US Patent & Trademark Office
Patent Public Search | Text View

United States Patent Application Publication	20250262757
Kind Code	A1
Publication Date	August 21, 2025
Inventor(s)	Tebyani; Maryam et al.

MULTI-MATERIAL, FLEXIBLE ROBOTIC ASSEMBLY WITH INTERLOCKING AND ELASTIC CABLES, EMBEDDED SENSORS, AND ACTUATORS

Abstract

A robotic assembly includes a plurality of rigid links formed from a first material and an elastic joint interconnecting a pair of rigid links of the plurality of rigid links. The elastic joint is formed from a second material. The robotic assembly also includes a conductive sensor coupled to the elastic joint and extending along at least one rigid link of the plurality of rigid links. The conductive sensor is formed from a third material. The plurality of rigid links, the elastic joint, and the conductive sensor are formed during a single printing process by a multi-material printer.

Inventors:	**Tebyani; Maryam (Santa Cruz, CA), Teodorescu; Mircea (Santa Cruz, CA), Levin; Zoe (Santa Cruz, CA)**
Applicant:	**The Regents of the University of California** (Oakland, CA)
Family ID:	**1000008620047**
Appl. No.:	**18/857570**
Filed (or PCT Filed):	**April 26, 2023**
PCT No.:	**PCT/US2023/019915**

Related U.S. Application Data

us-provisional-application US 63335765 20220428

Publication Classification

Int. Cl.: **B25J9/10** (20060101); **B33Y50/00** (20150101); **B33Y80/00** (20150101)

U.S. Cl.:

CPC **B25J9/104** (20130101); **B33Y50/00** (20141201); **B33Y80/00** (20141201);

Background/Summary

CROSS REFERENCE TO RELATED APPLICATIONS [0001] This application claims the benefit of and priority to U.S. Provisional Patent Application Ser. No. 63/335,765 filed Apr. 28, 2022, the entire contents of which is incorporated by reference herein.

BACKGROUND

[0002] Humans can actively and passively articulate their endoskeletal structure, a feat enabled by the ligaments and tendons that elastically connect the relatively rigid bone structure. Combined with internal musculature, this allows the body to be both compliant and load bearing. Cable-driven robotic hands have been particularly successful in replicating the motion and behavior of human hands through elaborate designs which approximate the tendons and ligaments. Creating these biomimetic robots typically consists of a design, fabrication, and assembly phase. The fabrication process may include integrating 3D printed parts and miscellaneous elements, like fasteners or wires, to anchor the cables required to articulate the links. This assembly can be tedious and highlights the need for a simple way to interface the links and cables which comprise these robotic platforms. This design methodology can lead to a tradeoff between mechanical simplicity and ease of fabrication for cable-driven robots. While human anatomy imposes physical limitations, robotic technologies often fall short in capturing the full range of capabilities offered by the human hand. This may be a result of lost complexity in most robotic designs. The proximal interphalangeal joint has been shown to have motion in the axial, coronal and sagittal planes. Under-actuated joints enable robust behavior and using traditional joints to achieve comparable motion can require advanced control techniques.

[0003] The typical design process for creating a cable-driven robot typically includes assembling multiple parts, such as, cables, pulleys, custom parts (e.g., 3D modeled/printed links and mounts). These parts need to be fabricated and tediously assembled, which includes cutting cables to length, mounting pulleys, and tying thin cables to attachment points along the links. In parallel, off-the-shelf sensing components like flex or pressure sensors are integrated at varied points throughout the fabrication and assembly process. Thus, there is a need for streamlined methods that allow a roboticist to 3D model all of these features and/or 3D print the robot as a single part which includes: 1) the links 2) the joints, 3) the cables, 4) the sensors, 5) the actuators, etc. This shifts the work that requires engineering expertise to the design phase, allowing complex designs to be realized through a multi-material fabricator.

SUMMARY

[0004] The disclosure provides a novel design and fabrication process that solves the interface problem inherent in building robots—how to easily connect robotic links, joints, cables, sensors, and actuators. The elastic joints and cables, along with the integrated sensing allow for design and construction of bio-inspired and highly biomimetic robotic models with cable-driven systems found in biological systems, such as the musculoskeletal structure of mammals. Such biological systems feature joints with high degrees of freedom, elastic tendons, proprioception, and a sense of touch, that would be time-consuming or impossible to recreate with other robotic fabrication methods.

