**DOCUMENT MADE AVAILABLE UNDER THE PATENT COOPERATION TREATY (PCT)**

<table>
<thead>
<tr>
<th>International application number:</th>
<th>PCT/US2015/050793</th>
</tr>
</thead>
<tbody>
<tr>
<td>International filing date:</td>
<td>17 September 2015 (17.09.2015)</td>
</tr>
<tr>
<td>Document type:</td>
<td>Certified copy of priority document</td>
</tr>
<tr>
<td>Document details:</td>
<td>Country/Office: US</td>
</tr>
<tr>
<td></td>
<td>Number: 62/051,546</td>
</tr>
<tr>
<td></td>
<td>Filing date: 17 September 2014 (17.09.2014)</td>
</tr>
<tr>
<td>Date of receipt at the International Bureau:</td>
<td>28 September 2015 (28.09.2015)</td>
</tr>
</tbody>
</table>

**Remark:** Priority document submitted or transmitted to the International Bureau in compliance with Rule 17.1(a),(b) or (b-bis)
THE UNITED STATES OF AMERICA
TO ALL TO WHOM THESE PRESENTS SHALL COME:

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office

September 27, 2015

THIS IS TO CERTIFY THAT ANNEXED HERETO IS A TRUE COPY FROM
THE RECORDS OF THE UNITED STATES PATENT AND TRADEMARK
OFFICE OF THOSE PAPERS OF THE BELOW IDENTIFIED PATENT
APPLICATION THAT MET THE REQUIREMENTS TO BE GRANTED A
FILING DATE.

APPLICATION NUMBER: 62/051,546
FILING DATE: September 17, 2014
RELATED PCT APPLICATION NUMBER: PCT/US15/50793

THE COUNTRY CODE AND NUMBER OF YOUR PRIORITY
APPLICATION, TO BE USED FOR FILING ABROAD UNDER THE PARIS
CONVENTION, IS US62/051,546

Certified by

[Signature]
Under Secretary of Commerce
for Intellectual Property
and Director of the United States
Patent and Trademark Office
UNITED STATES PROVISIONAL PATENT APPLICATION

FOR

SOFT ROBOTIC ACTUATOR ATTACHMENT HUB AND GRASPER ASSEMBLY AND REINFORCED
SOFT ROBOTIC ACTUATORS

INVENTORS:

KEVIN ALCEDO
JOSHUA AARON LESSING
RYAN RICHARD KNOPF
CARL VAUSE

PREPARED BY:

KACVINSKY DAISAK BLUNI, PLLC
50 DOAKS LANE
MARBLEHEAD, MA 01945
SOFT ROBOTIC ACTUATOR ATTACHMENT HUB AND GRASPER ASSEMBLY AND REINFORCED
SOFT ROBOTIC ACTUATORS

Field of the Disclosure

[0001] The disclosure relates generally to the field of robotics and relates particularly to hubs and assemblies for interfacing soft robotic actuators with other mechanical systems, and further relates particularly to reinforced soft robotic actuators.

Background

[0002] Robotics is used in many industries, such as, manufacturing, industrial applications, medical applications, or the like. As the use of robotics increases, the need for humans to interact with the robotics technologies increases. Soft robotics is a developing area of robotics that provides soft, conformal, and adaptive graspers and actuators to enable robots to interact with objects in a similar manner to a human. In particular, such robots are able to manipulate objects in the same manner as a human hand. For example, if an object is on a shelf or a moving belt, or is being moved from a shelf to a belt, an end effector may adapt to a side pick or a top down pick. This same grasper may also adapt to varying objects in each task, just as the human hand can.

However, the proposed combination of hard and soft robotics does not provide the versatility necessary to operate similar to a human.

[0004] In particular, current end effectors have difficulty adapting to varying part location (e.g., on a shelf, on a conveyor belt, or the like). Additionally, current end effectors have difficulty adapting to varying part sizes and geometries. Additionally, current end effectors need complex control systems to operate.

[0005] Furthermore, conventional soft robotic actuators are constructed from a single elastomeric material such as silicone elastomer. Some actuators incorporate elastomers of differing stiffness or wall thickness to accommodate a certain desired behavior. This layer of varying thickness or stiffness is sometimes referred to as a strain limiting layer. Some actuators use incorporated or coextruded fibrous materials in the elastomer body of the actuator itself. Such co-molded fibers are intended to improve resistance to puncture and to strengthen the actuator. Some actuators use textile socks with slits to increase the operating pressure regime of an actuator.

[0006] However, all of these actuators have several key limitations. In particular, actuators that use similar but stiffer elastomers to reinforce or restrain the actuator with thinned or thickened wall sections quickly become heavy and bulky because of the amount of excess material needed to achieve desired behaviors. This is because while stiffer, both materials are still elastomers of similar chemistries and can only achieve a very limited stiffness differential. In the case of silicones, whose stiffness is highly correlated with hardness, useful materials for soft actuators typically fall within the range of 10-80A Durometer yielding at most an 800%
differential in stiffness between select regions of the actuator. This also means that when higher differentials in stiffness are achieved, it is mostly at the expense of strength in the weaker and softer elastomer regions.

