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Jing

(10) **Patent No.: US 11,155,326 B2**
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(54) **BIO-INSPIRED UNDERWATER ROBOT**

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(51) **Int. Cl.**

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B63G 8/00	(2006.01)
B63H 1/36	(2006.01)
B63H 23/06	(2006.01)

(52) **U.S. Cl.**
CPC ***B63G 8/08*** (2013.01); ***B63G 8/001*** (2013.01); ***B63H 1/36*** (2013.01); ***B63H 23/06*** (2013.01); *B63G 2008/002* (2013.01)

(58) **Field of Classification Search**
CPC . B63G 8/00; B63G 8/001; B63G 8/08; B63G 8/16; B63G 8/22; B63H 1/00; B63H 1/36; B63H 23/00; B63H 23/06; B63H 11/00; B25J 9/00; B25J 9/06; B25J 9/065; B25J 9/08; B25J 9/12
USPC 114/331, 337; 606/1; 700/245
See application file for complete search history.

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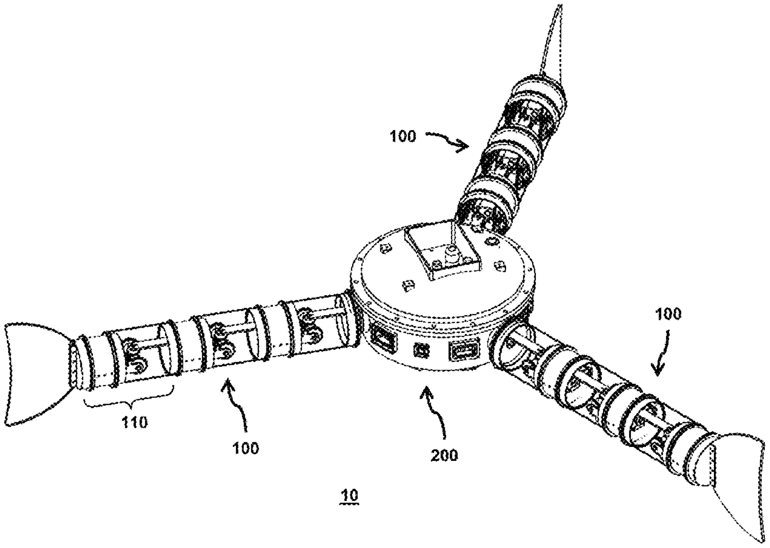
(57) **ABSTRACT**

A bionic underwater robot for achieving a variety of motions is disclosed. The bionic underwater robot includes a head and one or more tail structures. Each of the one or more tail structures includes one or more joint structures. Each of the one or more joint structures includes a connection plate, and a modular assembly, comprising an upper servo motor, a lower servo motor, and a bevel gear mechanism, is motorized for performing various movement motions of the joint structure. The bevel gear mechanism is integrally formed by an intermediate bevel gear, a first bevel gear, and a second bevel gear. The upper servo motor drives the first bevel gear from a first side of the modular assembly, while the lower servo motor drives the second bevel gear from a second side.

20 Claims, 24 Drawing Sheets



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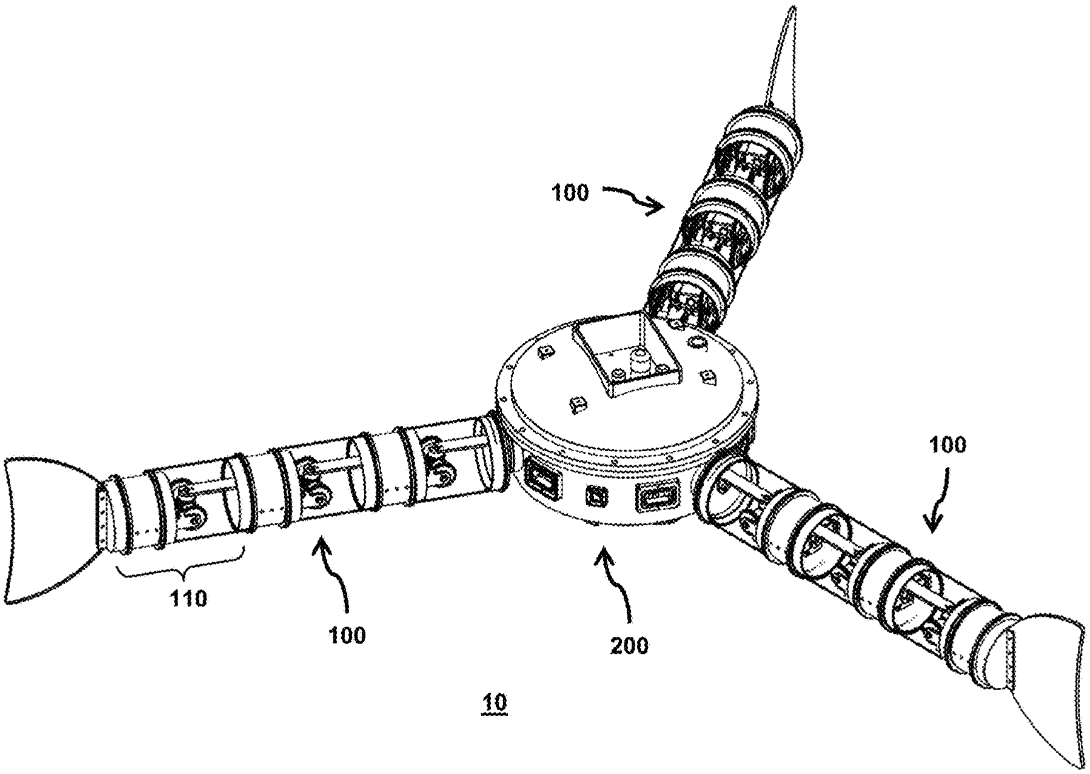
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FIG. 1

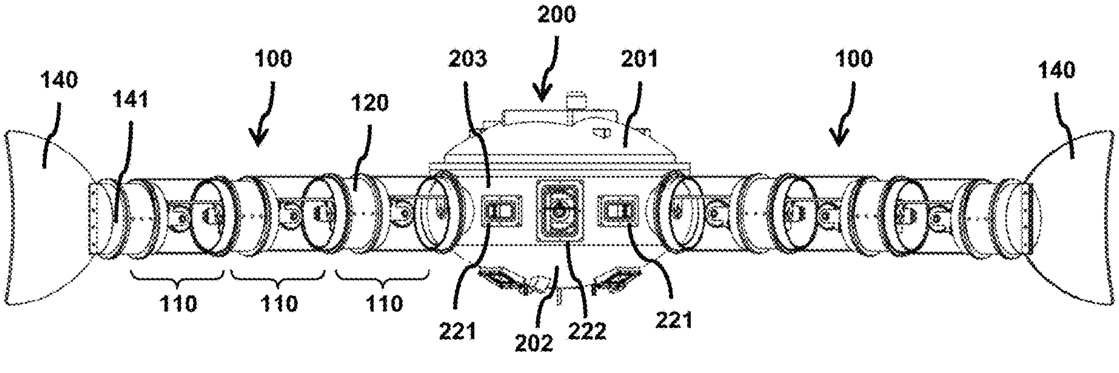
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FIG. 2

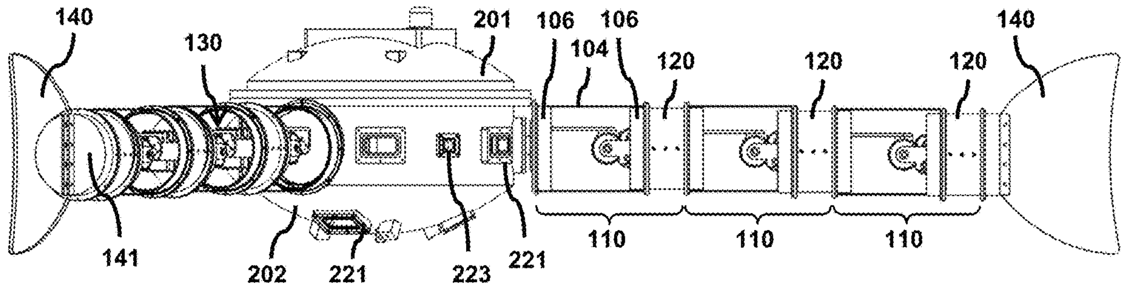
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FIG. 3

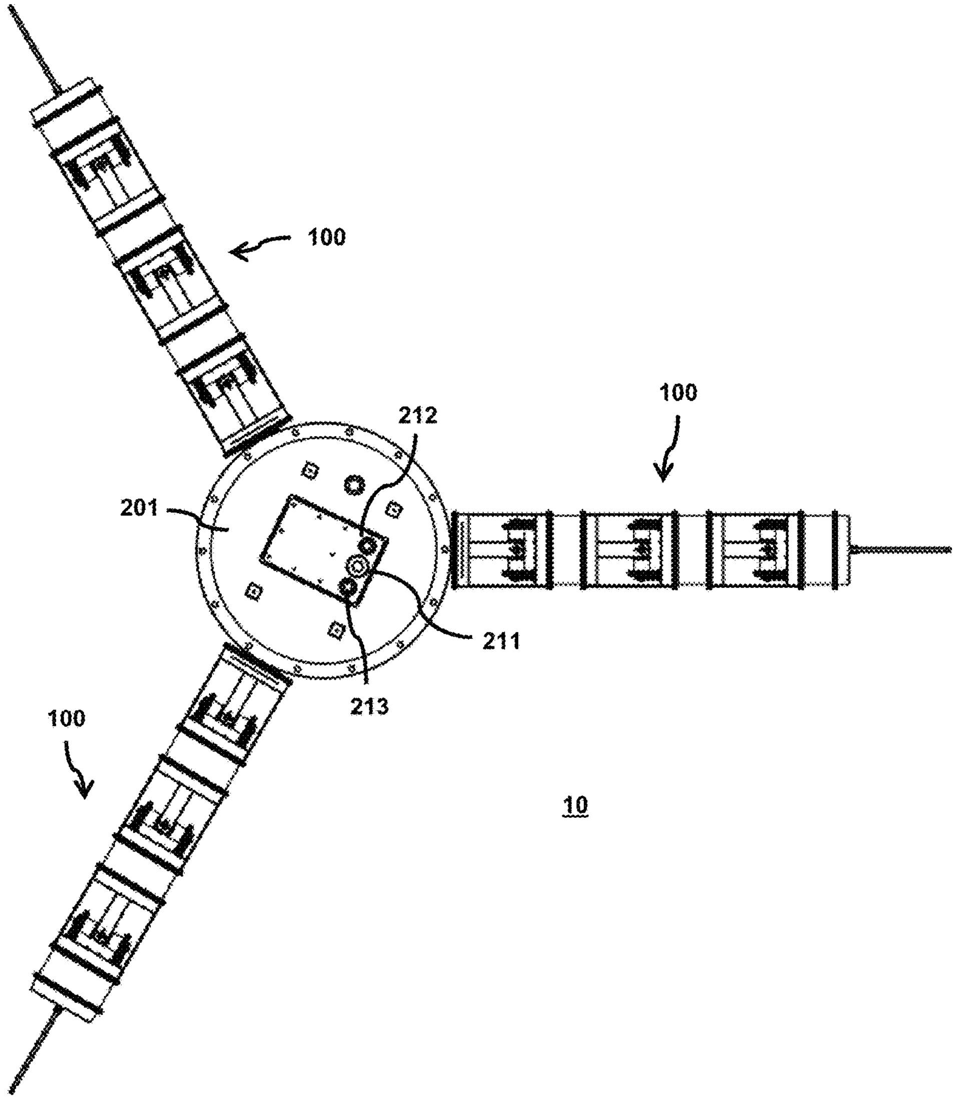
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FIG. 4

