[0008] It is desirable to position sensors and equipment in the ocean or lakes for long periods of time without using fuel or relying on anchor lines which can be very large and difficult to maintain. In recent years, the WPDs developed by Liquid Robotics, Inc. and marketed under the registered trademark Wave Glider®, have demonstrated outstanding value, particularly because of their ability to operate autonomously. It is noted that Wave Glider® WPDs are often referred to as Wave Gliders as a shorthand terminology. It is also noted that WPDs are often referred to as wave-powered vehicles ("WPVs").

SUMMARY OF THE INVENTION

[0009] A problem that arises with the known wave-powered devices is that they are difficult to transport, store, launch, and recover. Embodiments of the present disclosure seek to provide a solution to this problem by providing an assembly in which the tether and the wave-actuated component are nested closely to, and/or secured to, the float, thus making relatively compact assembly that can be maintained as a single unit until the time comes to launch the device on the water. A related solution, which is applicable when the tether, in use, is rigid, is described and claimed in detail in an application filed contemporaneously with this application and also claiming priority from U.S. Provisional Application Nos. 61/453,871 and 61/535,116. That related solution, which can be used in conjunction with the solution of this disclosure, it is to make use of a tether which, before the device is placed on water, can be maintained in a position adjacent to the float and which, before or after the device is placed on water, can be moved from the adjacent position to an extended position in which the tether is at least in part rigid.

[0010] The Summary of the Invention and the Detailed Description below, and the accompanying drawings, disclose many novel features, each of which is inventive in its own right, and any one or more of which can be used in combination where this is physically possible. The different aspects of the disclosure identified below are no more examples of the broad range of inventions disclosed herein.

[0010a] In one aspect of the present disclosure, a wave-powered device comprises (1) a float; (2) a wave-actuated component; (3) a flexible tether having a first end connected to the float and a second end connected to the wave-actuated component; and (4) a closure component that comprises a winch mounted to pivot about pitch axis of the tether, the winch having a spool to which the tether is connected, the closure component having a first state in which the tether is wound onto the winch to secure the float and the wave-actuated component together as an assembly that can be moved as a unit, and a second state in which the tether is unwound from the winch to permit the wave-actuated component to move away from the float wherein the winch is mounted on the float; wherein, when the closure component is in the second state and the float is placed on or near the surface of still water, the

float floats on or near the surface of the still water, the tether extends downwards from the float and under tension, and the wave-actuated component is submerged below the float, and when the closure component is in the second state and the float is placed on or near the surface of wave-bearing water, the float floats on or near the surface of the wave-bearing water, the tether extends downwards from the float, and the wave-actuated component is submerged below the float, and interacts with the water to generate forces that are transmitted to the tether.

[0010b] In another aspect of the present disclosure, a wave-powered water vehicle comprises a) a first component that is a float that travels on or near the water surface; b) a second component that is wave actuated and travels below the first component; c) a flexible tether that connects the first and second components; and (d) a winch, mounted so as to pivot about pitch axis of the tether, the winch being built into the first component, wherein the winch is operable to assume a first state in which the tether is wound onto the winch, whereby one of said components may be secured against the other, and a second state in which the tether is unwound from the winch, whereby one of said components can move away from the other.

[0010c] In another aspect of the present disclosure, a wave-powered water vehicle comprises a float that travels on or near the water surface; a wave-actuated component that travels below the float; a flexible tether connecting the float and the wave-actuated component; and a winch, mounted to the wave-powered water vehicle so as to pivot about pitch axis of the tether, the winch having: a first state in which the tether is wound onto the winch to secure the float and the wave-actuated component together as an assembly that can be moved as a unit, and a second state in which the tether is unwound from the winch to permit the wave-actuated component to move away from the float.

[0010d] In another aspect of the present disclosure, a wave-powered water vehicle comprises a float that travels on or near the water surface, the float having a longitudinal roll axis and a transverse pitch axis; a wave-actuated component that travels below the float; a flexible tether connecting the float and the wave-actuated component, wherein the tether has a substantially flat configuration with wide and narrow axes to reduce drag when the tether is oriented with its narrow axis directed parallel to pitch axis of the tether; and a winch, mounted to the wave-powered water vehicle so as to pivot about pitch axis, wherein the winch has a spool that rotates about an axis perpendicular to the pitch axis of the tether so that the tether can be wound onto the spool without twisting, and the winch is operable to assume first and second states where: in the first state, the tether is wound onto the winch to secure the float and the wave-actuated component together as an assembly that can be moved as a unit, and in the second state, the tether is unwound from the winch to permit the wave-actuated component to move away from the float.