[0007] Similarly, actuators that achieve higher function through reinforcement via thickened walls or slightly stiffer variants of elastomer are also limited to a select set of other equally important mechanical properties. As a result, these actuators can have poor mechanical damping characteristics, causing the actuator to appear floppy or poorly controlled. Additionally, such actuator can have limited resistance to tear or ablation compared to materials better suited to withstand puncture, acute damage, thermal shock, or general wear and fatigue. Additionally, the load response of these construction materials is almost universally isotropic.

[0008] Actuators with fibrous reinforcements have been introduced by molding fibers into the actuator or co-extruded fibrous “pulp” as filler. Although such techniques provide slight improvements in puncture resistance and increased overall strength, this type of actuator precludes the possibility of modularity or repairs to such reinforcements without discarding the entire actuator. Additionally, fibrous reinforced actuators present a vulnerable rubbery surface to the environment, and issues of fiber delamination from the elastomer, limited fatigue life, and poor environmental resistance are prevalent.

[0009] Actuators where the exterior of the actuator is wrapped as a “sock” do not utilize unfolding structures and for the singular and limited purpose of increasing the inflation pressure of an actuator causing it to have increased stiffness at equivalent states of curvature. Such wraps also utilized a limited number of fabrication techniques and material sets.
[0010] The present disclosure is directed to addressing the above limitations. In particular, the present disclosure provides improvements in interfacing hard and soft robotics and also provides improved actuators.

**Brief Description of the Drawings**

[0011] **FIG. 1** is a perspective view illustrating an exemplary embodiment of a hub assembly and soft robotic actuators in accordance with various examples of the present disclosure.

[0012] **FIGS. 2A-2C** are exploded views of the hub assembly of **FIG. 1**.

[0013] **FIGS. 3A-3E** are assembled views of the hub assembly and soft robotic actuators of **FIG. 1**.

[0014] **FIGS. 4A-4D** are perspective views illustrating an exemplary twist lock interface for the hub assembly of **FIG. 1**.

[0015] **FIG. 5** is an illustration of a method of using the twist lock interface of **FIGS. 4A-4D**.

[0016] **FIG. 6** is a cross sectional view of the twist lock interface of **FIGS. 4A-4D**.

[0017] **FIGS. 7A-7G** are perspective views illustrating an exemplary magnetic interface for the hub assembly of **FIG. 1**.

[0018] **FIG. 8** is a perspective view illustrating an exemplary electrostatic adhesion interface for the hub assembly of **FIG. 1**.
[0019] FIGS. 9A-9D are perspective views illustrating an example grasper using the hub assembly of FIG. 1 and soft actuators.

[0020] FIGS. 10A-10C are perspective views illustrating an example grasper using the hub assembly of FIG. 1 and soft actuators having electro mechanical portions.

[0021] FIGS. 11A-11E are perspective views illustrating a grasper using the hub assembly of FIG. 1 and soft actuators having side actuators configured to change the angle of attack.

[0022] FIGS. 12A-12D are perspective views illustrating a grasper using the hub assembly of FIG. 1 and soft actuators of different lengths configured to substantially enclose an object.

[0023] FIG. 13 is an illustration of a method of using the grasper of FIGS. 12A-12D.

[0024] FIGS. 14-21 are perspective views of reinforced actuators.

[0025] FIGS. 22-26 are perspective views of reinforcing wraps for use with a soft actuator.

**Summary**

[0026] “Soft robotic” actuators that are configured to perform new fundamental motions (e.g., bending, twisting, straightening, or the like) are described. Additionally, a hub and grasper assembly for such soft robotics actuators is described.

[0027] Various soft robotic technologies are discussed in PCT International Publication Number WO2012/148472, which application is incorporated herein by reference in its entirety. The present invention includes the implementation of soft robotic technologies into specific configurations that are useful as orthopedic devices, and related methods that employ such soft robotic configurations.
Some embodiments of the present disclosure describe a hub assembly capable of interfacing with various soft robotics actuators (e.g., Pneu-Net actuators, fiber reinforced actuators, soft tentacle actuators, accordion style actuators, or the like) and hard robotics (e.g., robotic arm, mechanical tool, or other mechanical system).

Additionally, some embodiments of the present disclosure provide a grasper including elastomeric actuators. The grasper is conformal and adaptive to enable the handling of a range of objects, with real-time adaption to the shape and size of objects.

Additionally, some embodiments of the present disclosure provide a reinforced actuator. In particular, an actuator with various geometries (e.g., unfolding accordion style actuator, or the like) and reinforced areas is provided.

Detailed Description of the Preferred Embodiments

Embodiments of the present disclosure will now be described more fully hereinafter with reference to the accompanying drawings. The disclosure, however, may be embodied in many different forms and should not be construed as being limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the disclosure to those skilled in the art. In the drawings, like numbers refer to like elements throughout.

In accordance with the present disclosure, a hub and/or grasper assembly for interfacing soft robotic actuators with hard robotic assemblies is provided. Additionally, reinforced actuators are described. The reinforced actuators may be used with the hub and/or grasper assembly. However, for purposes of convenience, they are discussed separately. In
particular, **FIGS. 1-13** depict examples of a hub or grasper assembly according to embodiments of the present disclosure while **FIGS. 14-26** depict examples of reinforced actuators according to embodiments of the present disclosure.