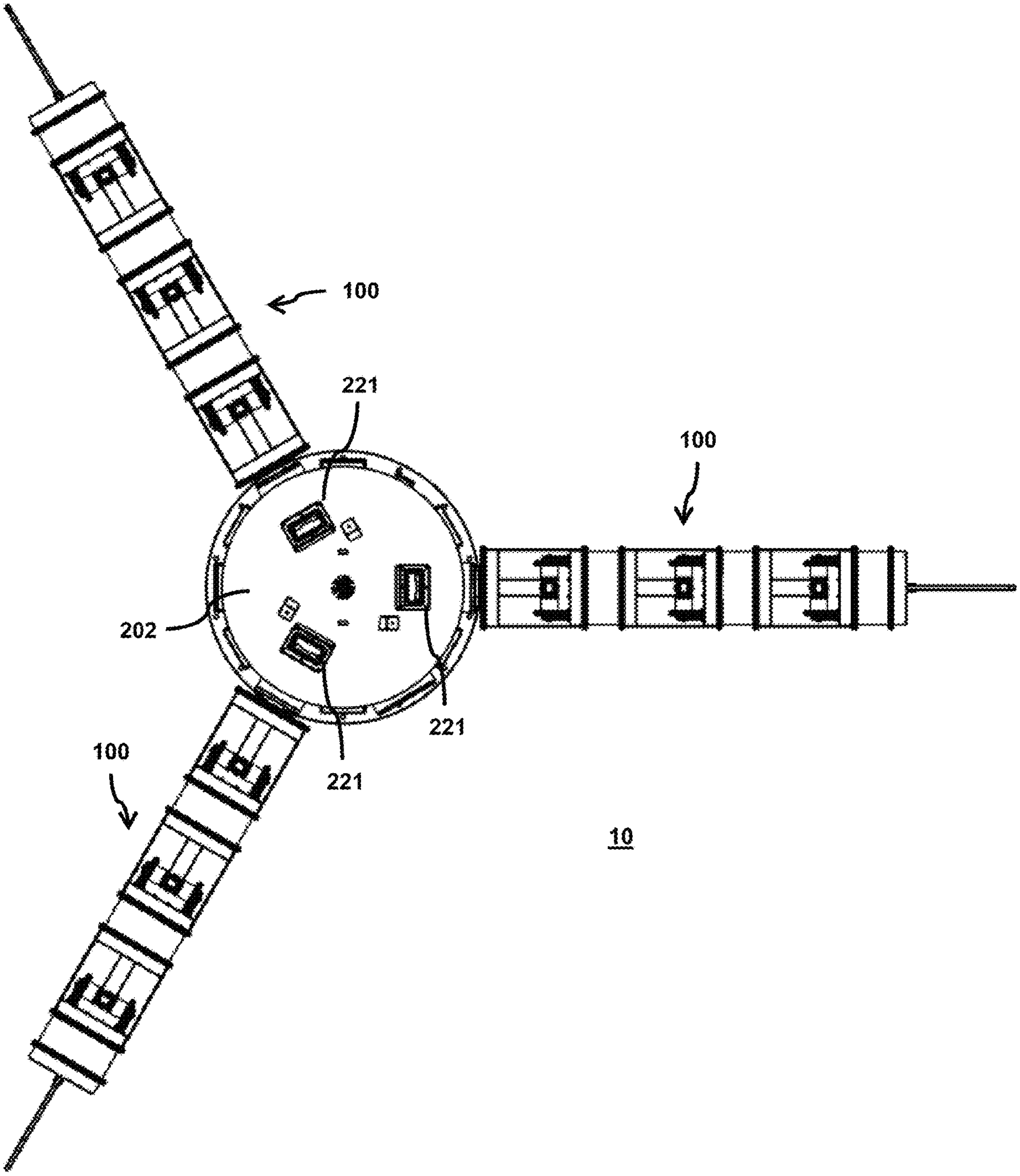

FIG. 5

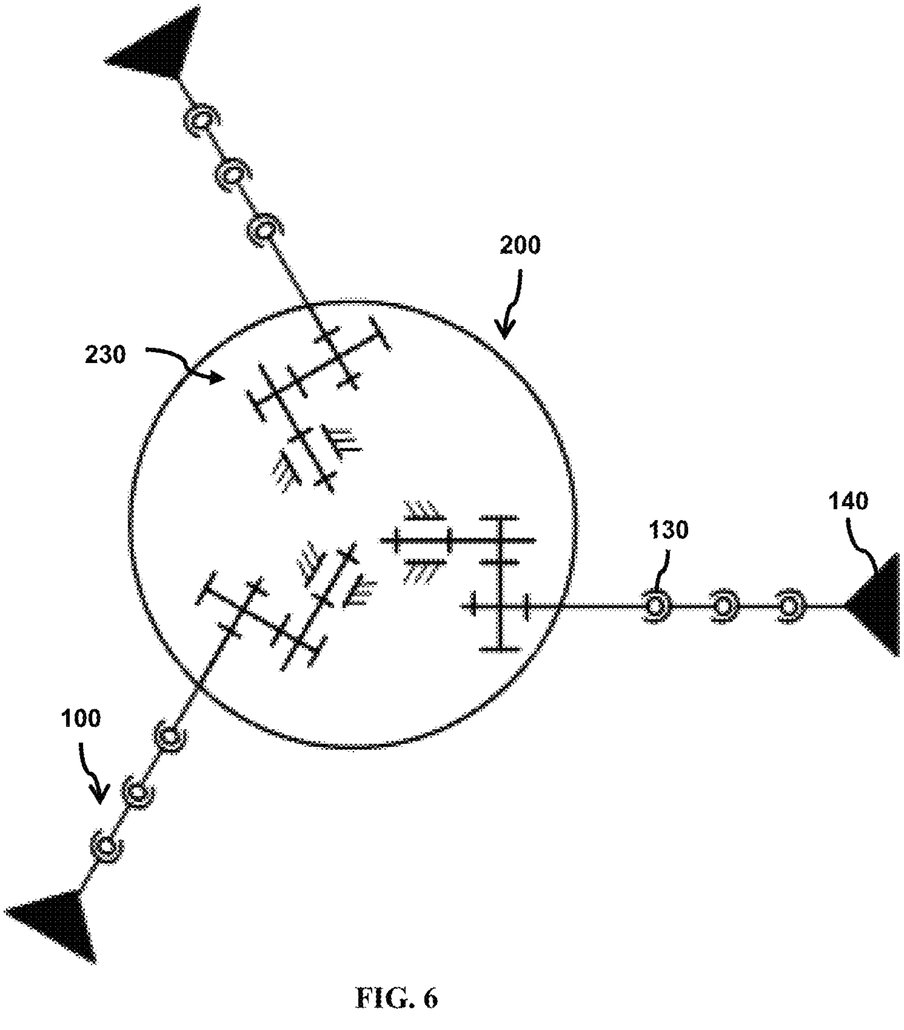

FIG. 6

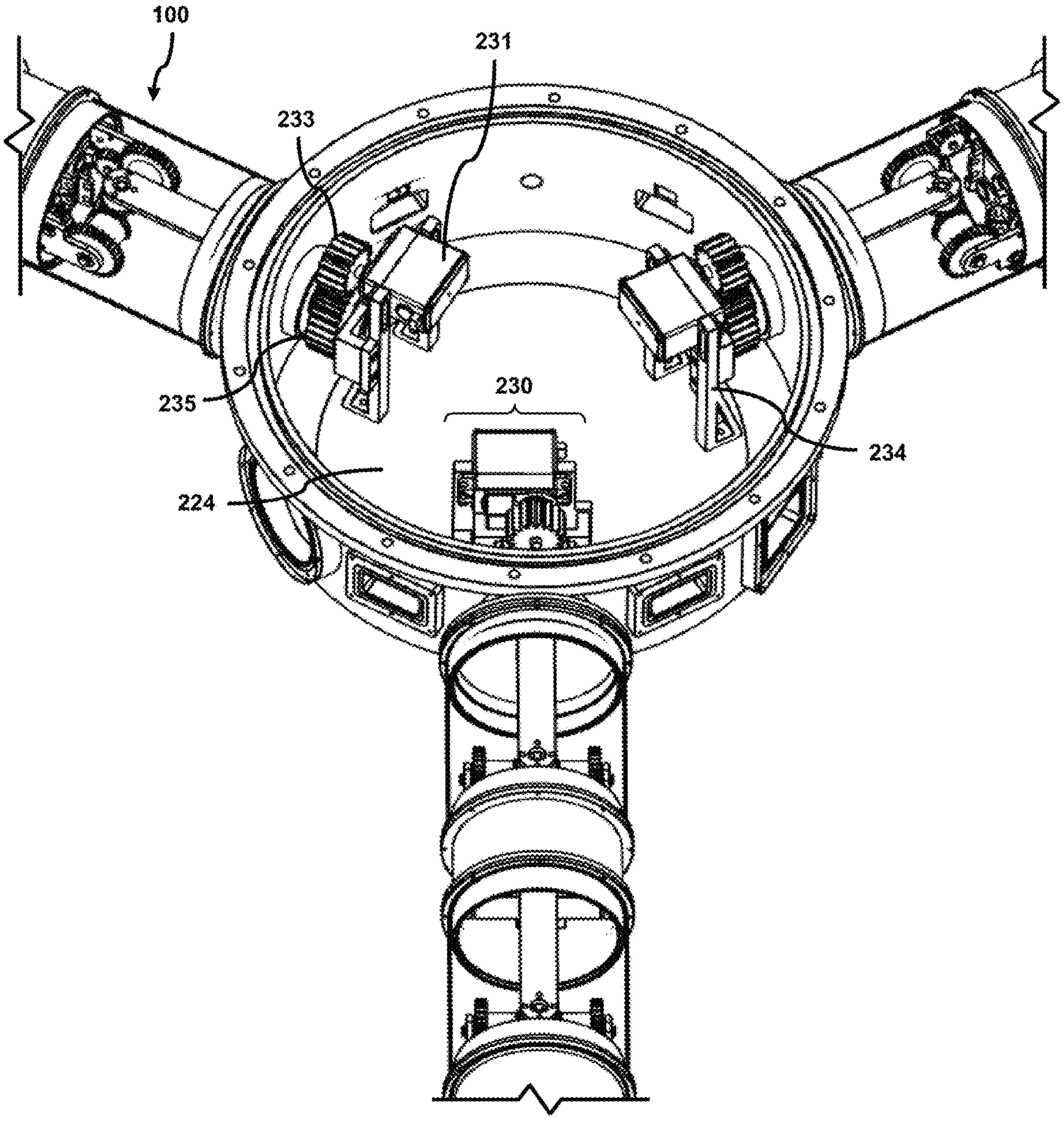

FIG. 7

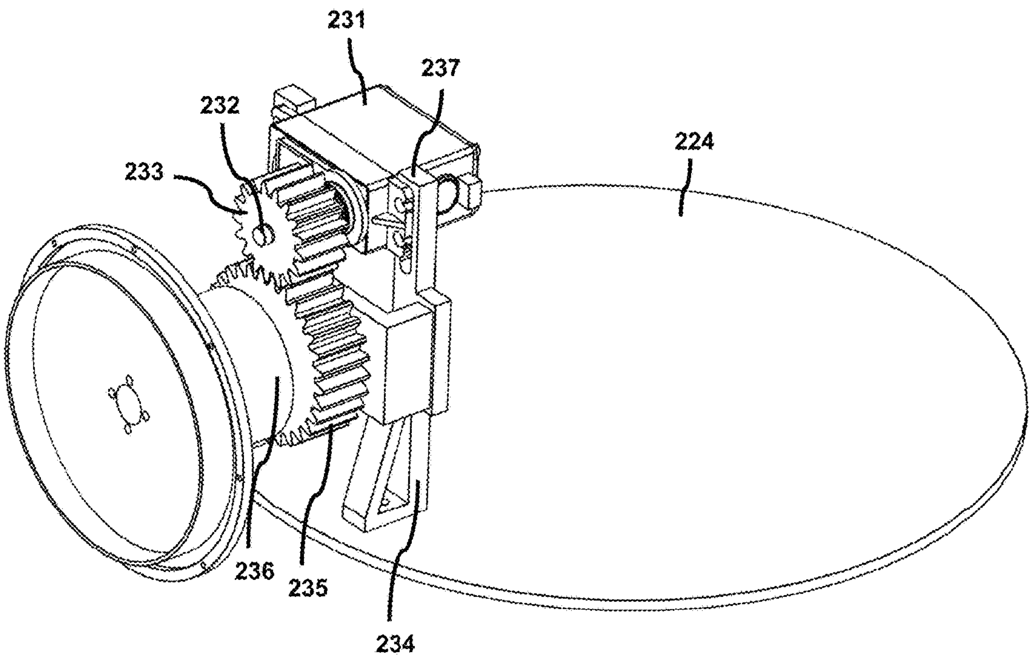
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FIG. 8

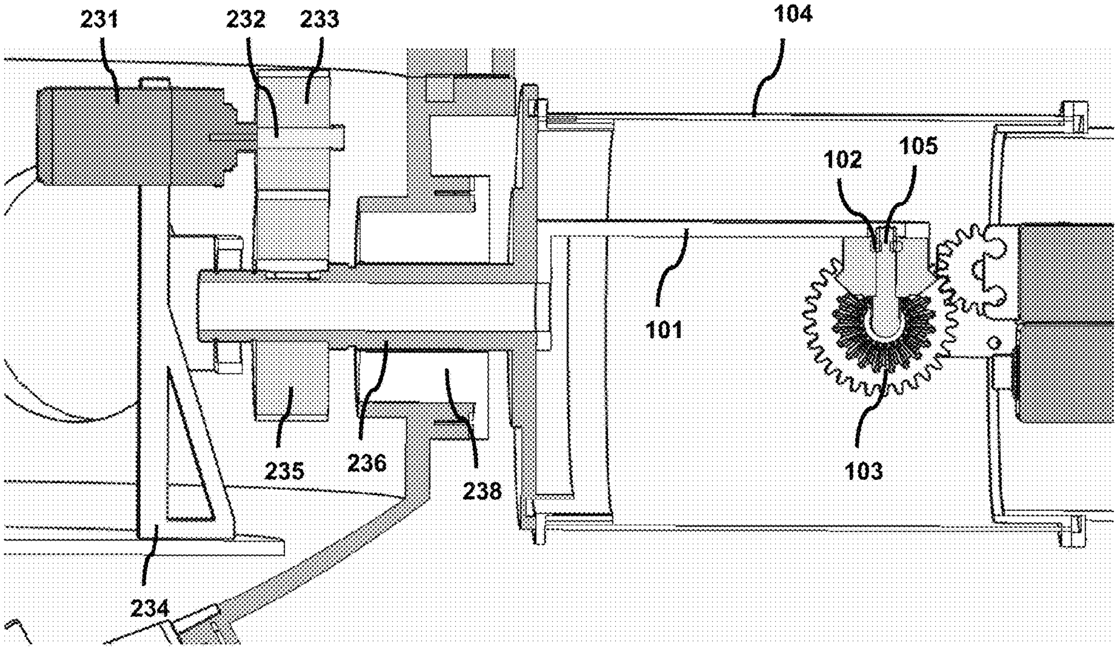
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FIG. 9