[0005] Previously, multi-material 3D printers were used to create elastic joints to connect rigid links, but did not provide for also embedding cables used for articulation of the robotic links and other components. Intricate mechanisms have been designed to route cables between systems of pulleys for cable driven robots, which require tedious assembly after fabrication. In other previous designs, the elastic elements were simply inserted into the inelastic links, which ultimately resulted in degradation of the components because the flexible and rigid parts could easily tear apart. Using 3D printed molds to create robotic features from silicone rubbers are also problematic, since using molds to create a similar platform requires a lengthier design process to include the mold geometry and an additional steps to mix, degas, pour, and cure the silicone rubber before the robot is ready to use.

[0006] Previously fabricated robots also lacked sensing capabilities and computer vision was used to track joint angles using fiducial markers placed joints. Furthermore, the actuators, which connect to the end of the cables, were designed to be detachable because the pulleys held the cables relatively tight, and the actuators would not be able to pass through the pulleys. So, the user also had to connect the actuators to the end of the routed tendons before using the robot.

[0007] The method according to the present disclosure includes initially designing a 3D model of a robot body. Any suitable computer aided design software may be used to design the 3D model. The robot body may include a plurality of components, each of which may be segmented depending on the desired material property for each components. The components may include rigid links, elastic joints, elastic pulleys, elastic cables, and sensors. Thus, the links, which are force bearing, may be formed from an inelastic material, e.g., thermoplastic polymer, while the cables that connect the links to actuators and joints which connect links to other links may be formed from an elastic material.

[0008] The design process may include initially designing the geometry of the links, followed by designing the joints that connect the links. Thereafter, pulleys are designed to hold cables close to the links. The pulley's clearance may be minimized while allowing the cable to pass through and avoid adhesion between the pulley and cable during the printing process. Printing distinct parts too close to each other can cause them to fuse. The required separation distance depends on the 3D printer. The cables are also designed to be printed as pre-routed through the pulleys.

[0009] Printed sensors include conductive traces, which are designed along the links, joints, and cables that correspond to relevant states of the robot's configuration, such as whether a link is in contact with an object, cable extension, and joint angles. These traces travel along the robotic assembly to a centralized processing unit that corresponds changes in electrical signals to the robot's configuration.

[0010] The present disclosure incorporates specific fabrication methods used to create flexible cable-driven robots to solve the interface problem of prior art 3D printed robotic assemblies with weak connection between elastic and rigid components. In embodiments, “closed chains” may be used, which are elastic joints modeled as a closed-loop to connect neighboring rigid links. In further embodiments, a ball-joint socket may also be used, which allow for cables to be inserted into a rigid link and expand inside of the link.

[0011] Once the design is finalized, a split body CAD function may be used to make hollow features in the inelastic links by removing material from overlapping elastic and conductive parts. Next, the distinct parts may be saved as separate files, e.g., stereolithography (STL) files, for use by the 3D printer. The files are then imported into a multi-material printer's dedicated software where the materials are designated, along with other 3D printing properties such as layer thickness and part orientation, etc.

[0012] After the design is completed, the 3D model may be produced by a multi-material 3D printer. Although durable adhesion between flexible and rigid materials may be difficult due to a mismatch in surface energy, the combination of multi-material printing and the two stated interface methods results in an integrated robot after a single 3D printing process. The robot may be created using any suitable multi-material 3D printer. In embodiments, a fused deposition modelling (FDM) printer may be used (e.g., Prusa i3 mk3 with multi material upgrade (MMU)), which uses a thermoplastic filament that is melted down and extruded from a print head and then is immediately set in the high temperatures of the machine and layered on a platform. Suitable polymer materials for use with FDM printers, include polylactide (PLA) for printing rigid components (inelastic), thermoplastic polyurethane (TPU) for printing elastic components, and electrically conductive composite PLA for printing sensor components.