[0011] In accordance with the disclosure, an assembly comprises: (1) a float; (2) a wave-actuated component; and (3) a closure component having a first state in which it secures the float and the wave-actuated component together as an assembly that can be moved as a unit and a second state that permits the wave-actuated component to move away from the float. The assembly is configured to accept a tether having a first end connected to the float and a second end connected to the wave-actuated component, such that when the closure component is in the second state and the assembly includes such a tether, the float, the tether, and the wave-actuated component form a wave-powered device (WPD).

[0012] When the float is placed on or near the surface of still water, the WPD has (a) the float floating on or near the surface of the still water, (b) the tether extending downwards from the float and under tension, and (c) the wave-actuated component being submerged below the float. When the float is placed on or near the surface of wave-bearing water, the WPD has (a) the float floating on or near the surface of the wave-bearing water, (b) the tether extending downwards from the float, and (c) the wave-actuated component being submerged below the float, and interacting with the water to generate forces that are transmitted to the tether.

[0013] The wave-actuated component is sometimes referred to herein as a "swimmer" or a "wing rack" (for those embodiments having multiple fins. It can comprise a fin system as disclosed in any of the documents incorporated herein by reference or any other mechanism that will interact with the water to generate forces that are transmitted to the tether.

[0014] In accordance with the disclosure, a float having top, bottom, and side surfaces comprises float side components that extend downwards from the side surfaces to create a space defined by the bottom surface and the float side components. Such a float is, for example, useful in accordance with the disclosure because the defined space can enclose the wave-actuated component.

[0015] In accordance with the disclosure, a wave-actuated component comprises components that extend upwards from the wave-actuated component and that will interact with a float to register the wave-actuated component in relation to the float.

[0016] In accordance with the disclosure, a wave-actuated component comprises components that extend downwards from the wave-actuated component, and when the wave-actuated component is placed upon a horizontal surface, the components that extend downwards separate the surface from any part of the wave-actuated component that might otherwise be damaged by contact with the surface.

[0017] In accordance with the disclosure, a wave-powered device comprises: (1) a float, (2) a flexible tether, and (3) a wave-actuated component, the tether connecting the float and the wave-actuated component. The float, the tether, and the wave-actuated component are such that, when (A) the device is in still water, (i) the float is on or near the surface of the water, (ii) the wave-actuated component is submerged below the float, and (iii) the tether is under tension, and (B) when the device is in wave-bearing water, the wave-actuated component interacts with the water to generate forces that are transmitted to the tether. In this aspect, the float comprises a winch that can be operated to change the length of the tether.

[0018] In accordance with the disclosure, a wave-powered device comprises: (1) a float, (2) a flexible tether, and (3) a wave-actuated component, the tether connecting the float and the wave-actuated component. The float, the tether, and the wave-actuated component are such that (A) when the device is in still water, (i) the float is on or near the surface of the water, (ii) the wave-actuated component is submerged below the float, and (iii) the tether is under tension, and (B) when the device is in wave-bearing water, the wave-actuated component interacts with the water to generate forces that are transmitted to the tether, wherein the tether has at least one of the following characteristics:

(1) the tether has a substantially at configuration, for example with an average thickness of 1-3 mm;

(2) the tether is free from components that carry electrical currents and/or is free from components that carry signals of any kind;

(3) the tether comprises a plurality of round tensile members;

(4) the tether is a flat webbing constructed of a synthetic polymer, e.g., a polymide, Spectran, Vectran, or Kevlar;

(5) the tether is a flat webbing that is tensioned only along the leading edge thereof, thus reducing fluttering and bowing;

(6) the tether is attached to the float at a hinge point that comprises a shaft and bushing arrangement such that the tether is not required to flex against its wide axis (pitch);

(7) at the float, the tether is guided through a 90° twist, and then flexes in the pitch axis over a pulley with its axis level and perpendicular to the longitudinal axis of the float;

(8) at the float, the tether is guided through a 90° twist, and then flexes in the pitch axis over a pulley with its axis level and perpendicular to the longitudinal axis of the float, wherein the pulley is crowned to increase the tension on the center of the tether to lessen the effect of the 90° twist increasing the tension of the outer parts of the tether, relative to the center of the tether.