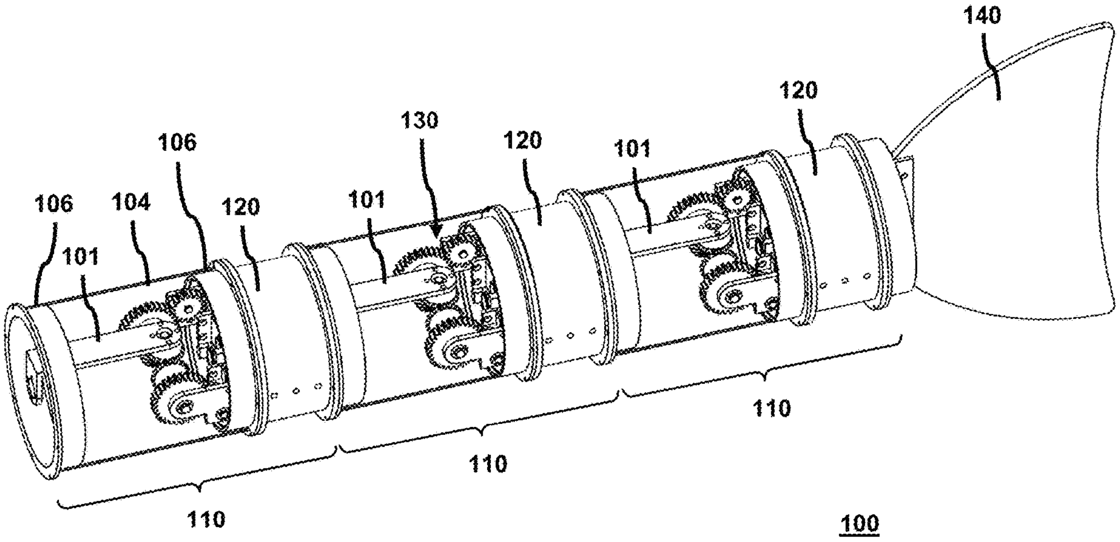

FIG. 10A

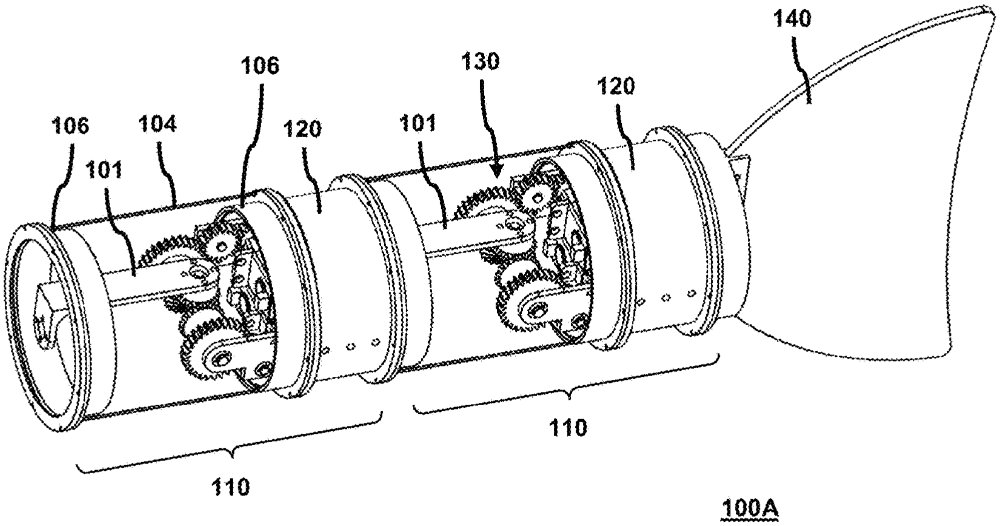

FIG. 10B

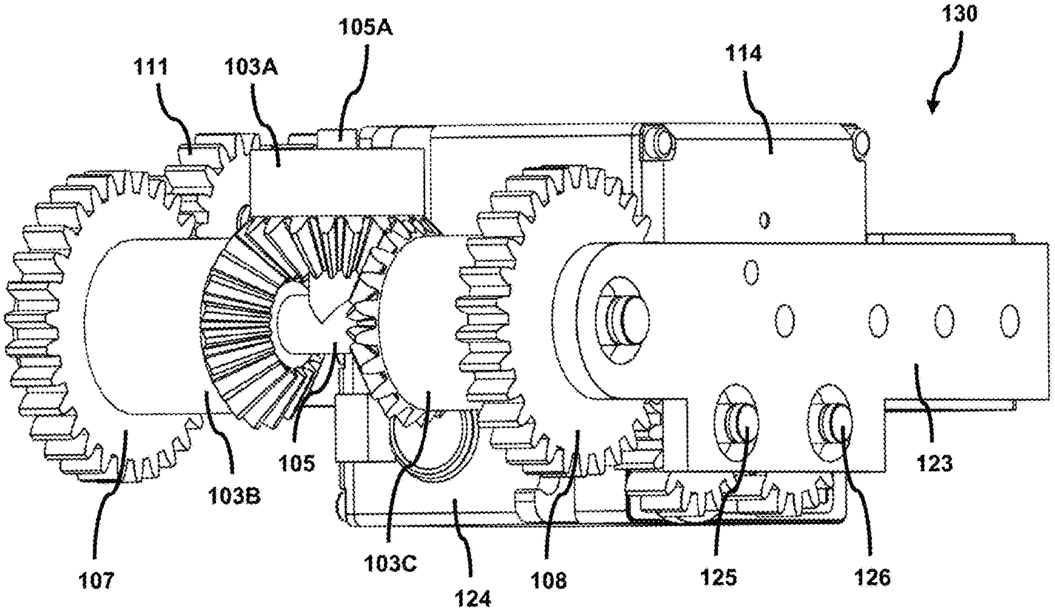
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FIG. 11

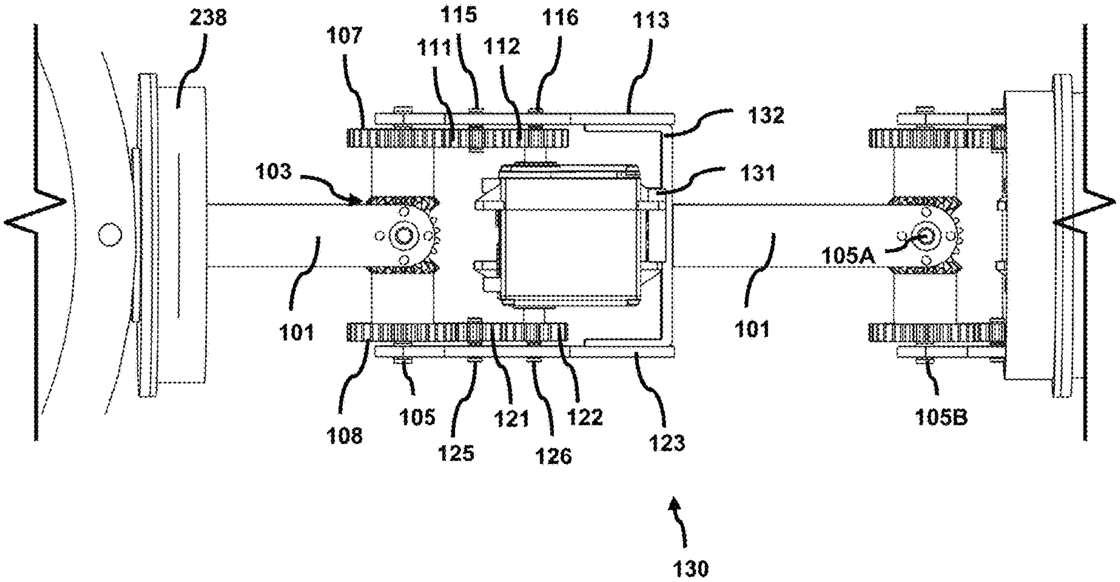
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FIG. 12

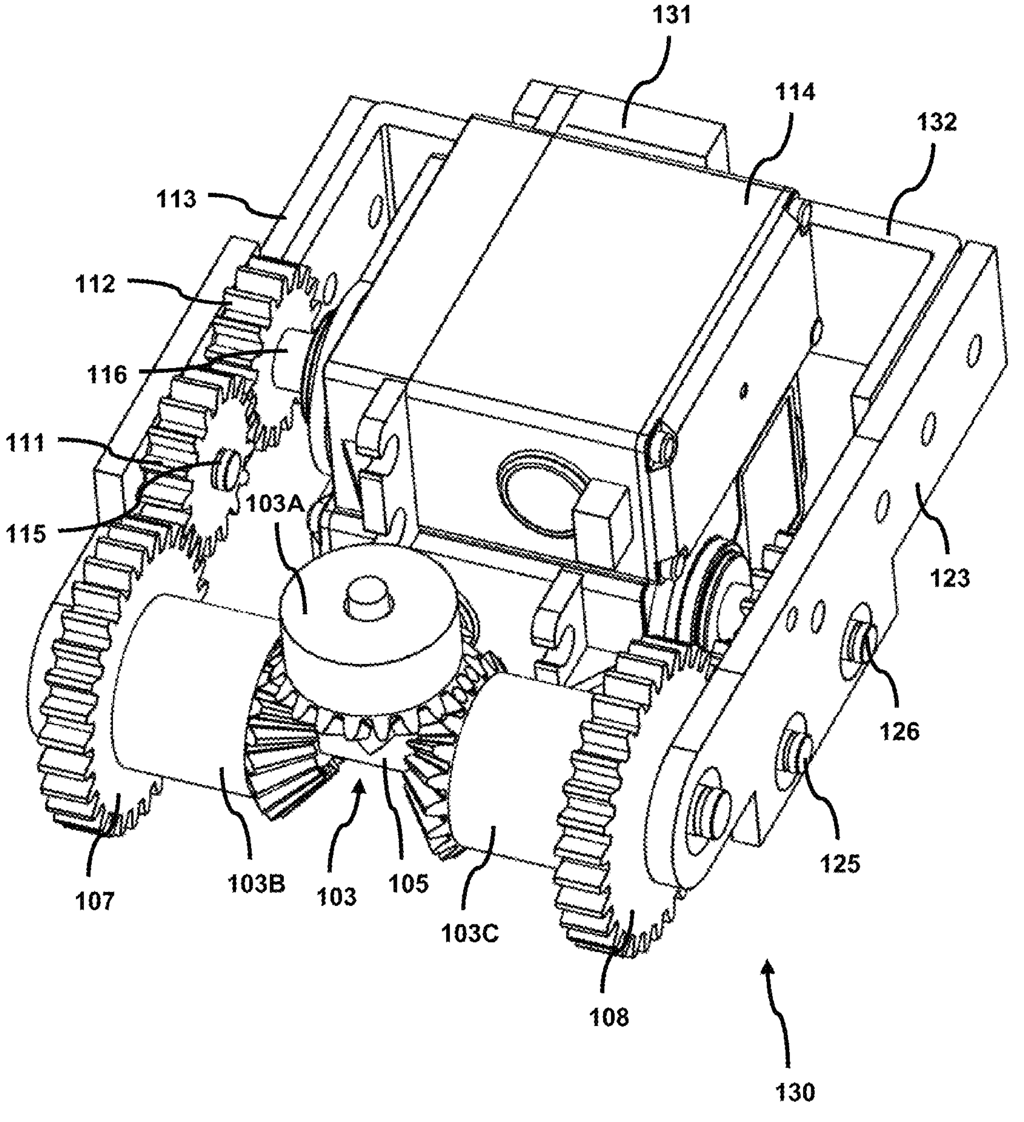
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FIG. 13