[0013] In further embodiments, a polyjet printer (e.g., Stratasys Objet500 Connex3), which uses a carriage that jets photopolymers onto a workspace that are then cured by a UV light. For polyjet printers, acrylic photopolymer compositions may be used, e.g., Vero Pure White may be used for rigid components and Tango Black Plus for elastic components.

[0014] Once the robot is printed and support material is removed, the robotic assembly is a fully-formed, single robotic body composed of rigid links interconnected by elastic joints, cables, pulleys, which support the cables by holding them close to the links, and conductive traces. The elastic cables pass through the pulleys are pulled to move the links by bending the joints. Conductive traces are used to measure the movement of the links by tracking the joint angle, or the angle formed between two neighboring links based on the electrical resistance, since the electrical resistance corresponds to the deformation of the conductive traces, due to the robot's configuration. Actuation mechanisms may also be printed to the ends of the routed tendons, such as a pneumatic bellow, which changes length as a function of internal pressure.

[0015] According to one embodiment of the present disclosure, a robotic assembly is disclosed. The robotic assembly includes a plurality of rigid links formed from a first material and an elastic joint interconnecting a pair of rigid links of the plurality of rigid links. The elastic joint is formed from a second material. The robotic assembly also includes a conductive sensor coupled to the elastic joint and extending along at least one rigid link of the plurality of rigid links. The conductive sensor is formed from a third material. The plurality of rigid links, the elastic joint, and the conductive sensor are formed during a single printing process by a multi-material printer.

[0016] Implementations of the above embodiment may include one or more of the following features. According to one aspect of the above embodiment, the robotic assembly may further include an elastic cable coupled to a distal rigid link of the plurality of rigid links. The cable may be formed from the second material. The distal rigid link may include an internal socket therein and a distal end of the elastic cable is embedded in the internal socket during printing of the distal rigid link and the elastic cable. The robotic assembly may further include a pulley coupled to a rigid link that is proximal of the distal rigid link. The pulley may be formed from the second material. The cable is routed through the pulley. The cable may be configured to be coupled to an actuator configured to move the cable thereby moving the distal rigid link. The pulley may have a closed loop structure. At least a portion of the closed loop structure may be embedded in the link that is proximal of the distal rigid link during printing of the pulley and the link that is proximal of the distal rigid link. The conductive sensor may include a pair of conductive traces coupled to the joint and extending in a longitudinal direction along the cable. The conductive sensor may be configured to sense a change in resistance in response to flexing of the pair of conductive traces. The elastic joint may also have a closed loop structure. At least a portion of the closed loop structure may be embedded in each rigid link of the pair of rigid links during printing of the elastic joint and the pair of rigid links. The first material may be a rigid polymeric material at room temperature and may include at least one of acrylonitrile butadiene styrene, polylactide, thermoplastic polyurethane, polyethylene terephthalate glycol, or polyetherimide. The second material may be an elastic polymeric material at room temperature and may include thermoplastic polyurethane. The third material may be an electrically conductive polymer and may include polylactide or thermoplastic polyurethane.

[0017] According to another embodiment of the present disclosure, a method for fabricating a robotic assembly is disclosed. The method includes receiving a design file at a multi-material modelling printer. The design file may include instructions for printing a robotic assembly having a plurality of rigid links formed from a first material. The robotic assembly also includes an elastic joint interconnecting a pair of rigid links of the plurality of rigid links. The elastic joint formed from a second material and a conductive sensor coupled to the elastic joint and extending along at least one rigid link of the plurality of rigid links. The conductive sensor is formed from a third material. The method also includes printing the plurality of rigid links, the elastic joint, and the conductive sensor during a single printing process.