[0033] Referring to **FIG. 1**, an exemplary hub 100 in accordance with the present disclosure is shown. The hub 100 includes a master side assembly 10 and a tool side assembly 20. In general, the master side assembly 10 may be connected or connectable to a mechanical assembly, such as a robotic arm, a robotic manipulator, or in general any end effector of a robotic (e.g., hard robotics) assembly. The tool side assembly 20 may be configured to operably connect various soft actuators 30-a (where a is a positive integer). In particular, the tool side assembly 20 may be provided with actuator attachment portions 20-b (where be is a positive number). It is important to note, that the tool side assembly 20 may be configured connect any number of soft actuators 30-a. However, for convenience and clarity, a number of soft actuators 30-a (e.g., 30-1, 30-2, 30-3, and 30-4) and a number of actuator attachment portions 20-b (e.g., 20-1, 20-2, 20-3, and 20-4) are depicted in the figures. Additionally, it is important to note that the number of actuator attachment portions 20-b may be different than the number of actuators 30-a connected to the tool side assembly 20.

[0034] In general, each of the master side assembly 10 and the tool side assembly 20 include an interface configured to releaseably couple the assemblies 10 and 20 to each other. In particular, the tool side assembly 20 includes an interface portion 21 while the master side assembly 10 includes an interface portion 11 (obscured by the angle of viewing). The interface portions 11 and 21 can be configured to couple the assemblies 10 and 20 and to provide a seal.
for inflation line (e.g., pneumatic, hydraulic, or the like) connections, electrical connections, or other connections.

[0035] FIGS. 2A-2C depict an exploded view of the hub 100 from various perspectives. In particular, FIG. 2A illustrates the hub 100 from a straight on side view showing the master side assembly 10 and the tool side assembly 20. Furthermore, actuator attachment portion 22-1 is shown in the tool side assembly 20. Additionally, the interface portions 11 and 21 are shown. FIG. 2B illustrates the hub 100 from an angled bottom up perspective view showing the master side assembly 10 and the tool side assembly 20. Furthermore, actuator attachment portions 22-1 and 22-2 are shown in the tool side assembly 20. FIG. 2B illustrates the hub 100 from an angled bottom up perspective view showing the master side assembly 10 and the tool side assembly 20. Furthermore, actuator attachment portion 22-1 and 22-2 are shown in the tool side assembly 20. Additionally, the interface portions 11 and 21 are shown. FIG. 2C illustrates the hub 100 from an angled top down perspective view showing the master side assembly 10 and the tool side assembly 20. Furthermore, actuator attachment portions 22-1 and 22-2 are shown in the tool side assembly 20. Additionally, the interface portions 11 and 21 are shown.

[0036] It is to be appreciated, that areas of the interface portions 11 and 21 are merely depicted in FIG. 1 and FIGS. 2A-2C. However, it is to be appreciated, that the interface portions 11 and 21 may have a variety of configurations and that the interface portions 11 and 21 should not be limited by those depicted in FIG. 1 and FIGS. 2A-2C.

[0037] FIGS. 3A-3E depict an assembled view of the hub 100 and attached actuators 30 from various perspectives. In particular, FIG. 3A illustrates the hub 100 from a straight on side view showing the master side assembly 10 and the tool side assembly 20. Furthermore, actuators
30-2 and 30-3 are shown attached to the tool side assembly 20. Actuators 30-2 and 30-3 are depicted in a “neutral” position (e.g., not inflated, deflated, or the like). FIG. 3B illustrates the hub 100 from a straight on side view showing the master side assembly 10 and the tool side assembly 20 and the attached actuators 30-2 and 30-3 in an inflated state. FIG. 3C illustrates the hub 100 from an angled side view while FIGS. 3D and 3E show the hub 100 from an angled bottom up and tom down (respectively) perspective view. In particular, the assemblies 10 and 20 are shown coupled together with actuators 30-1, 30-2, 30-3, and 30-4 attached to the tool side assembly and depicted as inflated.

[0038] Accordingly, the hub assembly 100 can be used to quickly switch between various grasper assemblies by changing the tool side assembly 20. Example grasper assemblies are now described. It is important to note, that a system may be implemented with one master side assembly 10 and multiple the tool side assemblies 20 each with a different grasper configuration. As such, the system can be quickly reconfigured and used to perform different operations needing different graspers or soft actuators.

[0039] FIGS. 4A-4D depict an example of the hub assembly 100 including a twist lock interface. In particular, FIG. 4A illustrates an exploded top down perspective view of the hub assembly 100 showing the master side assembly 10 and the tool side assembly 20. Furthermore, actuator attachment portions (e.g., 22-1) are shown in the tool side assembly 20. Furthermore, details of the interface portions 11 and 21 are shown. In particular, the interface portion 11 includes pegs 15 and connection port 16 while the interface portion 21 includes slots 25 and connection port 26. The pegs and the slots are configured to be releaseably secured to each other. In particular, the slots 25 may have a varying diameter, where one end of each slot is
proportioned to receive an end of a corresponding one of the pegs 15. Once the pegs 15 are fit into the slots 25, either the assembly 10 or the assembly 20 may be twisted to lock the pegs 15 in place, thereby securing the assembly 10 to the assembly 20.