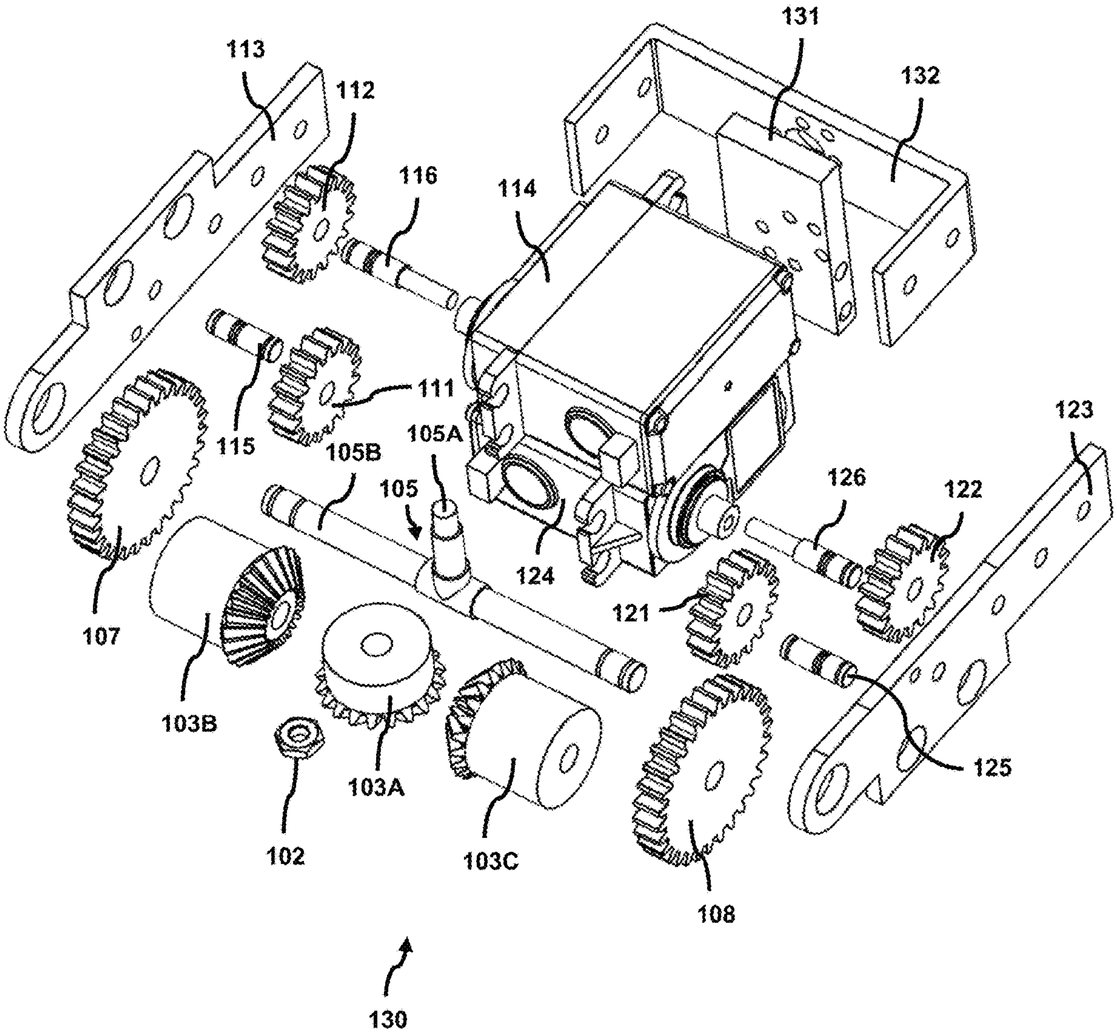
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FIG. 14

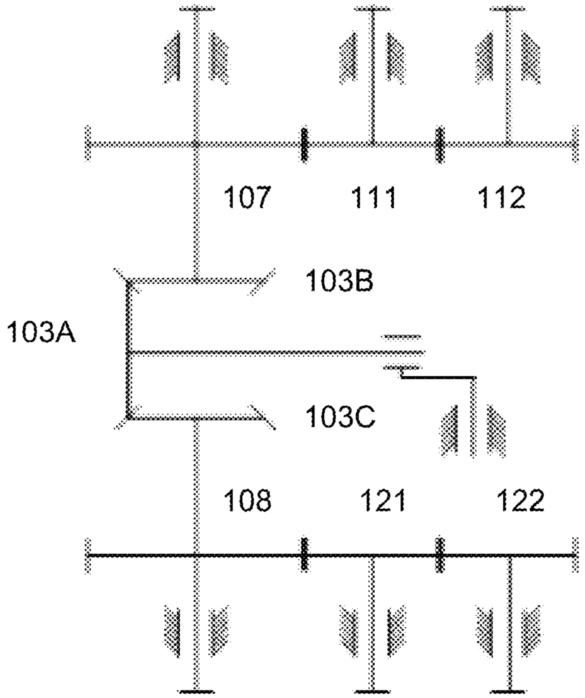


FIG. 15A

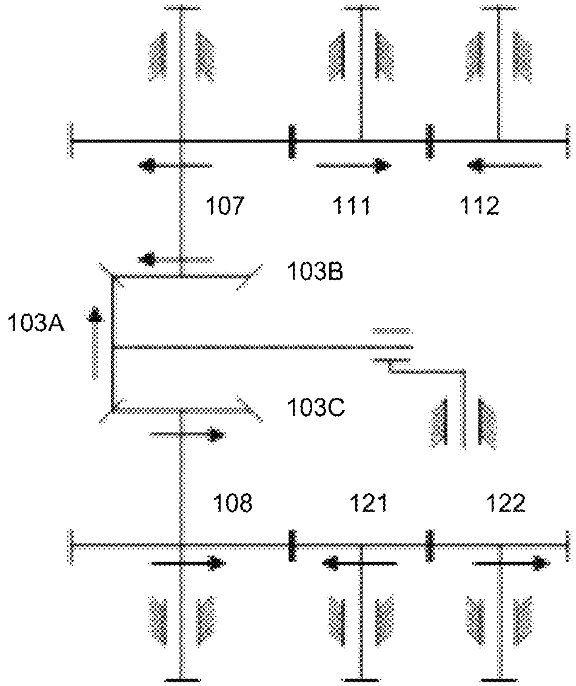


FIG. 15B

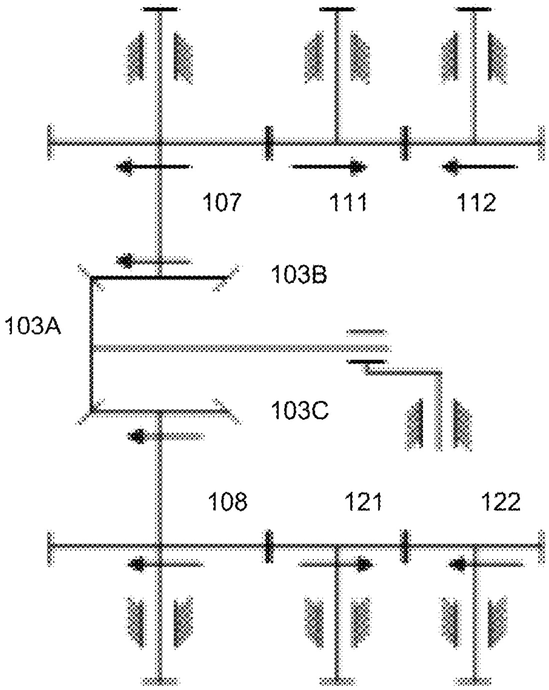


FIG. 15C

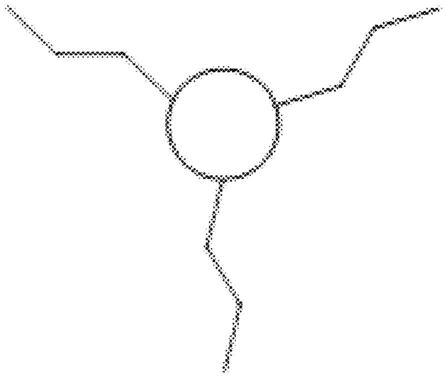


FIG. 16A

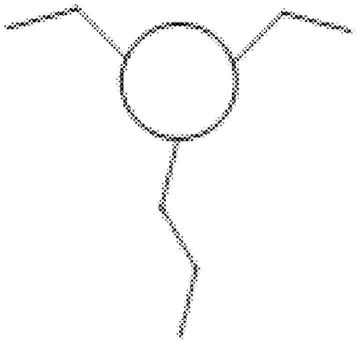
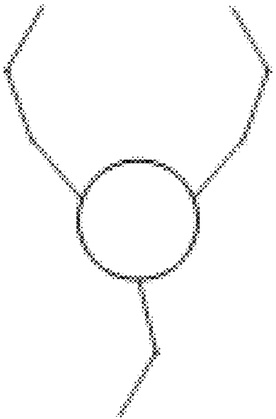


FIG. 16B



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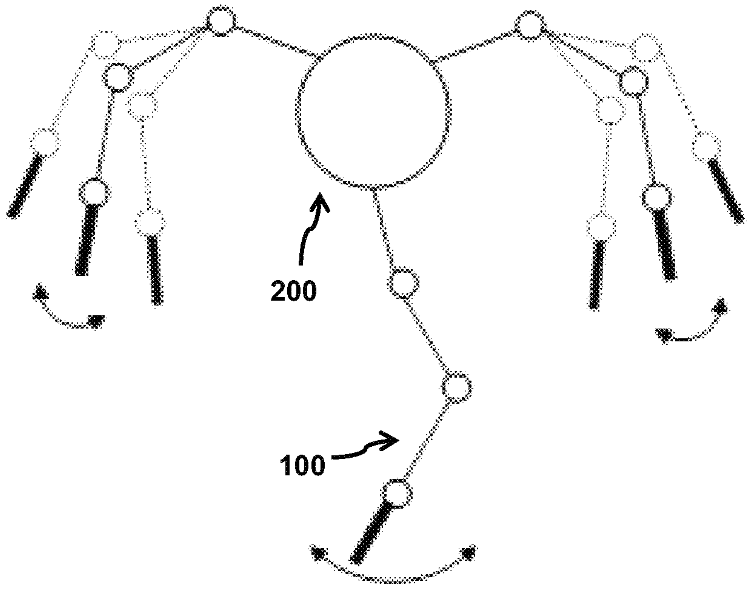