[0018] Implementations of the above embodiment may include one or more of the following features. According to one aspect of the above embodiment, the design file may also include instructions for printing an elastic cable coupled to a distal rigid link of the plurality of rigid links. The cable may be formed from the second material. The design file may also include instructions for printing an internal socket defined in the distal rigid link and a distal end of the elastic cable is embedded in the internal socket during printing of the distal rigid link and the elastic cable. The design file may also include instructions for printing pulley coupled to a rigid link that is proximal of the distal rigid link. The pulley may be formed from the second material. The method may further include printing the elastic cable and the pulley during the single printing process. The first material may be a rigid polymeric material at room temperature and may include at least one of acrylonitrile butadiene styrene, polylactide, thermoplastic polyurethane, polyethylene terephthalate glycol, or polyetherimide. The second material may be an elastic polymeric material at room temperature and may include thermoplastic polyurethane. The third material may be an electrically conductive polymer and may include polylactide.

Description

BRIEF DESCRIPTION OF DRAWINGS

[0019] Various embodiments of the present disclosure are described herein below with reference to the figures wherein:

[0020] FIG. **1** is a perspective view of a multi-material 3D printer for use with the present disclosure;

[0021] FIG. **2** is a perspective, partially transparent view of a robotic assembly according to the present disclosure;

[0022] FIG. **3** is a side, partially transparent view of the robotic assembly of FIG. **2** according to the present disclosure;

[0023] FIG. **4** is a top, partially transparent view of the robotic assembly of FIG. **2** according to the present disclosure;

[0024] FIG. **5** is a method of manufacture of the robotic assembly of FIG. **2** according to the present disclosure; and

[0025] FIGS. **6**A and B show photographs of a robotic assembly manufactured using the method of FIG. **5** according to the present disclosure.

DETAILED DESCRIPTION

[0026] Embodiments of the presently disclosed assembly are described in detail with reference to the drawings, in which like reference numerals designate identical or corresponding elements in each of the several views. As used herein the term “distal” refers to the portion of the robotic assembly that is closer to an end effector of the robotic assembly, while the term “proximal” refers to the portion that is farther from the end effector.

[0027] With reference to FIG. **1**, a multi-material 3D printer **10** may be used to fabricate a robotic assembly **20** (FIGS. **2-4**) according to the present disclosure. The printer **10** may be any suitable additive fabrication printer, such as an FDM printer or a polyjet printer. The printer **10** may include a carriage **12** configured to provide a plurality of materials for forming the robotic assembly **20**. The materials may include any suitable thermoplastic polymers including, but not limited to, acrylonitrile butadiene styrene (ABS), polylactide (PLA), thermoplastic polyurethane (TPU), polyethylene terephthalate glycol (PETG), polyetherimide (PEI), and the like. The materials may be stored as spools and provided to the carriage **12** for feeding to a heated nozzle **14**, which extrudes the filaments, and applying the extruded material layer by layer to a heated platform **16** to build the robotic assembly **20**. The printer **10** is configured to support at least three materials: a first material to print rigid components, a second material to print elastic components, and a third to print conductive traces for sensing components.

[0028] In embodiments, flexibility of the robotic assembly **20** may be achieved through material properties or through geometry. In particular, the same elastic material may be used for the first and second material, the geometry of the printed components may be used to vary the stiffness. This may be suitable since certain FDM multi-material printers may have a difficult time supporting the transition between PLA and TPU.

[0029] With reference to FIGS. **2-4**, the robotic assembly **20** includes a plurality of rigid links, namely, a distal rigid link **22**, a middle rigid link **24**, and a proximal rigid link **26**. The robotic assembly **20** also includes a distal elastic joint **23** interposed between the links **22** and **24** and a proximal elastic joint **25** interposed between the links **24** and **26**. The links **22**, **24**, **26** may be formed from any suitable thermoplastic polymer that forms a rigid material at room temperature, which denotes a temperature from about 20° C. to about 25° C., such as ABS, PLA, PETG, PEI, etc. The elastic joints **23** and **25** may be formed from any suitable elastomeric polymer that forms an elastic material at room temperature, such as TPU.