[0019] In accordance with the disclosure, a fin system for use in a wave-powered device of any kind, including the wave-powered devices disclosed in the documents incorporated by reference herein, has at least one fin that rotates about an axis and that has a neutral position, and a control system for controlling the rotation of the fin, and the control system comprises: a first means that controls the rotation of the fin within a first range about a neutral position; and a second means that controls the rotation of the fin when the movement of the fins is outside the first range. In embodiments, the angular movement of at least one

fin is primarily controlled by a first spring or other means when the movement of the fins is within a first range about a neutral position and is primarily controlled by a second spring or other means when the movement of the fins is within a second range that is outside the first range, wherein the second spring is stiffer than the first spring, thus making it more difficult for the fins to move within the first range. The movement can be controlled solely by the first spring or by a combination of first spring and a second spring.

[0020] Within the second range, the movement can be controlled solely by the second spring or by a combination of the first spring and a second spring. The system can include a stop that prevents the first spring from moving beyond a first limit. The system can include a stop that prevents the second spring from moving beyond a second limit, and thus prevents the fin from moving outside a second range. Either or both of the springs can be replaced by an equivalent means that may be mechanical or electromechanical. When using such a system, when the waves in the wave bearing water are small, the rotation of the fins is controlled by the first swing and only a little fluid force is needed to rotate the fins to an angle within an effective range. As the waves become larger, the second spring comes into play and, by preventing the fins from "overrotating" maintains the fins at an angle within an effective range. Excessive water forces can rotate the wing so that it dumps the load, thus protecting the system from overload.

[0021] In accordance with the disclosure, a method of obtaining information comprises receiving signals from, or recorded by, a WPD as disclosed, or a WPD that comprises a float as disclosed, or a wave-actuated component as disclosed, or a WPD that comprises a fin system as disclosed.

[0022] In accordance with the disclosure, a method for controlling a function of a WPD comprising sending signals to a WPD as disclosed, or a WPD that comprises a float as disclosed, or a wave-actuated component as disclosed, or a WPD that comprises a fin system as disclosed.

Nesting

[0023] The assembly as disclosed makes use of a float and a wave-actuated component that are designed to fit closely to each other, e.g., in a nested or bundled configuration. For example, the float can comprise components that extend downwards and fit around the swimmer, and/or the swimmer can comprise components that extend upwards and fit around the float. One or both of the float and the wave-actuated component can include clips that help to secure the float and the swimmer together. Alternatively or additionally, one or more separate components, e.g., straps, can secure the float and the wave-actuated component together.

[0024] Fins forming part of the wave-actuated component can remain within, or extend beyond, the periphery of the float. This makes it easier for the float and the wave-actuated component to be handled as a single unit for storage and/or transport, before being launched as a WPD and can also facilitate recovery of the WPD. In some cases, the float and the swimmer can together form a package that can be handled as a single unit for shipping within recognized national and/or international weight and dimension restrictions. The combination of the float and the wave-actuated component can include the tether, so that, when the components are separated, there is a WPD ready for use. Alternatively, the tether can be absent from the package and be added to the assembly when the WPD is ready to be launched. The tether can comprise one or more rigid sections that can be folded, telescoped or otherwise collapsed, or a tether that can be wound up on a winch on the float.

[0025] In accordance with the disclosure, a method of launching a WPD comprises (1) providing a WPD precursor that comprises a float and a wave-actuated component that are nested together, and a tether that is coiled and/or folded within the float and/or the wave-actuated component, and/or between the float and the wave-actuated component; (2) placing the WPD precursor on water; and (3) releasing the wave-actuated component from the float so that the wave-actuated component is submerged below the float and the tether is under tension between the float and the wave-actuated component.