FIG. 17

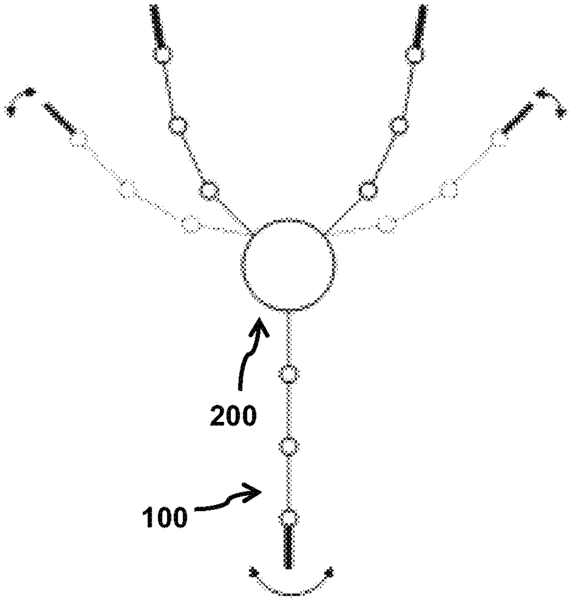

FIG. 18

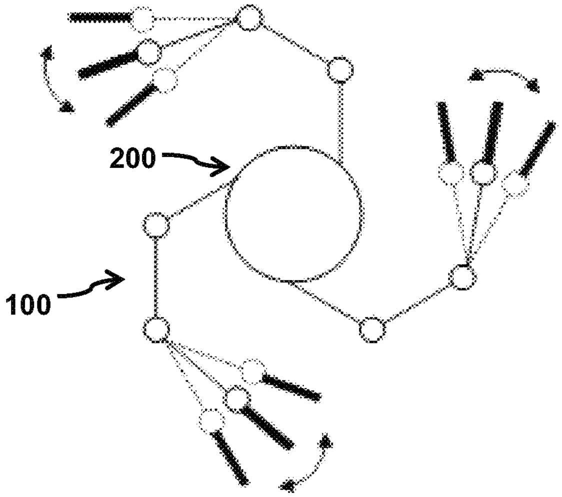

FIG. 19

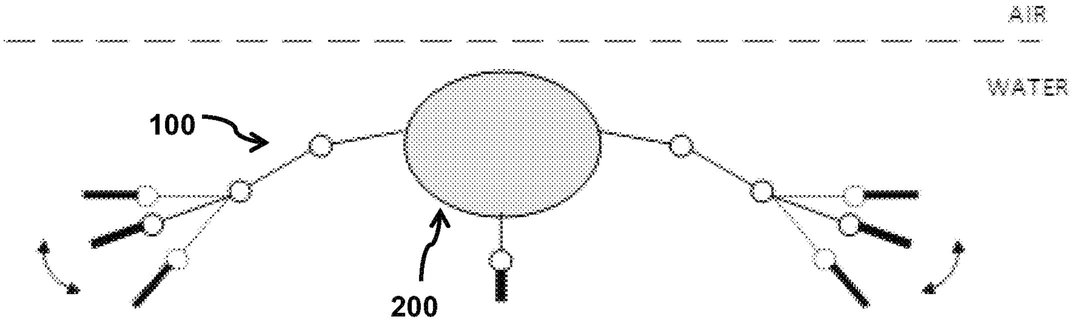

FIG. 20

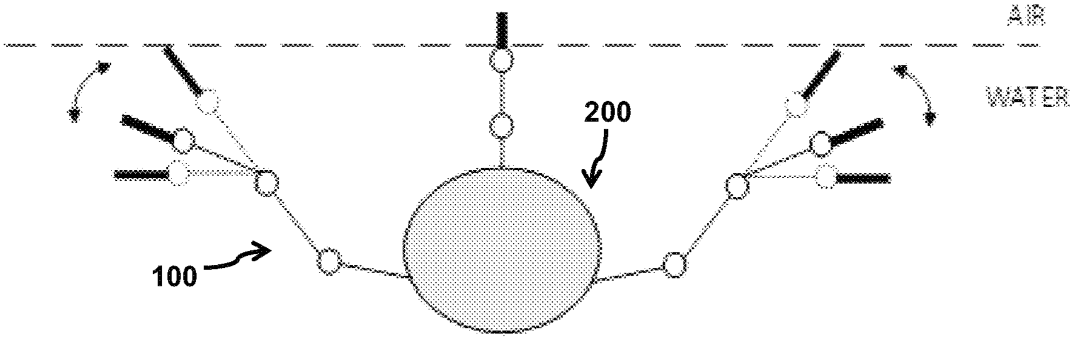

FIG. 21

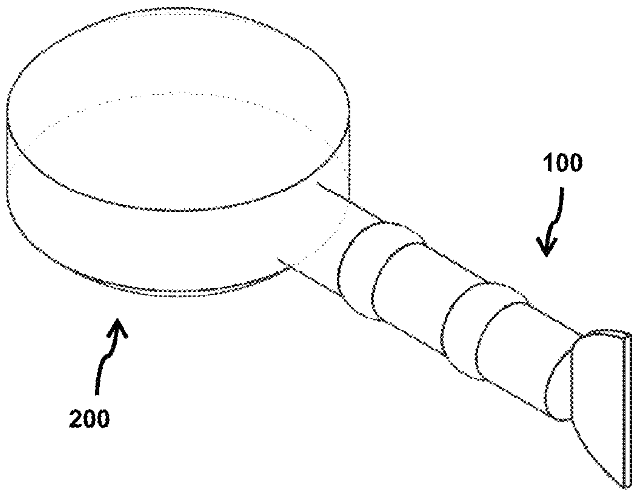

FIG. 22

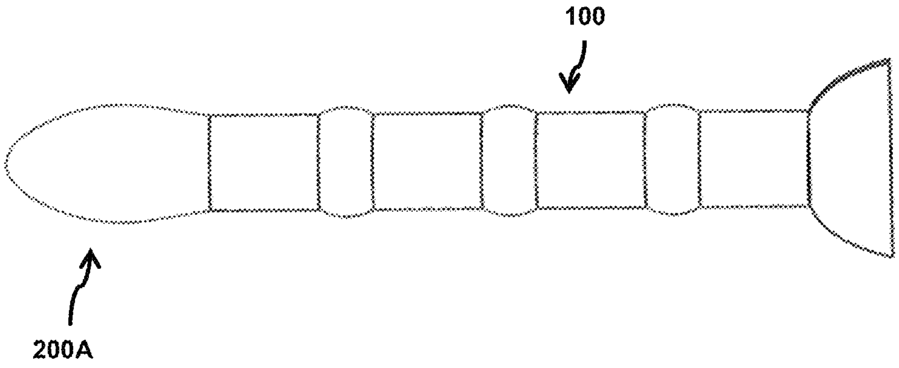

FIG. 23

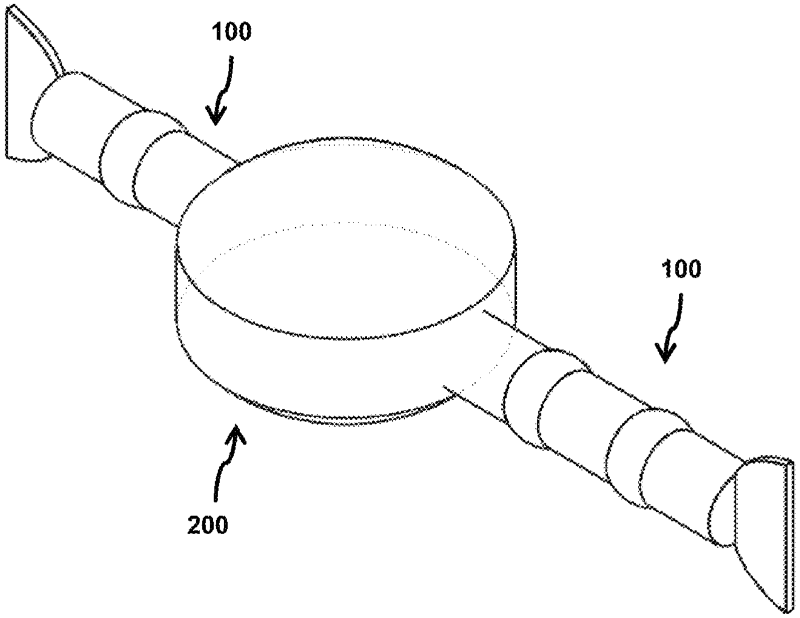

FIG. 24

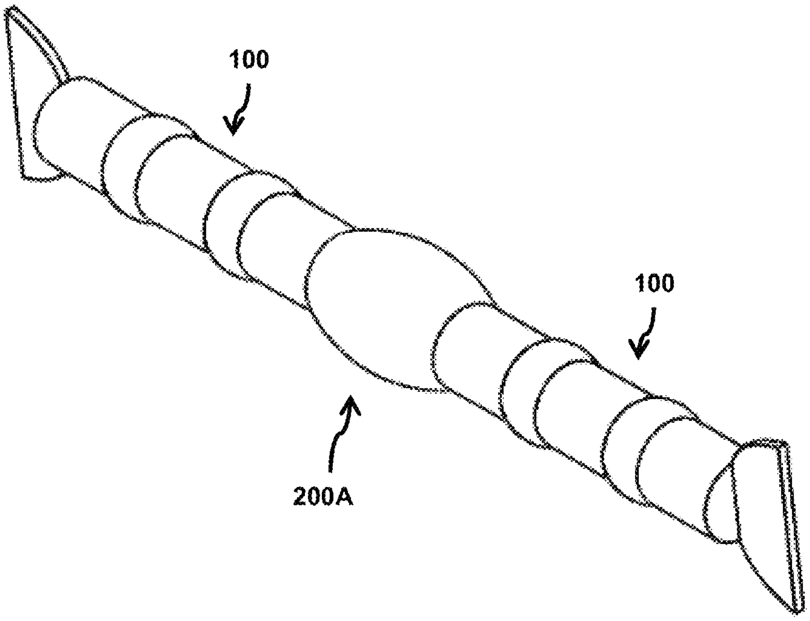

FIG. 25

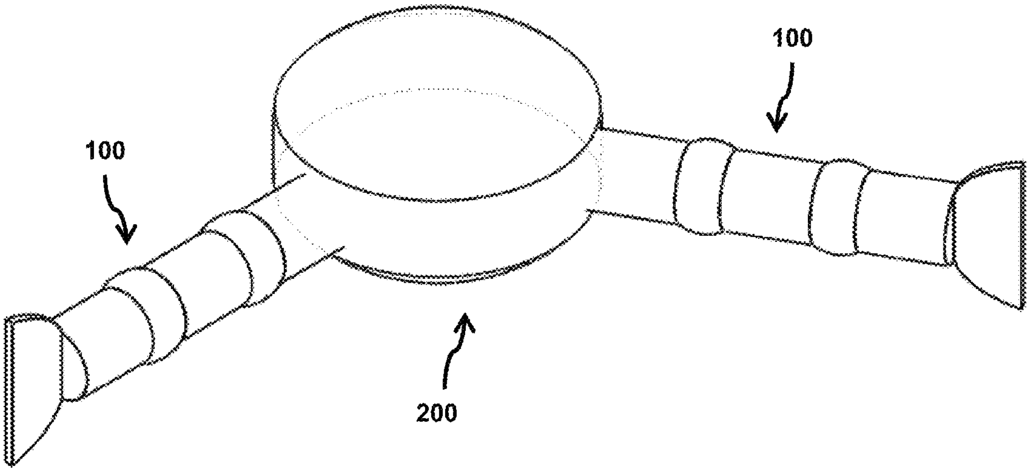

FIG. 26

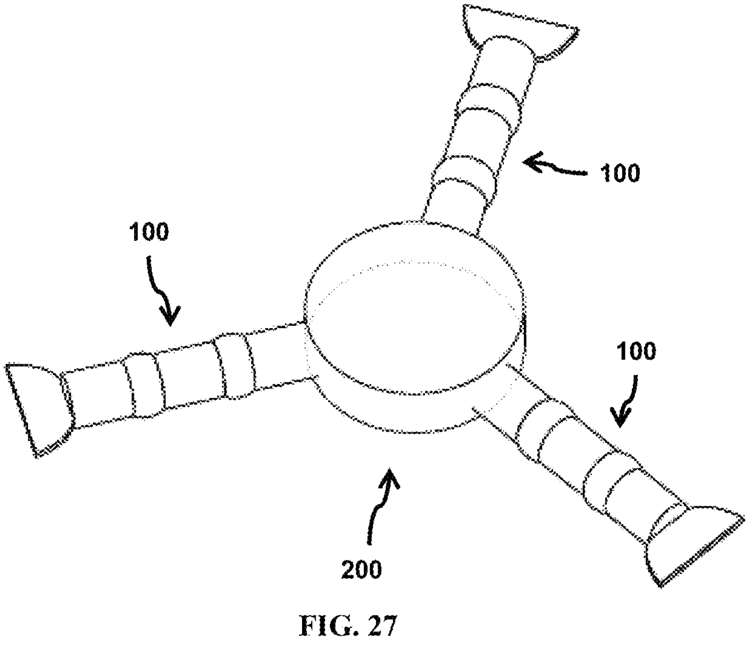

FIG. 27

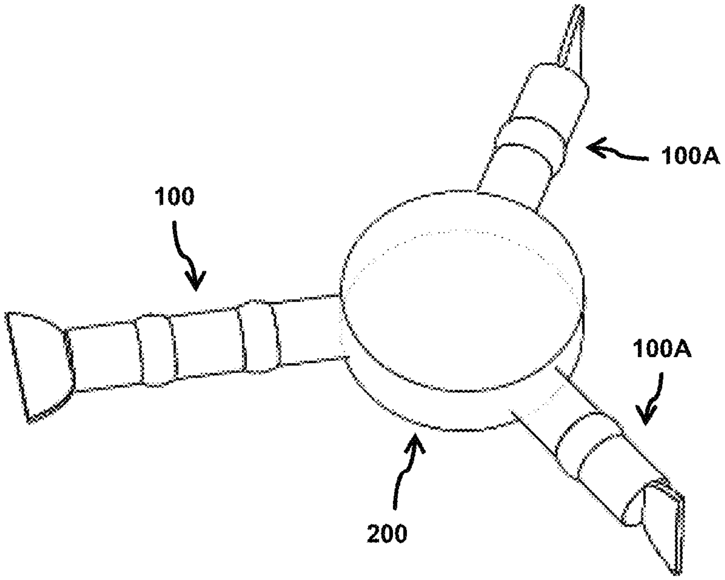

FIG. 28

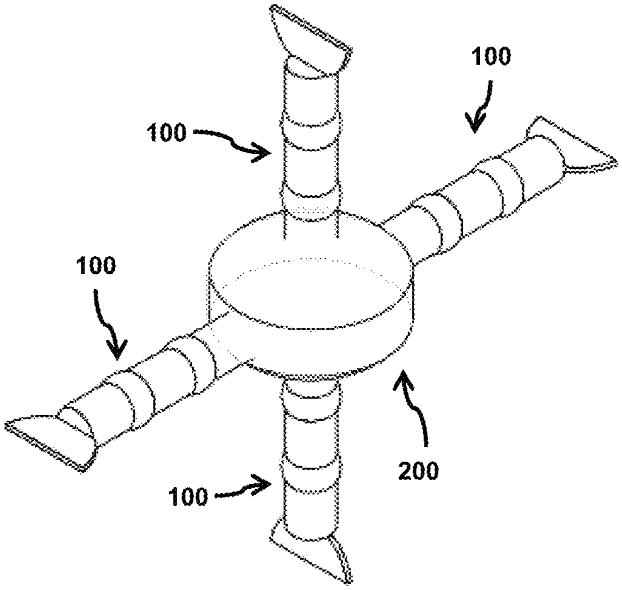

FIG. 29

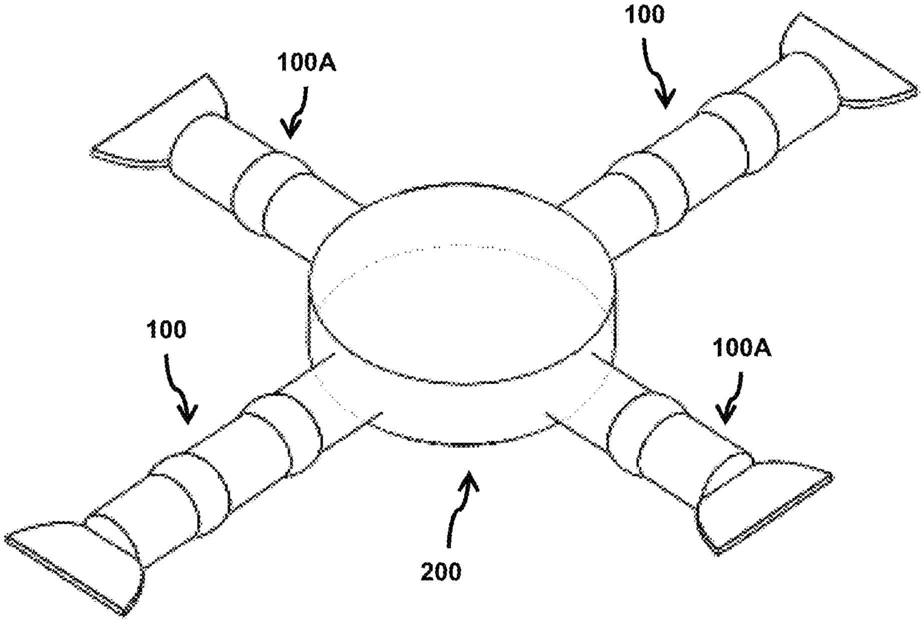

FIG. 30

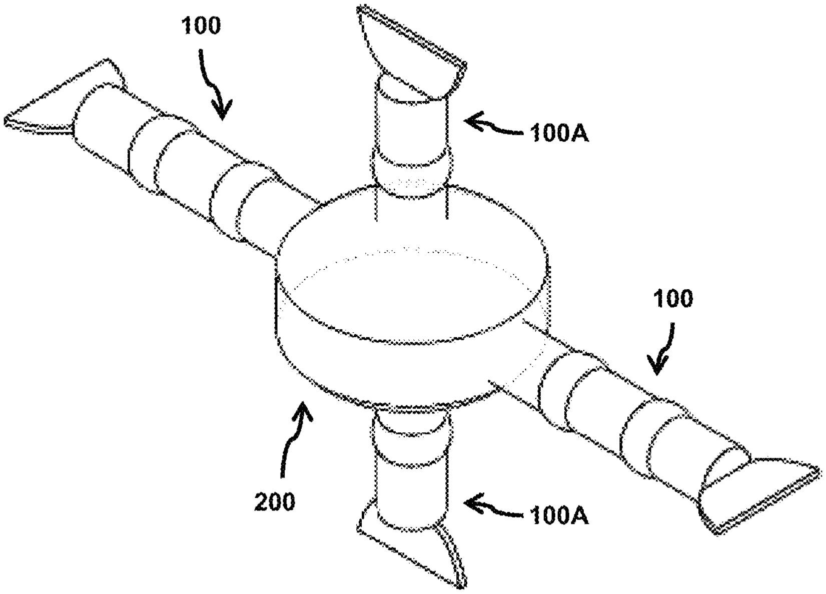

FIG. 31

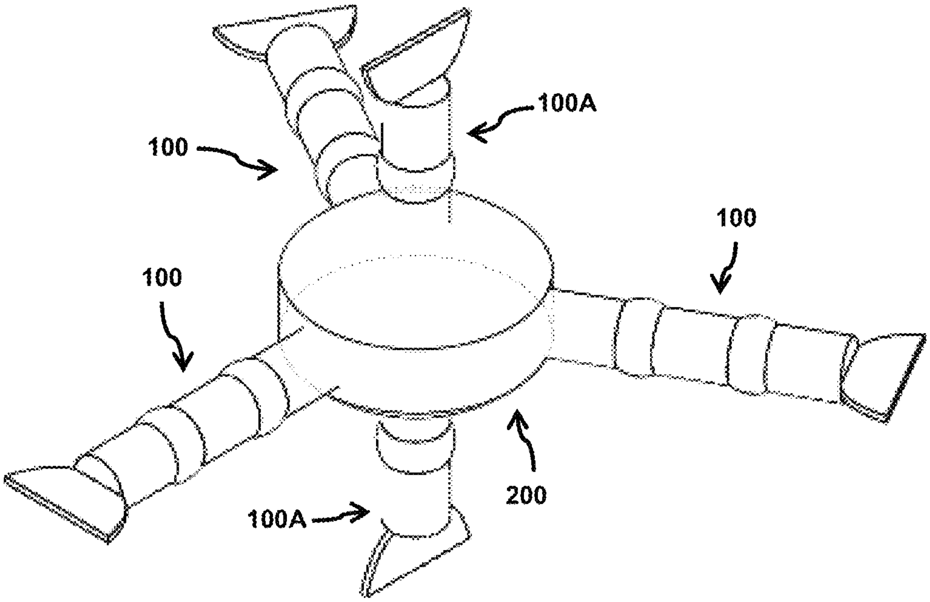

FIG. 32

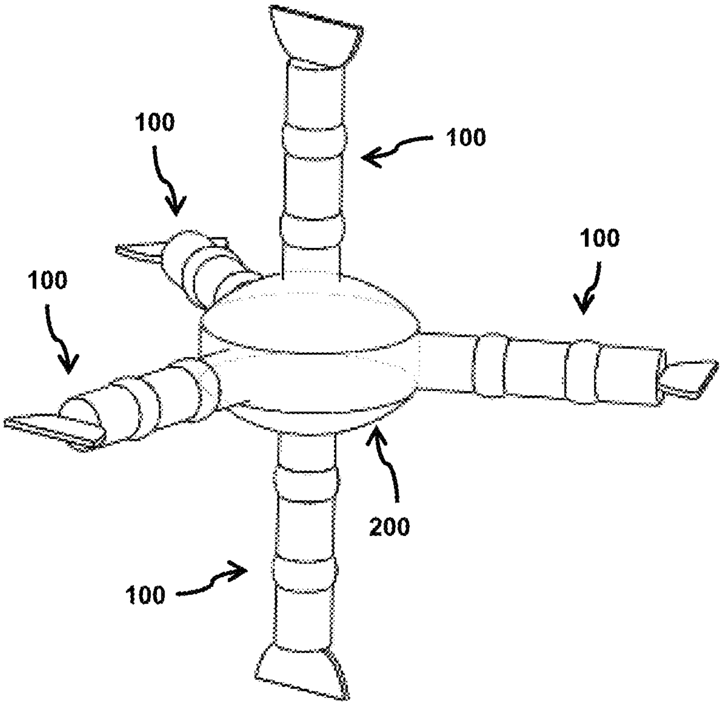

FIG. 33

BIO-INSPIRED UNDERWATER ROBOT

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Patent Application No. 62/825,918, filed on Mar. 29, 2019, which is incorporated by reference herein in its entirety.

FIELD OF THE INVENTION

The present disclosure generally relates to the field of bionic underwater robot, and particularly relates to a bio-inspired underwater robot for achieving a variety of motions with better stability, mobility, agility, and loading capability in a diverse water flow environment.

BACKGROUND OF THE INVENTION

In the field of underwater vehicles, bio-inspired underwater robots are the ongoing research trend and development. The underwater device can be used in applications such as underwater inspection, surveillance, maintenance, repair, and marine life observation. However, the conventional underwater devices are generally bulky and noisy. The acoustic noise of the rotating propellers may disturb the marine environment and adversely affect the effectiveness of the inspection and observation activities.

At present, there are a few bionic underwater robots or drones proposed. Such underwater robots may mimic the natural movements of a variety of marine life, for example, cuttlefish, tuna, dolphin, snake, turtle, shark, manta ray, etc. However, in view of the size and structure, the existing bio-inspired underwater robots cannot maintain a stable and smooth movement above or under the water when there is a variable flow of water. The ability to carrying monitoring equipment or other bulky devices is also in doubt. Furthermore, the underwater robots may only be propelled by a tin or tail of a simple structure. There is usually only one movement mode, and the movement direction is limited to be within a small angle or in accordance with a particular manner.

Accordingly, there is a need in the art to have an improved bio-inspired underwater robot for achieving omnidirectional movement under the sea with stable movement in a variable water flow environment. Furthermore, other desirable features and characteristics will become apparent from the subsequent detailed description and the appended claims, taken in conjunction with the accompanying drawings and this background of the disclosure.

SUMMARY OF THE INVENTION

Provided herein is a bionic underwater robot. It is an objective of the present disclosure to provide a bionic underwater robot that can achieve a variety of motions with better stability, mobility, agility, and loading capability in a diverse water flow environment.

In accordance with certain embodiments of the present disclosure, a bionic robot for underwater use is provided. The bionic robot comprises a head and one or more tail structures. Each of the one or more tail structures comprises one or more joint structures. Each of the one or more joint structures comprises a connection plate, and a modular assembly motorized for performing various movement

motions of the joint structure. The modular assembly comprises an upper servo motor, a lower servo motor, and a bevel gear mechanism.

In accordance with a further aspect of the present disclosure, the bevel gear mechanism is integrally formed by an intermediate bevel gear, a first bevel gear, and a second bevel gear. The upper servo motor drives the first bevel gear from a first side of the modular assembly. The lower servo motor drives the second bevel gear from a second side of the modular assembly.

In accordance with a further aspect of the present disclosure, the connection plate is fixedly attached to or screwed to the intermediate bevel gear for achieving a yaw motion or a pitch motion of the joint structure.

In accordance with a further aspect of the present disclosure, the upper servo motor drives an upper motor gear coupled to a first reduction gear via a first middle gear, and the lower servo motor drives a lower motor gear coupled to a second reduction gear via a second middle gear. The first reduction gear and the first bevel gear are fixed, and the second reduction gear and the second bevel gear are fixed.

Preferably, the first reduction gear has a larger number of teeth than the first middle gear, and the second reduction gear has a larger number of teeth than the second middle gear.