[0030] The elastic joints **23** and **25** are partially embedded in the links **22**, **24**, **26** and may have any suitable shape and a unitary, i.e., closed loop, structure, such as a rectangle, with two parallel sides being embedded in the interconnected links. In particular, the elastic joint **23** includes four sides **23***a*, **23***b*, **23***c*, **23***d*, which two parallel sides **23***a* and **23***c* being embedded in the distal and middle links **22** and **24**, respectively. Thus, the sides **23***b* and **23***d* are disposed in parallel with a longitudinal axis defined by the robotic assembly **20** and are located outside the links **22** and **24** allowing for flexing of the elastic joint **23**. In the same manner, the elastic joint **25** also includes four sides **25***a*, **25***b*, **25***c*, **25***d*, which two parallel sides **25***a* and **25***c* being embedded in the middle link **24** and the proximal link **26**, respectively, while the sides **25***b* and **25***d* are outside the links **24** and **26** and allow for flexing of the elastic joint **25**. In embodiments, the elastic joints **23** and **25** may include one or more strips, i.e., open chain, interconnecting the links **22**, **24**, **26**. However, a closed chain structure provides additional structural integrity for the joints **23** and **25** by embedding a larger portion of the joints **23** and **25** in the links **22**, **24**, **26**.

[0031] The distal link **22** includes a socket **28** configured to secure a distal end **30***a* (FIG. **2**) of an elastic cable **30** therein. In embodiments, a plurality of cables may be attached to one or more of the links **22**, **24**, **26** to allow for multi-directional articulation of the robotic assembly **20**. The distal end **30***a* is embedded in the socket **28** during the manufacturing process. The socket **28** may be larger, e.g., wider, than the cable, to allow for an increased contact area between the socket **28** and the distal end **30***a*.

[0032] Each of the middle link **24** and the proximal link **26** is also coupled to an elastic pulley **34** and **36**, respectively. The cable **30** extends from an opening **29** defined in a surface **22***a* (FIG. **2**) of the distal link **22**. The cable **30** then passes through each of the pulleys **34** and **36**, which extend from the surfaces **24***a* and **26***a* of the middle link **24** and the proximal link **26**, respectively (FIG. **2**). The surfaces **22***a*, **24***a*, **26***a*, are aligned approximately along the same plane such that the cable **30** can travel in a longitudinal direction unobstructed.

[0033] The pulleys **34** and **36** may have any suitable shape that defines an opening therethrough to allow for routing of the cable **30**, e.g., a rectangular frame, similar to the shape of the joints **23** and **25**. The pulleys **34** and **36** may be attached to their respective middle link **24** and proximal link **26** by embedding a portion of the middle link **24** and proximal link **26** during the manufacturing process in a similar manner as the joints **23** and **25**. The cable **30** and the pulleys **34** and **36** may also be formed from any suitable elastomeric polymer that forms an elastic material at room temperature, such as TPU.

[0034] The robotic assembly **20** also includes conductive sensors **40** and **42**. The first conductive sensor **40** includes a pair of conductive traces **40***a* and **40***b* and the second conductive sensor **42** also includes a pair of conductive traces **42***a* and **42***b*. The first pair of conductive traces **40***a* and **40***b* are disposed distally of the second pair of conductive traces **42***a* and **42***b*. In particular, the first pair of conductive traces **40***a* and **40***b* are coupled to the distal joint **23** and extend in substantially parallel manner through the middle link **24** and along the proximal joint **25** and through the proximal link **26**. The second pair of conductive traces **42***a* and **42***b* are coupled to the proximal joint **25** and extend in substantially parallel manner through the proximal link **26**. The first pair of conductive traces **40***a* and **40***b* and the second pair of conductive traces **42***a* and **42***b* may be formed from any suitable electrically conductive polymer that forms a flexible material at room temperature, such an electrically conductive PLA.

[0035] Each of the conductive sensors **40** and **42**, i.e., the first pair of conductive traces **40***a* and **40***b* and the second pair of conductive traces **42***a* and **42***b* may be coupled to a controller (not shown) configured to measure a change in electrical resistance of the conductive sensors. Since the conductive traces **40***a*, **40***b*, **42***a*, **42***b* are designed to be placed along their respective links **24**, **26**, joints **23**, **25**, and the cable **30**, as these components are moved, i.e., articulated, the conductive traces **40***a*, **40***b*, **42***a*, **42***b* are bent or flexed accordingly, which results in a change of the resistance of the conductive sensors **40** and **42**. The controller continuously monitors the resistance of the conductive sensors **40** and **42** and determines corresponding relevant states of the configuration of the robotic assembly **20**, i.e., whether the robotic assembly **20** is in contact with an object, extension of the cable **30**, and angles between the links **22**, **24**, **26**, etc.

