steerable device of claim **1**, wherein each stiffening element has a diameter between about 0.2 mm to about 0.4 mm.

6. The steerable device of claim **1**, wherein the multi-conductor cable comprises one or more of wire or wires, coax cable, optical or other optic fibers, capillary tubes, or flex circuitry.

7. The steerable device of claim **1**, wherein each stiffening element is anchored on either end of the respective deflection region in which the stiffening element is located.

8. The steerable device of claim **1**, wherein each stiffening element is stiffer in the longitudinal direction than regions of the multi-conductor cable that are unbundled and more flexible in the lateral direction than regions of the multi-conductor cable that are bundled.

9. A steerable device, comprising:
- one or more deflection regions;
- a flexible circuit within a lumen of the steerable device, wherein the flexible circuit, within the deflection regions, comprises at least one slit running substantially parallel to conductive elements within the flexible circuit; and
- at least one stiffening element disposed within each deflection region.

10. The steerable device of claim **9**, wherein respective slits in the flexible circuit do not extend beyond the respective deflection regions.

11. The steerable device of claim **9**, wherein the flexible circuit is flexible in-plane within the deflection regions relative to the in-plane flexibility exhibited outside the deflection regions.

12. The steerable device of claim **9**, wherein each stiffening element comprises a spring wire.

13. The steerable device of claim **9**, wherein each stiffening element has a diameter between about 0.2 mm to about 0.4 mm.

14. The steerable device of claim **9**, wherein each stiffening element comprises stainless steel.

15. The steerable device of claim **9**, wherein each stiffening element is anchored on either end of the respective deflection region in which the stiffening element is located.

16. The steerable device of claim **9**, wherein each stiffening element is stiffer in the longitudinal direction of a respective deflection region than regions of the flexible circuit that are slit.

17. A method for improving steerability of a steerable device, comprising:
- for one or more deflection regions of a steerable device, physically separating two or more conductive elements of a multi-conductor structure running through the respective deflection region; and
- providing one or more stiffening elements along with the multi-conductor structure in the one or more deflection regions.

18. The method of claim **17**, wherein the multi-conductor structure comprises a multi-conductor cable and physically separating the two or more conductive elements comprises unbundling the two or more conductive elements from the multi-conductor cable.

19. The method of claim **17**, wherein the multi-conductor structure comprises a flexible circuit and physically separating the two or more conductive elements comprises slitting the flexible circuit to form one or more slits at the location of the respective deflection regions.

20. The method of claim **17**, wherein providing one or more stiffening elements comprises providing one or more spring wires in the one or more deflection regions.

* * * * *

patsnap

专利名称(译)	用于可转向设备的导体电缆		
公开(公告)号	US20170340861A1	公开(公告)日	2017-11-30
申请号	US15/163312	申请日	2016-05-24
[标]申请(专利权)人(译)	通用电气公司		
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当前申请(专利权)人(译)	通用电气公司		
[标]发明人	WILDES DOUGLAS GLENN		
发明人	WILDES, DOUGLAS GLENN		
IPC分类号	A61M25/01 A61B1/00		
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外部链接	Espacenet USPTO		

摘要(译)

描述了一种用于导管的多芯电缆。导体电缆具有各向同性的柔性以允许导管转向，但也具有足够的纵向刚度以推动和拉动整个电缆穿过导管管腔。在一种实施方式中，多导体电缆在其大部分长度上被捆扎，以提供纵向刚度并支撑推拉电缆穿过导管内腔。然而，在一个这样的实施方式中，导管的可转向部分内的电缆部分被非捆绑并且被分成单独的导体或组，其足够柔韧以使得它们不偏置或以其他方式干扰导管的转向。在一种这样的方法中，弹簧线或其他加强元件在该位置处添加到电缆，以保持或增强电缆穿过非捆绑柔性部分的纵向刚度（张力和压缩）。