In accordance with a further aspect of the present disclosure, each tail structure comprises a fin structure fixed to an end plate sealed at a longitudinal distal end of the tail structure. The fin structure is a bionic fishtail with an emarginate caudal fin shape.

In accordance with a further aspect of the present disclosure, the joint structure is mechanically sealed within a silicone tube and a skeleton, thereby the modular assembly is sealed inside the joint structure. The silicone tube is tightly clamped to the skeleton using a clamp and silicone glue to prevent water seepage.

In accordance with a further aspect of the present disclosure, the head comprises one or more tail drive assemblies for controlling movement of the one or more tail structure. The tail drive assembly comprises a head servo motor, a motor pinion, a spur gear, a motor shaft, and a rotary shaft, wherein the motor shaft is fixed to the motor pinion for driving the spur gear and the rotary shaft.

Preferably, the motor pinion has a smaller number of teeth than the spur gear for reducing the rotational speed of the rotary shaft.

Preferably, the rotary shaft is connected to the tail structure for driving the tail structure with a good sealing effect from an external water environment.

In accordance with a further aspect of the present disclosure, the head comprises three sealed connectors for connecting to an underwater acoustic transceiver or other accessory devices, wherein the underwater acoustic transceiver is configured to communicate based on an underwater acoustic network (UAN).

In accordance with a further aspect of the present disclosure, the head comprises a plurality of infrared sensors.

In accordance with a further aspect of the present disclosure, the head comprises one or more pressure sensors.

In accordance with a further aspect of the present disclosure, the modular assembly is cable driven, or hydraulic driven.

This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter. Other aspects and advantages of the present invention are disclosed as illustrated by the embodiments hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

The appended drawings contain figures to further illustrate and clarify the above and other aspects, advantages, and features of the present disclosure. It will be appreciated that these drawings depict only certain embodiments of the present disclosure and are not intended to limit its scope. It will also be appreciated that these drawings are illustrated for simplicity and clarity and have not necessarily been depicted to scale. The present disclosure will now be described and explained with additional specificity and detail through the use of the accompanying drawings in which:

FIG. **1** shows a perspective view of a bionic robot in accordance with certain embodiments of the present disclosure;

FIG. **2** shows a front view of the bionic robot of FIG. **1**;

FIG. **3** shows a side view of the bionic robot of FIG. **1**;

FIG. **4** shows a top view of the bionic robot of FIG. **1**;

FIG. **5** shows a bottom view of the bionic robot of FIG. **1**;

FIG. **6** shows a simplified schematic diagram of the bionic robot in accordance with certain embodiments of the present disclosure;

FIG. **7** shows an internal view of the head of the bionic robot of FIG. **1**;

FIG. **8** shows a perspective view of a tail drive assembly in accordance with certain embodiments of the present disclosure;

FIG. **9** shows a cross-sectional view of the tail drive assembly connecting to a tail structure in accordance with certain embodiments of the present disclosure;

FIG. **10**A shows a perspective view of a tail structure in a first configuration in accordance with certain embodiments of the present disclosure;

FIG. **10**B shows a perspective view of a tail structure in a second configuration in accordance with certain embodiments of the present disclosure;

FIG. **11** shows a front left side view of a modular assembly in accordance with certain embodiments of the present disclosure;

FIG. **12** shows a top view of the modular assembly in a tail structure in accordance with certain embodiments of the present disclosure;

FIG. **13** shows a perspective view of the modular assembly of FIG. **11**;

FIG. **14** shows an exploded view of the modular assembly of FIG. **11**;

FIG. **15**A shows a gear schematic of the modular assembly of FIG. **11**;

FIG. **15**B shows a gear schematic of the modular assembly of FIG. **11** during a yaw motion;

FIG. **15**C shows a gear schematic of the modular assembly of FIG. **11** during a pitch motion;

FIG. **16**A shows a simplified conceptual drawing of the bionic robot in a first configuration;

FIG. **16**B shows a simplified conceptual drawing of the bionic robot in a second configuration;

FIG. **16**C shows a simplified conceptual drawing of the bionic robot in a third configuration;