[0040] FIGS. 4B-4C illustrate a top perspective and a top down (respectively) view of the tool side assembly 20. As can be seen, the tool side assembly 20 includes actuator attachment portions (e.g., 20-1), slots 25, and connection port 26. FIG. 4D illustrates a side view of the tool side assembly 20. As can be seen, the tool side assembly 20 may include a top stepped or recessed portion 22 configured to fit into a corresponding recessed portion in the interface portion 11 of the master side assembly 10.

[0041] Additionally, the connection ports 16 and 26 may seal or form a seal when the assemblies 10 and 20 are secured together (e.g., refer to FIG. 6). As such, a sealed pathway or connection point for inflation lines (e.g., pneumatic, hydraulic, or the like) as well as electrical signal lines can be provided through the connection points 16 and 26.

[0042] FIG. 5 illustrates a method for securing the tool side assembly 20 to the master side assembly 10. In particular, at 510, the interface portion 11 of the master side assembly 10 is lowered (or dropped) onto the interface portion 21 of the tool side assembly 20. In particular, the interface portions 11 and 21 are brought together such that the pegs 15 fit into the slots 25. It is important to note, that this figure depicts pegs disposed on the tool side assembly and slots on the master side assembly. Examples are not to be limited in this context. At 520, the master side assembly 10 is twisted relative to the tool side assembly 20 to lock the pegs 15 into the slots 25. Accordingly, at 530, the tool side assembly 20 is securely coupled to the master side assembly 10.
FIG. 6 illustrates a cross sectional view of the assembled hub 100. In particular, as depicted, the pegs 15 are secured into slots 25 and the connection points 16 and 26 form a sealed connection.

FIGS. 7A-7G depict an example of the hub assembly 100 including a magnetic interface. In particular, FIG. 7A illustrates an exploded bottom up perspective view of the hub assembly 100 showing the master side assembly 10 and the tool side assembly 20. Furthermore, actuator attachment portions (e.g., 22-1) are shown in the tool side assembly 20. Furthermore, details of the interface portions 11 and 21 are shown. In particular, the interface portion 11 includes connection ports 16 and 26, respectively. Furthermore, the interface portion 11 includes a geometric (e.g., hexagonal, triangular, rectangular, star shaped, or the like) recess 13 while the interface 21 includes a corresponding geometric stepped portion 23. The stepped portion 23 is configured to fit into the recessed portion 13. Furthermore, the interfaces 10 and 20 include magnetic portions 41 and 42, respectively. The geometric stepped portion 23 and the recessed portion 13 are configured to prevent any shear forces from disengaging the tool side assembly 20 from the master side assembly 10. Furthermore the stepped portion 23 and the recessed portion 13 facilitate the location and insertion of the tool side assembly 10.

FIGS. 7B-7C illustrate the hub assembly 100 in an alternative perspective view and a side view, respectively. Additionally, FIGS. 7D-7G illustrate the tool side assembly from various angles and/or views.

FIG. 8 depicts an example of the hub assembly 100 including an electrostatic adhesion interface. In particular, this figure illustrates an exploded bottom up perspective view of the hub assembly 100 showing the master side assembly 10 and the tool side assembly 20.
Furthermore, actuator attachment portions (e.g., 22-1) are shown in the tool side assembly 20. Furthermore, details of the interface portions 11 are shown. In particular, the interface portion 11 includes electrostatic adhesion pads 51. As depicted, the electrostatic adhesion pads are disposed on the master side assembly 10. However, in some examples, the electrostatic adhesion pads 51 can be disposed on the tool side assembly 20. Furthermore, in some examples, electrostatic adhesion pads (e.g., 51) may be disposed on both the master side assembly and the tool side assembly interface portions 11 and 21.

[0047] FIGS. 9A-9D illustrate an example hub assembly 100 and an example configuration of soft actuators 30 attached to the tool side assembly 20. In particular, the soft actuators 30 are depicted in FIGS. 9A-9C as deflated to vacuum (e.g., reverse inflated) to provide an increase in grasping fidelity. In some examples, the connection ports 16, 26 may provide for sealing inflation lines between the assemblies 10 and 20 such that the soft actuators 30 can be deflated and/or inflated. In some examples, the soft actuators 30 may be inflated from the deflated portion, resulting in inflated actuators 30, as shown in FIG. 9D.

[0048] FIGS. 10A-10C illustrate an example hub assembly 100 and an example configuration of soft actuators 30, that include an electro-mechanical portion 31. The electromechanical portions 31 can be used to modify and/or adjust the angle of attack of the actuators from when they are in the neutral position (e.g., refer to FIGS. 10A-10B) to when they are in the inflated position (e.g., refer to FIG. 10C).

[0049] FIGS. 11A-11E depict an example of the tool side assembly 20 and attached soft actuators 30. In some examples, a tool side assembly 20 may be provided with the soft actuators depicted in this example to adjust the angle of attack for picking up object. For example, FIG.
11A illustrates the tool side assembly 20 and the soft actuators 30 from various angles and perspectives. As depicted, the soft actuators 30 include soft angle adjustors 32. FIG. 11B illustrates a bottom view of the tool side assembly 20 with the soft actuators 30 attached and a magnified view 200 of the soft angle adjustors 32. As can be seen, the soft angle adjustors 32 are disposed laterally between the soft actuators 30. During operation, the soft angle adjustors 32 can be independently inflated and deflated (e.g., independent from each other, independent from the soft actuators, some combination of this, or the like) to adjust the angle between the soft actuators 30.