[0036] With reference to FIG. **5** a flow chart of a method for designing and fabricating the robotic assembly **20** includes designating the geometry of the rigid components of the robotic assembly **20**, i.e., links **22**, **24**, **26**, at step **100**. This step may be performed using any suitable 3D CAD software that allows for creating virtual models of components. At step **102**, elastic components, i.e., joints **23** and **25** and pulleys **34** and **36**, are designed and are virtually attached to the links **22**, **24**, **26**. The pulleys **34** and **36** are designed to hold the cable **30** close to the links **22**, **24**, **26** within minimal clearance while allowing for the cable **30** to pass through the pulleys **34** and **36** and avoiding adhesion between the cable **30** and the pulleys **34** and **36** during printing. Printing distinct parts too close to each other may cause them to fuse. The separation distance may be adjusted based on the parameters of the printer **10**. At step **104**, the cable **30** is designed to be attached to the socket **28** at the distal end **30***a*. In embodiments, the cable **30** may be designed to be pre-routed through the pulleys **34** and **36** or to be attached only to the distal link **22** for later manual routing. The elastic components may be designed in any order, depending on the needs of the robotic designer, and the sequence of steps of the method of FIG. **5** is not intended to be limiting, but is merely illustrative. At step **106**, the conductive traces **40***a*, **40***b*, **42***a*, **42***b* are designed to be coupled to the proximal and distal joints **23** and **25**, respectively, and to be routed along their respective links **24**, **26**, joints **23**, **25**, and the cable **30**.

[0037] After the design is complete, at step **108**, one or more design files containing instructions, i.e., slices, for the printer **10** to print the robotic assembly **20** is generated. At step **110**, the printer **10** is loaded with three different materials, namely, a first material for printing rigid components, i.e., the links **22**, **24**, **26**, a second material printing elastic components, i.e., joints **23**, **25**, cable **30**, and pulleys **34** and **36**, and a third material for printing electrical components, i.e., the conductive traces **40***a*, **40***b*, **42***a*, **42***b*. In embodiments, other types of components beyond the three disclosed herein may also be incorporated into the robotic assembly **20** using other types of material, i.e., semiflexible polymers.

[0038] At step **112**, the printer **10** performs the print job to fabricate the robotic assembly **20** using the design file. At step **114**, postproduction of the robotic assembly **20** may be performed to clean up supports and route the cable **30**. At step **116**, the cable **30** is connected to an actuator (not shown), e.g., bellows, and the conductive traces **40***a*, **40***b*, **42***a*, **42***b* are connected to the controller, thereby allowing for use of the robotic assembly **20**, including monitoring the articulation of the robotic assembly **20** and controlling the robotic assembly **20** based on the feedback from the conductive sensors **40** and **42**.

[0039] The following Examples illustrate embodiments of the present disclosure. These Examples are intended to be illustrative only and are not intended to limit the scope of the present disclosure.

Example 1

[0040] This Example describes design and fabrication of an exemplary robotic assembly according to the present disclosure.

[0041] An FDM printer Prusa i3 mk3 with MMU loaded with PLA and TPU was used to print a robotic assembly designed using the method according to the present disclosure. FIGS. **6**A and B show the robotic assembly printed by the Prusa printer incorporating two distinct materials in a single printing process, thus, resulting in a complete robotic assembly. All the components were attached to each other and did not require further assembly. As shown in FIG. **6**A, a cable disposed within a socket of a distal rigid link was initially printed in an unrouted configuration and was then routed through two pulleys as shown in FIG. **6**B.

[0042] It will be appreciated that of the above-disclosed and other features and functions, or alternatives thereof, may be desirably combined into many other different systems or applications. Also, that various presently unforeseen or unanticipated alternatives, modifications, variations or improvements therein may be subsequently made by those skilled in the art which are also intended to be encompassed by the following claims. Unless specifically recited in a claim, steps or components according to claims should not be implied or imported from the specification or any other claims as to any particular order, number, position, size, shape, angle, or material.