FIG. **17** shows a simplified conceptual drawing of the bionic robot of FIG. **16**A in a forward motion;

FIG. **18** shows a simplified conceptual drawing of the bionic robot of FIG. **16**A in a 2-tail forward motion;

FIG. **19** shows a simplified conceptual drawing of the bionic robot of FIG. **16**A in an in-situ rotation with zero turning radius motion;

FIG. **20** shows a simplified conceptual drawing of the bionic robot of FIG. **16**A in a floating upward motion;

FIG. **21** shows a simplified conceptual drawing of the bionic robot of FIG. **16**A in a diving downward motion;

FIG. **22** is a simplified conceptual drawing of the bionic robot with one tail structure in accordance with certain embodiments of the present disclosure;

FIG. **23** is a simplified conceptual drawing of the bionic robot with one tail structure and a small head in accordance with certain embodiments of the present disclosure;

FIG. **24** is a simplified conceptual drawing of the bionic robot with two tail structures in accordance with certain embodiments of the present disclosure;

FIG. **25** is a simplified conceptual drawing of the bionic robot with two tail structures and a small head in accordance with certain embodiments of the present disclosure;

FIG. **26** is a simplified conceptual drawing of another bionic robot with two tail structure in accordance with certain embodiments of the present disclosure;

FIG. **27** is a simplified conceptual drawing of the bionic robot with three tail structures in accordance with certain embodiments of the present disclosure;

FIG. **28** is a simplified conceptual drawing of another bionic robot with three tail structures in accordance with certain embodiments of the present disclosure;

FIG. **29** is a simplified conceptual drawing of the bionic robot with four tail structures in accordance with certain embodiments of the present disclosure;

FIG. **30** is a simplified conceptual drawing of another bionic robot with four tail structures in accordance with certain embodiments of the present disclosure;

FIG. **31** is a simplified conceptual drawing of yet another bionic robot with four tail structures in accordance with certain embodiments of the present disclosure;

FIG. **32** is a simplified conceptual drawing of the bionic robot with five tail structures in accordance with certain embodiments of the present disclosure; and

FIG. **33** is a simplified conceptual drawing of another bionic robot with five tail structures in accordance with certain embodiments of the present disclosure.

Skilled artisans will appreciate that elements in the figures are illustrated for simplicity and clarity and have not necessarily been depicted to scale.

DETAILED DESCRIPTION OF THE INVENTION

The present disclosure generally relates to the structure of a bionic underwater robot. More specifically, but without limitation, the present disclosure provides a bio-inspired underwater robot for achieving a variety of motions with better stability, mobility, agility, and loading capability in a diverse water flow environment.

The following detailed description is merely exemplary in nature and is not intended to limit the disclosure or its application and/or uses. It should be appreciated that a vast number of variations exist. The detailed description will enable those of ordinary skilled in the art to implement an exemplary embodiment of the present disclosure without undue experimentation, and it is understood that various changes or modifications may be made in the function and structure described in the exemplary embodiment without departing from the scope of the present disclosure as set forth in the appended claims.

The benefits, advantages, solutions to problems, and any element(s) that may cause any benefit, advantage, or solution to occur or become more pronounced are not to be construed as a critical, required, or essential features or elements of any or all of the claims. The invention is defined solely by the appended claims including any amendments made during the pendency of this application and all equivalents of those claims as issued.

Terms such as “upper”, “lower”, “inner”, “outer”, “front”, “rear”, “top”, “bottom”, and any variations thereof are used for ease of description to explain the positioning of an element, or the positioning of one element relative to another element, and are not intended to be limiting to a specific orientation or position. Terms such as “first”, “second”, and the like are used herein to describe various elements, components, regions, sections, etc., and are not intended to be limiting.

When introducing elements of the present disclosure or the preferred embodiments thereof, the articles “a”, “an”, and “the” are not intended to denote a limitation of quantity, but rather to denote the presence of at least one of the items being referred to, unless otherwise indicated or clearly contradicted by context. Further, the terms “comprise”, “comprising”, “including”, and “having” are intended to be inclusive and mean that there may be additional elements other than the listed elements.

A bionic robot **10** assembled with three tail structures **100** is shown in FIG. **1**. The bionic robot **10** comprises a head **200** and one or more tail structures **100**. The head **200** is preferably in the shape of an oblate spheroid, but it is apparent that the head **200** may also be in the shape of a cube, cuboid, prism, circular cone, circular truncated cone, pyramid, multi-sided pyramid, cylinder, elliptical cylinder, or any combinations thereof without departing from the scope and spirit of the present disclosure. In FIGS. **1**-**7** and **16**A-**21**, a bionic robot **10** having three tail structures **100** is used in the drawings, and it is appreciated that such tail structure **100** configuration as shown in FIGS. **1**-**7** and **16**A-**21** is provided solely for the purpose of illustrating a preferred embodiment of the present invention and not for the purpose of limiting the same, and that the bionic robot **10** may take other suitable configurations. In certain embodiments, the bionic robot **10** may have one, two, three, four, five, or more tail structures **100**, wherein each tail structure **100** may have one, two, three, four, or more joint structures **110**. The configuration on the number of tail structures **100** and the number of joint structures **110** is based on the required underwater task and the respective underwater condition. Each tail structure **100** of the bionic robot **10** may have a different number of joint structures **110**. When using in an open sea or rough water conditions, the number of tail structures **100** can be increased to provide better stability, mobility, agility, and loading capability.

As shown in FIGS. **2**-**5**, the head **200** includes a generally vertical circular wall **203**, concentrically mounted to or otherwise welded to a generally half dome-shaped top housing **201** and a generally half dome-shaped bottom housing **202**. On the circular wall **203**, there is provided a plurality of infrared sensors **221**, one or more pressure sensors **223**, and one or more sealed covers **222**. On the bottom housing, there is also provided a plurality of infrared sensors **221**. In the illustrated bionic robot **10**, there are six infrared sensors **221** on the circular wall **203**, and three infrared sensors **221** on the bottom housing **202**. The infrared sensors **221** are mounted on a printed circuit board configured to receive infrared signals for communication or distance measurement purposes. Preferably, the infrared sensors **221** are positioned symmetrically around the circular wall **203** and the bottom housing **202** to acquire accurate information of the underwater conditions. The pressure sensor **223** is configured to detect the submerged depth of the bionic robot **10** based on the water pressure. The data communication between the bionic robot **10** and a sub-surface device (not shown in the drawings) may be based on an UAN, and the head **200** may be connected to an underwater acoustic transceiver for acoustically communicating to and from the sub-surface device. The UAN communication may include at least a command signal, a data signal, or any combinations thereof. Alternatively, the data communication may be performed through a wired network or other wireless signal networks.

The top housing **201**, as shown in FIG. **4**, includes three sealed connectors **211**-**213**, which may be connected to the underwater acoustic transceiver. In other embodiments, one or more of the three sealed connectors **211**-**213** may be connected to other accessory devices. For example, the head **200** may be connected to measurement equipment, video recorder, robotic gripper, or other accessory devices. The accessory device can rest on the top housing **201** to achieve superior loading capability. In certain embodiments, counterweights (not shown in drawings) are added inside the head **200** to ensure that the bionic robot **10** has the ability to dive with sufficient stability. Electrical power can be supplied to the bionic robot **10**, which can be supplied from a battery placed inside the head **200** or otherwise on the sub-surface connected with a power cable. Interconnecting wirings and cables, battery, printed circuit boards, and other electronic parts may be used and may be positioned inside the head **200**. For convenience and simplicity, the battery and the respective electronic parts have not been shown in the figures.

Each tail structure **100** is an elongated cylindrical tube comprising one or more joint structures **110** and a fin structure **140**. The fin structure **140** is a bionic fishtail with an emarginate caudal fin shape. In other embodiments, the fin structure **140** may have a truncated or rounded caudal fin shape. The fin structure **140** is fixed to an end plate **141** sealed at a longitudinal distal end of each tail structure **100**.

The joint structure **110** is mechanically sealed within a silicone tube **104** (or other rubber tubes) and a skeleton **120** to achieve waterproofing and the flexibility for performing various movement motions. The silicone tube **104** is tightly clamped to the skeleton **120** using a clamp **106** and silicone glue to prevent water seepage. A modular assembly **130** is sealed inside the joint structure **110**, which is motorized for the realization of the various movement motions of the joint structure **110**. Throughout the specification, the silicone tubes **104** are illustrated as transparent cylinders for simplicity, and it is appreciated that the silicone tubes **104** may not necessarily be transparent and may not have the shape of a cylinder. Instead, the silicone tubes **104** may be elastically connected between the skeletons **120** such that the joint structures **110** have the flexibility and freedom to turn for performing various movement motions. In certain embodiments, the joint structure **110** may also be designed in a flexural way and the skeleton **120** may be removed or replaced by other components made of flexible material.

FIG. **6** shows a simplified schematic diagram of the bionic robot **10** having three tail structures **100** along the circumference of the circular wall **203** of the head **200**. Although the three tail structures **100** are spaced evenly with 120 degrees apart, it is obvious that they may be located in other positions and may or may not be spaced evenly from one another, depending on the application and the number of tail structures **100** in the bionic robot **10**. Inside the head **200**, there is a separated tail drive assembly **230** in associated with each tail structure **100** for controlling a one-directional movement of the entire tail structure **100**. Inside each tail structure **100**, there are one or more modular assemblies **130** for controlling the movement of each joint. The farthest modular assembly **130** of each tail structure **100** can control the movement of the fin structure **140**.

In more detail, the structure of the tail drive assembly **230** is depicted in. FIGS. **7-9**. The tail drive assembly **230** is placed on a bottom plate **224** inside the head **200**. The bottom plate **224** may have a circular shape with a diameter equal to or less than the diameter of the circular wall **203**, and is firmly mounted inside the head **200** by screws or other fasteners. For each tail structure **100**, there is a tail drive assembly **230** placed at the corresponding position adjacent to the tail structure **100** inside the head **200**. Therefore, if there are two tail structures **100**, the head **200** may only include two tail drive assemblies **230**. A mechanical support **234** is mounted on the bottom plate **224** to secure the tail drive assembly **230** thereto. The tail drive assembly **230** comprises a head servo motor **231**, a motor pinion **233**, a spur gear **235**, a motor shaft **232**, and a rotary shaft **236**. The head servo motor **231** is fixed on a motor mount **237** on the mechanical support **234**, and drives a motor shaft **232** to rotate. The motor shaft **232** is fixed to the motor pinion **233** for driving the spur gear **235** and the rotary shaft **236**. The spur gear **235** is engaged with the motor pinion **233** and rotates concentrically with the rotary shaft **236**. The motor pinion **233** has a smaller number of teeth than the spur gear **235** for reducing the rotational speed of the rotary shaft **236**. The rotary shaft **236** is a hollowed shaft connected to the tail structure **100** for driving the rotational movement of the entire tail structure **100** with a sealing **238** for providing a good sealing effect from the external water environment.

The tail structure **100** may have a different number of joint structures **110**. The typical case is shown in FIG. **10**A with three joint structures **110**. An alternative case is shown in FIG. **10**B with two joint structures **110**, and denoted as a short tail structure **100**A. The short tail structure **100**A can also be connected to the head **200** for specific applications. The joint structure **110** comprises a modular assembly **130** and a connection plate **101**.

FIG. **11-14** shows an exemplary structure of the modular assembly **130** in accordance with certain embodiments of the present disclosure. The modular assembly **130** is a gear driven modular ball pair that can achieve a variety of motions, such as a yaw motion and a pitch motion. It is appreciated that the modular assembly **130** may otherwise be configured to be driven by cable or hydraulic without departing from the scope and spirit of the present disclosure. The modular assembly **130** comprises a bevel gear mechanism **103**, an upper servo motor **114**, a lower servo motor **124**, and a plurality of gears. The bevel gear mechanism **103** is integrally formed by three bevel gears coupled together. The modular assembly **130** is configured to enable the joint structure **110** to perform both longitudinal rotation and lateral rotation, with one-directional movement or two-directional movement. In the case of cable driven modular assembly **130**, the bevel gear mechanism **103** is driven by a plurality of pulleys and pulley cables for transferring the driving force to the connection plate **101**. In yet another alternative, the modular assembly **130** may be driven by one or more hydraulic powered structures.

The upper servo motor **114** drives an upper motor shaft **116** and the upper motor gear **112** to rotate. The upper motor gear **112** is engaged to a first middle gear **111**, and further engaged to a first reduction gear **107**. The gears are aligned along a first side of the modular assembly **130** and driven by the upper servo motor **114** to transmit power to the bevel gear mechanism **103**. The upper motor gear **112** and the first middle gear **111** may have the same number of teeth, while the first reduction gear **107** has a larger number of teeth for reducing the rotational speed of the first reduction gear **107**. The upper motor gear **112** and the first middle gear **111** are respectively mounted on the upper motor shaft **116** and the middle shaft **115**, which are both fixed on a first side plate **113**.