[0050] FIG. 11C-11E illustrate the soft actuators 30 and soft angle adjustors 32 in various states. In particular, FIG. 11C illustrates the soft actuators 30 in a neutral position and the soft angle adjustors 32 deflated. As such, the angle between pairs of the soft actuators 30 (e.g., between 30-1 and 30-2 and between 30-3 and 30-4, or the like) is reduced. FIG. 11D illustrates the soft actuators 30 in a neutral position and the soft angle adjustors 32 inflated. As such, the angle between pairs of the soft actuators 30 (e.g., between 30-1 and 30-2 and between 30-3 and 30-4, or the like) is increased. FIG. 11E illustrates the soft actuators 30 in an inflated position and the soft angle adjustors 32 inflated. As such, the angle between pairs of the soft actuators 30 (e.g., between 30-1 and 30-2 and between 30-3 and 30-4, or the like) is increased and the angle of attack of the inflated soft actuators 30 is also increased.

[0051] FIGS. 12A-12D depicts an example of the tool side assembly 20 and attached soft actuators 30. In some examples, a tool side assembly 20 may be provided with the soft actuators depicted in this example (e.g., soft actuators of varying sizes) to enable the soft actuators to fully encapsulate and object. For example, FIG. 12A illustrates the tool side assembly 20 and the soft
actuators 30 from various angles and perspectives. As depicted, there are a variety of different sized soft actuators 30. In particular, the soft actuators 30 depicted have various lengths. FIGS. 12B-12D illustrate the tool side assembly 20 and each of the different sized the soft actuator 30 and their corresponding range of motion. In particular, FIG. 12B illustrates the longest of the soft actuators 30 and their corresponding range of motion (e.g., deflated to fully inflated). FIG. 12C illustrates the middle length soft actuators 30 and their corresponding range of motion (e.g., deflated to fully inflated). FIG. 12D illustrates the shortest of the soft actuators 30 and their corresponding range of motion (e.g., deflated to fully inflated).

[0052] FIG 13 illustrates a method of fully encapsulating an object using an example tool side apparatus and soft actuators arranged according to the present disclosure. In particular, at 1310, the tool side assembly and soft actuators are arranged above an object 1301 to be encapsulated (e.g., mug, or the like). As 1320, the tool side assembly and the soft actuators are lowered or positioned just above the object. At 1330, the shortest soft actuators 30 are inflated to hold the object in place. At 1340, the middle length soft actuators are inflated to more fully surround the object 1301. As 1350, the longest soft actuators are inflated to substantially encapsulate the object 1301.

[0053] FIG. 14 depicts an embodiment of a reinforced actuator 1400 that uses a reinforcing wrap 1401 that can be fabricated in a flat sheet and then subsequently affixed about an actuator 1402 by mating its ends in one of a variety of different methods. This reinforcing wrap 1401 may be fabricated through any method suitable for such a shape and is not necessarily limited to being completely flat. For instance it may be formed to achieve texture for gripping, ridges for stiffness, or unfolding features to accommodate extension. The material from which the
reinforcing warp 1401 is made may vary greatly depending on the intended application. For example, without limitations, the wrap 1401 can be fabricated from metal meshes or fabrics, polypropylene, polyester, polyethylene, lubricant impregnated polymers, mylar, spandex, neoprene, nitrile, latex, textiles, elastomeric textiles, sealable or film coated textiles, elastomers, thermoplastic films or sheets, thermoplastic elastomer films or sheets, nonwoven textiles, paper or other cellulosic materials, uniaxially oriented textiles, fibrous composites, foams, thermoplastic foams, thermoplastic elastomer foams, thermally and electrically conductive materials, strain sensitive materials, flexible electronic substrates such as polyamide, and others. In addition, the reinforcing wrap 1401 may also include less flexible stiffening elements designed to provide completely rigid regions or tunably stiff regions. Such materials may include, for example, nitinol hyper-elastic springs, spring steel, metal plates, helical springs, plastic or thermoplastic plates, traditional printed circuit boards, and others.

[0054] **FIG. 15** depicts a reinforced actuator 1500 including a reinforcing wrap 1501 that can be constructed from woven materials, such as, for example, a co-weave of elastomeric strands such as neoprene or spandex. The wrap 1501 has the unique ability to apply tension and conform about the surface of the actuator 1502 it is reinforcing. By default a specific amount of expansion will be resisted by the elasticity of the fabric up to some point where the mesh angle of fabric collapses and it begins to respond as a rigid fibrous mesh.

[0055] **FIG. 16** depicts a reinforced actuator 1600 having internal reinforcements 1601 molded within the body of the actuator 1602. Such a configuration may reinforce the actuator 1600 against undesirable expansion.
[0056] **FIG. 17** depicts a reinforced actuator 17000 including an external reinforcement 1701. The external reinforcement 1701 may be a tunably stiff element configured to change the resistance of the actuator 1702 to unfolding and extending under pressure. For example, the external reinforcement 1701 may be a member that is rigid along the straight sides of the accordion geometry (depicted as checkered) and “spring-like” in the curved regions between (depicted as white) augments the normal response of the accordion actuator to pressure and effectively raises its operating pressure regime. This leads to a part which is substantially stiffer in the curved state and which is capable of exerting greater forces on its environment.