Claims

1. A robotic assembly comprising: a plurality of rigid links formed from a first material; an elastic joint interconnecting a pair of rigid links of the plurality of rigid links, the elastic joint formed from a second material; and a conductive sensor coupled to the elastic joint and extending along at least one rigid link of the plurality of rigid links, the conductive sensor formed from a third material, wherein the plurality of rigid links, the elastic joint, and the conductive sensor are formed during a single printing process by a multi-material printer.

2. The robotic assembly according to claim 1, further comprising: an elastic cable coupled to a distal rigid link of the plurality of rigid links, the elastic cable formed from the second material.

3. The robotic assembly according to claim 2, wherein the distal rigid link includes an internal socket therein and a distal end of the elastic cable is embedded in the internal socket during printing of the distal rigid link and the elastic cable.

4. The robotic assembly according to claim 2, further comprising: a pulley coupled to a rigid link that is proximal of the distal rigid link, the pulley formed from the second material.

5. The robotic assembly according to claim 4, wherein the elastic cable is routed through the pulley.

6. The robotic assembly according to claim 5, wherein the elastic cable is configured to be coupled to an actuator configured to move the elastic cable thereby moving the distal rigid link.

7. The robotic assembly according to claim 4, wherein the pulley has a closed loop structure.

8. The robotic assembly according to claim 7, wherein at least a portion of the closed loop structure is embedded in the rigid link that is proximal of the distal rigid link during printing of the pulley and the rigid link that is proximal of the distal rigid link.

9. The robotic assembly according to claim 1, wherein the elastic joint has a closed loop structure.

10. The robotic assembly according to claim 9, wherein at least a portion of the closed loop structure is embedded in each rigid link of the pair of rigid links during printing of the elastic joint and the pair of rigid links.

11. The robotic assembly according to claim 2, wherein the conductive sensor includes a pair of conductive traces coupled to the elastic joint and extending in a longitudinal direction along the elastic cable.

12. The robotic assembly according to claim 11, wherein the conductive sensor is configured to sense a change in resistance in response to flexing of the pair of conductive traces.

13. The robotic assembly according to claim 1, wherein the first material is a rigid polymeric material at room temperature and includes at least one of acrylonitrile butadiene styrene, polylactide, thermoplastic polyurethane, polyethylene terephthalate glycol, or polyetherimide.

14. The robotic assembly according to claim 1, wherein the second material is an elastic polymeric material at room temperature and includes thermoplastic polyurethane.

15. The robotic assembly according to claim 1, wherein the third material is an electrically conductive polymer and includes polylactide.

16. A method for fabricating a robotic assembly, the method comprising: receiving a design file at a multi-material printer, the design file including instructions for printing a robotic assembly including: a plurality of rigid links formed from a first material; an elastic joint interconnecting a pair of rigid links of the plurality of rigid links, the elastic joint formed from a second material; and a conductive sensor coupled to the elastic joint and extending along at least one rigid link of the plurality of rigid links, the conductive sensor formed from a third material; and printing the plurality of rigid links, the elastic joint, and the conductive sensor during a single printing process.

17. The method according to claim 16, wherein the design file includes instructions for printing: an elastic cable coupled to a distal rigid link of the plurality of rigid links, the elastic cable formed from the second material; an internal socket defined in the distal rigid link; and a distal end of the elastic cable is embedded in the internal socket during printing of the distal rigid link and the elastic cable.

18. The method according to claim 17, wherein the design file includes instructions for printing: a pulley coupled to a rigid link that is proximal of the distal rigid link, the pulley formed from the second material.

19. The method according to claim 18, further comprising: printing the elastic cable and the pulley during the single printing process.

20. The method according to claim 18, wherein the first material is a rigid polymeric material at room temperature and includes at least one of acrylonitrile butadiene styrene, polylactide, thermoplastic polyurethane, polyethylene terephthalate glycol, or polyetherimide; the second material is an elastic polymeric material at room temperature and includes thermoplastic polyurethane; and the third material is an electrically conductive polymer and includes polylactide.