Similarly, the lower servo motor **124** drives a lower motor shaft **126** and the lower motor gear **122** to rotate. The lower motor gear **122** is engaged to a second middle gear **121**, and further engaged to a second reduction gear **108**. The gears are aligned along a second side of the modular assembly **130** symmetrical to the first side and driven by the lower servo motor **124** to transmit power to the bevel gear mechanism **103**. The lower motor gear **122** and the second middle gear **121** may have the same number of teeth, while the second reduction gear **108** has a larger number of teeth for reducing the rotational speed of the second reduction gear **108**. The lower motor gear **122** and the second middle gear **121** are respectively mounted on the lower motor shaft **126** and the middle shaft **125**, which are both fixed on a second side plate **123**.

The bevel gear mechanism **103** includes an intermediate bevel gear **103**A, a first bevel gear **103**B, and a second bevel gear **103**C. As carried on a T-shaped shaft **105**, the intermediate bevel gear **103**A is affixed to the vertical element **105**A of the T-shaped shaft **105**, while the first bevel gear **103**B and the second bevel gear **103**C are both affixed to the horizontal element **105**B of the T-shaped shaft **105** such that they are 90 degrees apart from the intermediate bevel gear **103**A with a change of direction. Preferably, the three bevel gears in the bevel gear mechanism **103** are a matched set of bevel gears with the same number of teeth.

The first bevel gear **103**B and the first reduction gear **107** are fixed by screw such that the upper motor gear **112** can be rotated to drive the first bevel gear **103**B. The second bevel gear **103**C and the second reduction gear **108** are also fixed by screw such that the lower motor gear **122** can be rotated to drive the second bevel gear **103**C. The connection plate **101** is fixedly attached to or screwed to the intermediate bevel gear **103**A.

On the rear side of the modular assembly **130**, a motor mounting plate **131** is vertically arranged for fixedly securing the upper servo motor **114** and the lower servo motor **124** thereto. A U-shaped rear plate **132** may be used to connect the first side plate **113** and the second side plate **123** as a protective shield for the two servo motors **114**, **115**. The connection plate **101** from the subsequent joint structure **110** is fixedly mounted to the rear plate **132** such that the two joint structures **110** are connected. For the joint structure **110** at the distal end of the tail structure **100**, the rear plate **132** is fixedly mounted to an end plate **141** and the fin structure **140**.

The gear schematic of the modular assembly **130** is depicted in FIG. **15**A. The gear transmission on the first side of the modular assembly **130** is configured to drive the first bevel gear **103**B by rotating the upper motor gear **112** via the first middle gear **111** and the first reduction gear **107**. Similarly, the gear transmission on the second side of the modular assembly **130** is configured to drive the second bevel gear **103**C by rotating the lower motor gear **122** via the second middle gear **121** and the second reduction gear **108**. Both the first bevel gear **103**B and the second bevel gear **103**C are engaged to the intermediate bevel gear **103**A.

Now referring to the gear schematic in FIG. **15**B, when the upper motor gear **112** and the lower motor gear **122** are rotated in the opposite direction, the first bevel gear **103**B and the second bevel gear **103**C are also rotated in the opposite direction. The connection plate **101** fixedly attached to the intermediate bevel gear **103**A will do a yaw motion of the joint structure **110**. With the use of two servo motors **114**, **115**, the joint structure **110** can perform a one-directional movement or a two-directional movement, and the degree of the yaw motion can be precisely controlled.

Now referring to the gear schematic in FIG. **15**C, when the upper motor gear **112** and the lower motor gear **122** are rotated in the same direction, the first bevel gear **103**B and the second bevel gear **103**C are also rotated in the opposite direction. The connection plate **101** fixedly attached to the intermediate bevel gear **103**A will do a pitch motion of the joint structure **110**. With the use of two servo motors **114**, **115**, the joint structure **110** can perform a one-directional movement or a two-directional movement, and the degree of the pitch motion can be precisely controlled.

FIGS. **16**A-**16**C show the simplified conceptual drawings of the bionic robot **10** arranged in three different configurations. In the conceptual drawings, a short line represents a joint structure **110** with a modular assembly **130** provided therein. FIG. **16**A shows a bionic robot **10** with three tail structures **100** having three joint structures **110** each. FIG. **16**B shows a bionic robot **10** with a tail structure **100** having three joint structures **110**, and two short tail structures **100**A. FIG. **16**C shows a bionic robot **10** with two tail structures **100** having three joint structures **110**, and a short tail structure **100**A. As the underwater environment may be different case by case, the number of the joint structures **110** varies for simulating the movement of different aquatic life, which can optimize the bionic robot **10** based on the required underwater task and the respective underwater condition.

In particular, the bionic robot **10** is based on coordinated control of the three tail structures **100** for realizing different swimming movement modes. There is no propeller or rotating blades to drive the bionic robot **10** forward, and so the movement may generate less noise with higher efficiency. In the following exemplary embodiments, a bionic robot **10** having three tail structures **100**, each with three joint structures **110**, is used as an example. Those various motions described below are programmed in the motor driver, and the operator can control the bionic robot **10** to perform such motion by sending a control command.

FIG. **17** shows a conceptual drawing of the bionic robot **10** in a forward motion. The three tail structures **100** mimic the fishtail of a fish in nature and generate forward thrust to propel the bionic robot **10** by swinging the fin structure **140**. With more joint structures **110**, each tail structure **100** has a wider angle of oscillation to achieve higher efficiency and a larger propelling force.

FIG. **18** shows a conceptual drawing of the bionic robot **10** in a 2-tail forward motion. Two of the tail structures **100** are arranged to swing on the front side, while the third tail structure **100** is positioned at the back in a generally stable manner, thereby a forward directional thrust is generated to propel the bionic robot **10** in the forward direction.

FIG. **19** shows a conceptual drawing of the bionic robot **10** in an in-situ rotation with zero turning radius motion. The tail structures **100** are arranged in either a clockwise or an anticlockwise manner to generate rotational thrust.

FIG. **20** shows a conceptual drawing of the bionic robot **10** in floating upward motion. The tail structures **100** are arranged to point downwardly and oscillate to create an upward floating force, thereby the bionic robot **10** can be propelled up to the water surface.

FIG. **21** shows a conceptual drawing of the bionic robot **10** in a diving downward motion. The tail structures **100** are arranged to point upwardly and oscillate to create a downward diving force, thereby the bionic robot **10** can be propelled down into the water.

The bionic robot **10** may have one, two, three, four, five, or more tail structures **100**, wherein each tail structure **100** may have one, two, three, four, or more joint structures **110**. FIGS. **22**-**33** illustrate various possible configurations of the bionic robot **10** in accordance with certain aspects of the present disclosure. These figures are by no means restrictive of the possible configurations thereof.

FIG. **22** is a conceptual drawing of the bionic robot **10** with one tail structure **100** connecting to the head **200**. The single-tailed bionic robot **10** mimics the movement of a fish in the water, and the tail structure **100** is akin to the caudal fin of a fish. Due to the problem of the proportion and balancing between the head **200** and the tail structure **100**, a smaller head **200**A may be used, and the number of the joint structures **110** may further be increased to mimic the movement of a tuna or a snake, as shown in FIG. **23**. However, with only one tail structure **100**, the loading capability may be limited, and the bionic robot **10** may only carry fewer sensors.

FIG. **24** is a conceptual drawing of the bionic robot **10** with two tail structures **100** connecting to the head **200**. The two tail structures **100** are arranged on the same plane and may mimic the movement of a manta ray or a snake. In certain applications, when a smaller head **200**A is used, the two tail structures **100** can also be arranged similarly to have a bionic robot **10** configured to mimic the movement of a snake, as shown in FIG. **25**. The tail structures **100** may not be spaced evenly with 180 degrees apart. In the conceptual drawing of FIG. **26**, the two tail structures **100** are spaced by an angle ranged from 60 to 165 degrees apart, or spaced by 120 degrees apart. This is particularly useful if the bionic robot **10** is required to carry heavy objects and many sensors, as this tail structure **100** arrangement can ensure better balance and stronger power for propelling the bionic robot **10** forward.

FIG. **27** illustrates the preferred configuration of the bionic robot **10** with three tail structures **100** evenly distributed around the head **200**. This configuration can achieve a variety of motions with better stability, mobility, agility, and loading capability in a diverse water flow environment. FIG. **28** is an alternative configuration of the bionic robot **10** with two short tail structures **100**A and one tail structure **100** with three joint structures **110**. A different number of joint structures **110** can be configured for different propulsion power and efficiency.

FIGS. **29**-**31** illustrate different configurations of the bionic robot **10** with four tail structures **100**. The different positions and lengths of the tail structure **100** can provide thrust in multiple directions of space, which can optimize the bionic robot **10** for particular applications.

There are two conceptual drawings for the bionic robot **10** with four tail structures **100**, as shown in FIGS. **32**-**33**. The increased number of tail structures **100** can provide multiple locomotion modes, such as using three tail structures **100** to maintain movement direction and balance, and two tail structures **100** for grabbing the target. Alternatively, the three tail structures **100** can be used to perform in-situ rotation along one direction, while the other two tail structures **100** can move the bionic robot **10** forward or background.

Therefore, the bionic robot **10** of the present disclosure can mimic the movement patterns of a wide variety of marine life, for example, tuna, snake, turtle, shark, manta ray, etc. This combined structure, as described above, allows for omnidirectional motion movements without the need for turns in the water. In the flowing environment, the multiple tail structures **100** can achieve stronger stability, mobility, agility, and loading capability. This illustrates the fundamental structure of a bionic underwater robot in accordance with the present disclosure. It will be apparent that variants of the above-disclosed and other features and functions, or alternatives thereof, may be combined into many other different methods or apparatuses. The present embodiment is, therefore, to be considered in all respects as illustrative and not restrictive. The scope of the disclosure is indicated by the appended claims rather than by the preceding description, and all changes that come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

What is claimed is:

1. A bionic robot for underwater use, comprising:

a head; and

one or more tail structures,

wherein:

each of the one or more tail structures comprises one or more joint structures;

each of the one or more joint structures comprises a connection plate, and a modular assembly motorized for performing various movement motions of the joint structure; and

the modular assembly comprises an upper servo motor, a lower servo motor, and a bevel gear mechanism.

2. The bionic robot of claim **1**, wherein the bevel gear mechanism is integrally formed by an intermediate bevel gear, a first bevel gear, and a second bevel gear, wherein:

the upper servo motor drives the first bevel gear from a first side of the modular assembly; and

the lower servo motor drives the second bevel gear from a second side of the modular assembly.

3. The bionic robot of claim **2**, wherein the connection plate is fixedly attached to or screwed to the intermediate bevel gear for achieving a yaw motion or a pitch motion of the joint structure.

4. The bionic robot of claim **2**, wherein:

the upper servo motor drives an upper motor gear coupled to a first reduction gear via a first middle gear;

the lower servo motor drives a lower motor gear coupled to a second reduction gear via a second middle gear;

the first reduction gear and the first bevel gear are fixed; and

the second reduction gear and the second bevel gear are fixed.

5. The bionic robot of claim **4**, wherein:

the first reduction gear has a larger number of teeth than the first middle gear; and

the second reduction gear has a larger number of teeth than the second middle gear.

6. The bionic robot of claim **1**, wherein each tail structure comprises a fin structure fixed to an end plate sealed at a longitudinal distal end of the tail structure.

7. The bionic robot of claim **6**, wherein the fin structure is a bionic fishtail with an emarginate caudal fin shape.

8. The bionic robot of claim **1**, wherein the joint structure is mechanically sealed within a silicone tube and a skeleton, thereby the modular assembly is sealed inside the joint structure.

9. The bionic robot of claim **8**, wherein the silicone tube is clamped to the skeleton using a clamp and silicone glue to prevent water seepage.

10. The bionic robot of claim **1**, wherein the head comprises one or more tail drive assemblies for controlling movement of the one or more tail structure.

11. The bionic robot of claim **10**, wherein the tail drive assembly comprises a head servo motor, a motor pinion, a spur gear, a motor shaft, and a rotary shaft, wherein the motor shaft is fixed to the motor pinion for driving the spur gear and the rotary shaft.

12. The bionic robot of claim **11**, wherein the motor pinion has a smaller number of teeth than the spur gear for reducing the rotational speed of the rotary shaft.

13. The bionic robot of claim **11**, wherein the rotary shaft is connected to the tail structure for driving the tail structure with a sealing effect from an external water environment.

14. The bionic robot of claim **1**, wherein the head comprises three sealed connectors for connecting to an underwater acoustic transceiver or other accessory devices, wherein the underwater acoustic transceiver is configured to communicate based on an underwater acoustic network.

15. The bionic robot of claim **1**, wherein the head comprises a plurality of infrared sensors.

16. The bionic robot of claim **1**, wherein the head comprises one or more pressure sensors.

17. The bionic robot of claim **1**, wherein the modular assembly is cable driven, or hydraulic driven.

18. A bionic robot for underwater use, comprising:

a head; and

three tail structures,

wherein:

each of the three tail structures comprises one or more joint structures;

each of the one or more joint structures comprises a connection plate, and a modular assembly motorized for performing various movement motions of the joint structure; and

the modular assembly comprises an upper servo motor, a lower servo motor, and a bevel gear mechanism.

19. The bionic robot of claim **18**, wherein one of the three tail structures comprises three joint structures, and each of the other two tail structures comprises two joint structures.

20. The bionic robot of claim **18**, wherein one of the three tail structures comprises two joint structures, and each of the other two tail structures comprises three joint structures.

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