[0057] **FIG. 18** depicts a reinforced actuator 1800 including dampening reinforcements 1801 disposed inside the actuator 1802. The actuator 1800 may be implemented in systems where closed loop control is to be applied or in applications where a high level human interaction dictates the appearance of precise control. In such systems it is often desirable to dampen oscillations within the system. For example, it may be advantageous to reject oscillations introduced by external stimuli and control the actuator 1800 in a frequency band far from its mechanical natural resonance frequency. To this effect, the dampening reinforcements 1801 may be highly damping viscoelastic foams or gels that fill the interior of the actuator 1802 in an open celled configuration. An inflation channel 1803 is left open in this depiction to ensure all areas of the actuator inflate at the same time. If the material comprising the dampening reinforcement 1801 is mechanically robust as well as highly damping, it can also serve as a voluminous internal reinforcement against undesired expansion of the part.

[0058] **FIG. 19** depicts a reinforced actuator 1900 where a dampening reinforcement 1901 (e.g., similar to that dampening reinforcement 1801) is disposed on the exterior of the actuator
1902. This amplifies their damping effect, as this region of the part must stretch the most for the actuator 1902 to bend.

[0059] **FIG. 20** depicts a reinforced actuator 2000 that includes an external reinforcement 2001 and an actuator 2002. The external reinforcement 2001 may have any of a variety of configurations and features, even complex configurations and features. Such complex external reinforcement features may be achieved using additive manufacturing techniques. In such techniques, a material that is sensitive to a particular wavelength or spectrum is applied uncured to a surface upon which it is subsequently cured via exposure to radiation. In particular, the use of micro dispensed fluids also enables the deposition of a controlled mixture of multiple compounds across a surface, effectively setting up micro-scale reactions on the surface that can spatially modulate the properties of the cured material. Such techniques may be employed to form the complex reinforcement 2001 shown on the surface of a soft actuator 2002. Additionally, these techniques may be employed on the surface of soft actuators to selectively add patterned layers of material with a wide range of properties. They may be stiff reinforcements, elastomeric textures, aesthetic patterns, optical elements, protective layers, conductive layers, or strain sensitive resistive materials.

[0060] **Fig. 21** depicts a reinforced actuator 2100 comprising a soft actuator 2102 and a protective skin 2101 drawn over the soft actuator 2102. Thin and wrinkled or highly elastomeric skin materials can be used for a multitude of different applications including protection of the actuator, containers for filler materials (not shown) that surround the actuator, high or low friction, chemical resistance, or the like.
[0061] FIGS. 22-26 depict examples of reinforcing wraps (e.g., the wrap 1401, 1501, or the like) that may be implemented with various examples of the present disclosure. The wraps 1401 and 1501 discussed above may be formed as described below. Turning to FIG. 22, a reinforcing wrap 2200 is depicted. The wrap 2200 can be permanently or reversibly affixed about an unfolding accordion soft actuator. The wrap 2200 can be formed using laser cutting, knife cutter plotting, sewing, impulse sealing, RF welding, ultrasonic welding, hot embossing, compression molding, or injection molding. Additionally, the wrap 2200 may include side release buckles 2201 to be affixed about a soft actuator. The wrap 2200 can also houses a number of sensors 2202 and/or electrical payloads 2203 that may be disposed on and/or embedded within the wrap 2200. For example, as depicted, the electrical payload 2203 includes a traditional printed circuit board with microcontroller based application circuit, battery power and distribution, and a suite of myoelectric sensors 2202 designed to detect the muscle intent of the biological subject they are in contact with.

[0062] Turning now to FIG. 23, a reinforcing wrap 2300 is depicted. The wrap 2300 may include any combination of features described above for reinforcing wraps. Additionally, the wrap 2300 includes re-closable interlocking pegs 2301 as a fastener and force sensing resistors or pressure transducers 2302 sensed via conductive threads 2303 embedded within the wrap material.

[0063] Turning now to FIG. 24, a reinforcing wrap 2400 is depicted. The wrap 2400 may include any combination of features described above for reinforcing wraps. Additionally, the wrap 2400 includes strain sensing materials 2401 spanning the reinforcements that connect the two halves of the wrap’s structure.
Turning now to FIG. 25, a reinforcing wrap 2500 is depicted. The wrap 2500 may include any combination of features described above for reinforcing wraps. Additionally, the wrap 2500 includes strips of adhesive 2501 as a fastener and a bank of light emitting diodes 2502 powered externally via wires 2503 embedded within the wrap.

Turning now to FIG. 26, a reinforcing wrap 2600 is depicted. The wrap 2600 may include any combination of features described above for reinforcing wraps. Additionally, the wrap 2600 includes protective armor plates 2601 embedded within its bottom facing surface and a tuned nitinol or spring steel accordion spring 2602 to provide additional resistance to unfolding and elongation of the contained actuator.

As used herein, an element or step recited in the singular and proceeded with the word “a” or “an” should be understood as not excluding plural elements or steps, unless such exclusion is explicitly recited. Furthermore, references to “one embodiment” of the present invention are not intended to be interpreted as excluding the existence of additional embodiments that also incorporate the recited features.

While the present invention has been disclosed with reference to certain embodiments, numerous modifications, alterations and changes to the described embodiments are possible without departing from the sphere and scope of the present invention, as defined in the appended claim(s). Accordingly, it is intended that the present invention not be limited to the described embodiments, but that it has the full scope defined by the language of the following claims, and equivalents thereof.
Provisional Application for Patent Cover Sheet
This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c)

Inventor(s)

<table>
<thead>
<tr>
<th>Inventor 1</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Given Name</td>
<td>Middle Name</td>
<td>Family Name</td>
<td>City</td>
<td>State</td>
</tr>
<tr>
<td>Kevin</td>
<td></td>
<td>ALCEDO</td>
<td></td>
<td>US</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Inventor 2</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Given Name</td>
<td>Middle Name</td>
<td>Family Name</td>
<td>City</td>
<td>State</td>
</tr>
<tr>
<td>Joshua</td>
<td>Aaron</td>
<td>LESSING</td>
<td>Cambridge</td>
<td>MA</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Inventor 3</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Given Name</td>
<td>Middle Name</td>
<td>Family Name</td>
<td>City</td>
<td>State</td>
</tr>
<tr>
<td>Ryan</td>
<td>Richard</td>
<td>KNOPF</td>
<td>Cambridge</td>
<td>MA</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Inventor 4</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Given Name</td>
<td>Middle Name</td>
<td>Family Name</td>
<td>City</td>
<td>State</td>
</tr>
<tr>
<td>Carl</td>
<td>Everett</td>
<td>VAUSE</td>
<td>Concord</td>
<td>MA</td>
</tr>
</tbody>
</table>

All Inventors Must Be Listed – Additional Inventor Information blocks may be generated within this form by selecting the Add button.

Title of Invention
SOFT ROBOTIC ACTUATOR ATTACHMENT HUB AND GRASPER ASSEMBLY AND REINFORCED SOFT ROBOTIC ACTUATORS

Correspondence Address
Direct all correspondence to (select one):

- The address corresponding to Customer Number
- Firm or Individual Name

Customer Number
121159

The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.

- No.
- Yes, the name of the U.S. Government agency and the Government contract number are:
Entity Status
Applicant claims small entity status under 37 CFR 1.27

☐ Yes, applicant qualifies for small entity status under 37 CFR 1.27
☐ No

Warning
Petitioner/applicant is cautioned to avoid submitting personal information in documents filed in a patent application that may contribute to identity theft. Personal information such as social security numbers, bank account numbers, or credit card numbers (other than a check or credit card authorization form PTO-2038 submitted for payment purposes) is never required by the USPTO to support a petition or an application. If this type of personal information is included in documents submitted to the USPTO, petitioners/applicants should consider redacting such personal information from the documents before submitting them to USPTO. Petitioner/applicant is advised that the record of a patent application is available to the public after publication of the application (unless a non-publication request in compliance with 37 CFR 1.213(a) is made in the application) or issuance of a patent. Furthermore, the record from an abandoned application may also be available to the public if the application is referenced in a published application or an issued patent (see 37 CFR 1.14). Checks and credit card authorization forms PTO-2038 submitted for payment purposes are not retained in the application file and therefore are not publicly available.

Signature
Please see 37 CFR 1.4(d) for the form of the signature.

<table>
<thead>
<tr>
<th>Signature</th>
<th>Date (YYYY-MM-DD)</th>
<th>Registration Number (If appropriate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>/Scott Bluni/</td>
<td>2014-09-17</td>
<td>40916</td>
</tr>
</tbody>
</table>

This collection of information is required by 37 CFR 1.51. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 8 hours to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. This form can only be used when in conjunction with EFS-Web. If this form is mailed to the USPTO, it may cause delays in handling the provisional application.
The Privacy Act of 1974 (P.L. 93-579) requires that you be given certain information in connection with your submission of the attached form related to a patent application or patent. Accordingly, pursuant to the requirements of the Act, please be advised that: (1) the general authority for the collection of this information is 35 U.S.C. 2(b)(2); (2) furnishing of the information solicited is voluntary; and (3) the principal purpose for which the information is used by the U.S. Patent and Trademark Office is to process and/or examine your submission related to a patent application or patent. If you do not furnish the requested information, the U.S. Patent and Trademark Office may not be able to process and/or examine your submission, which may result in termination of proceedings or abandonment of the application or expiration of the patent.

The information provided by you in this form will be subject to the following routine uses:

1. The information on this form will be treated confidentially to the extent allowed under the Freedom of Information Act (5 U.S.C. 552) and the Privacy Act (5 U.S.C. 552a). Records from this system of records may be disclosed to the Department of Justice to determine whether disclosure of these records is required by the Freedom of Information Act.

2. A record from this system of records may be disclosed, as a routine use, in the course of presenting evidence to a court, magistrate, or administrative tribunal, including disclosures to opposing counsel in the course of settlement negotiations.

3. A record in this system of records may be disclosed, as a routine use, to a Member of Congress submitting a request involving an individual, to whom the record pertains, when the individual has requested assistance from the Member with respect to the subject matter of the record.

4. A record in this system of records may be disclosed, as a routine use, to a contractor of the Agency having need for the information in order to perform a contract. Recipients of information shall be required to comply with the requirements of the Privacy Act of 1974, as amended, pursuant to 5 U.S.C. 552a(m).

5. A record related to an International Application filed under the Patent Cooperation Treaty in this system of records may be disclosed, as a routine use, to the International Bureau of the World Intellectual Property Organization, pursuant to the Patent Cooperation Treaty.

6. A record in this system of records may be disclosed, as a routine use, to an other federal agency for purposes of National Security review (35 U.S.C. 181) and for review pursuant to the Atomic Energy Act (42 U.S.C. 218(c)).

7. A record from this system of records may be disclosed, as a routine use, to the Administrator, General Services, or his/her designee, during an inspection of records conducted by GSA as part of that agency’s responsibility to recommend improvements in records management practices and programs, under authority of 44 U.S.C. 2904 and 2906. Such disclosure shall be made in accordance with the GSA regulations governing inspection of records for this purpose, and any other relevant (i.e., GSA or Commerce) directive. Such disclosure shall not be used to make determinations about individuals.

8. A record from this system of records may be disclosed, as a routine use, to the public after either publication of the application pursuant to 35 U.S.C. 122(b) or issuance of a patent pursuant to 35 U.S.C. 151. Further, a record may be disclosed, subject to the limitations of 37 CFR 1.14, as a routine use, to the public if the record was filed in an application which became abandoned or in which the proceedings were terminated and which application is referenced by either a published application, an application open to public inspection or an issued patent.

9. A record from this system of records may be disclosed, as a routine use, to a Federal, State, or local law enforcement agency, if the USPTO becomes aware of a violation or potential violation of law or regulation.
### Electronic Acknowledgement Receipt

<table>
<thead>
<tr>
<th>EFS ID:</th>
<th>20166346</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application Number:</td>
<td>62051546</td>
</tr>
<tr>
<td>International Application Number:</td>
<td></td>
</tr>
<tr>
<td>Confirmation Number:</td>
<td>9296</td>
</tr>
<tr>
<td>Title of Invention:</td>
<td>SOFT ROBOTIC ACTUATOR ATTACHMENT HUB AND GRASPER ASSEMBLY AND REINFORCED SOFT ROBOTIC ACTUATORS</td>
</tr>
<tr>
<td>First Named Inventor/Applicant Name:</td>
<td>Kevin ALCEDO</td>
</tr>
<tr>
<td>Customer Number:</td>
<td>121159</td>
</tr>
<tr>
<td>Filer:</td>
<td>Scott Bluni/Pamela J. Pari</td>
</tr>
<tr>
<td>Filer Authorized By:</td>
<td>Scott Bluni</td>
</tr>
<tr>
<td>Attorney Docket Number:</td>
<td>3325864-7369351001</td>
</tr>
<tr>
<td>Receipt Date:</td>
<td>17-SEP-2014</td>
</tr>
<tr>
<td>Filing Date:</td>
<td></td>
</tr>
<tr>
<td>Time Stamp:</td>
<td>15:42:27</td>
</tr>
<tr>
<td>Application Type:</td>
<td>Provisional</td>
</tr>
</tbody>
</table>

### Payment information:

- Submitted with Payment: yes
- Payment Type: Credit Card
- Payment was successfully received in RAM: $130
- RAM confirmation Number: 2084
- Deposit Account:          
- Authorized User:          

### File Listing:

<table>
<thead>
<tr>
<th>Document Number</th>
<th>Document Description</th>
<th>File Name</th>
<th>File Size(Bytes)/Message Digest</th>
<th>Multi Part./.zip</th>
<th>Pages (if appl.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Specification</td>
<td>Document Name</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---------------</td>
<td>---------------</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>1</td>
<td>Specification</td>
<td>7369351001_Provisional_Application.pdf</td>
<td>93360</td>
<td>no</td>
<td>22</td>
</tr>
<tr>
<td>2</td>
<td>Drawings-only black and white line drawings</td>
<td>7369351001_Figures.pdf</td>
<td>661589</td>
<td>no</td>
<td>25</td>
</tr>
<tr>
<td>3</td>
<td>Provisional Cover Sheet (SB16)</td>
<td>7369351001_Provisional_Cover_Sheet.pdf</td>
<td>79839</td>
<td>no</td>
<td>3</td>
</tr>
</tbody>
</table>

**Warnings:**
This is not a USPTO supplied Provisional Cover Sheet SB16 form.

**Information:**

|   | Fee Worksheet (SB06) | fee-info.pdf | 30027 | no | 2 |

**Warnings:**

**Total Files Size (in bytes):** 864815

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

**New Applications Under 35 U.S.C. 111**
If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

**National Stage of an International Application under 35 U.S.C. 371**
If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

**New International Application Filed with the USPTO as a Receiving Office**
If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/R0/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.
Claims

1. A soft robotic hub assembly comprising:
   a master side assembly to be coupled to a mechanical robotic component;
   a tool side assembly configured to be releasably coupled to the master side assembly; and
   a number of soft actuators coupled to the tool side assembly.

2. A reinforced soft actuator comprising:
   a soft actuator body; and
   a reinforcement attached to the soft actuator body.
Abstract of the Disclosure

A hub assembly for coupling different grasper assemblies including soft actuators in various configurations to mechanical robotic components, and soft actuators having various reinforcements.