[0026] In accordance with the disclosure, a method of recovering a WPD that comprises a float, a wave-actuated component, and at least two tethers, that link the float and the wave-actuated component, the method comprising pulling one of the tethers upwards so that fins on the wave-actuated component have reduced resistance to upward motion.

[0027] In accordance with the disclosure, a method of recovering a WPD that comprises a float, a wave-actuated component, and a tether that comprises at least one rigid section, the

method comprising folding the tether upwards so that fins on the swimmer have reduced resistance to upward motion.

[0028] In accordance with the disclosure, a WPD in which the tether is free from components that carry electrical currents and/or is free from components that carry signals of any kind. In this case, the wave-actuated component will generally also be free from electrical and electronic components. This reduces the danger that the performance of the WPD will be compromised by damage to the tether, particularly when making use of a tether that is flexible, since it is difficult to prevent failure of electrical wires in the tether, since the tether can be subject to large snap loads, and bending loads, resulting in damage to insulation surrounding electrical/electronic components, which in turn results in failure due to salt water incursion. Tethers without electrical wires can be thinner, and stiffer, and can have cross sections that make it easier to store the tether before the WPD is launched and/or to gather up the tether when the WPD is to be removed from the water.

[0029] A further understanding of the nature and advantages of the present invention may be realized by reference to the remaining portions of the specification and the drawings, which are intended to be exemplary and not limiting.

BRIEF DESCRIPTION OF THE DRAWINGS

[0030] FIG. 1 is a pictorial view showing the operation of a wave-powered device ("WPD") in still water (fins/wings in neutral position), when a wave lifts the float (up-stroke), and when the WPD sinks into the wave trough (down-stroke);

[0031] FIG. 2A is a perspective view taken from above of a WPD having two rigid tethers and a wave-actuated component having two horizontal rigid spines (side beams) and a fin system between the rigid spines, with the tethers in their extended positions;

[0032] FIG. 2B is a perspective view taken from above of the WPD of FIG. 2A with the rigid tethers in their retracted positions so that the WPD is in a bundle configuration with the float sitting atop the wave-actuated component;

[0033] FIGS. 3A and 3B are perspective views taken from the bottom of the WPD of FIGS. 2A and 2B;

[0034] FIG. 4 is a perspective end view of a WPD showing three wing racks;

[0035] FIG. 5A is an end view of the WPD of FIG. 4 with the wing racks having been retracted and nested;

WHAT IS CLAIMED IS:

1. A wave-powered device comprising:

(1) a float;

(2) a wave-actuated component;

(3) a flexible tether having a first end connected to the float and a second end connected to the wave-actuated component; and

(4) a closure component that comprises a winch mounted to pivot about pitch axis of the tether, the winch having a spool to which the tether is connected, the closure component having a first state in which the tether is wound onto the winch to secure the float and the wave-actuated component together as an assembly that can be moved as a unit, and a second state in which the tether is unwound from the winch to permit the wave-actuated component to move away from the float wherein the winch is mounted on the float;

wherein,

when the closure component is in the second state and the float is placed on or near the surface of still water,

the float floats on or near the surface of the still water,

the tether extends downwards from the float and under tension, and

the wave-actuated component is submerged below the float, and

when the closure component is in the second state and the float is placed on or near the surface of wave-bearing water,

the float floats on or near the surface of the wave-bearing water,

the tether extends downwards from the float, and the wave-actuated component is submerged below the float, and interacts with the water to generate forces that are transmitted to the tether.

2. The wave-powered device of claim 1 wherein the float has top, bottom, and side surfaces, and comprises float side components that extend downwards generally parallel to the side surfaces to create a space defined by the bottom surface and the float side components, and the wave-actuated component is at least partially within that space.

3. The wave-powered device of claim 1 wherein the wave-actuated component comprises components that extend upwards from the wave-actuated component and that interact with components of the float to locate the wave-actuated component in a fixed

position in relation to the float, and/or the float comprises components that extend downwards and that interact with components of the wave-actuated component to locate the wave-actuated component in a fixed position in relation to the float.

4. The wave-powered device of claim 1 wherein:

the wave-actuated component comprises fins that, when the wave-powered device is in wave-bearing water, rotate about an axis to generate the forces that are transmitted to the tether; and

the wave-actuated component includes members that extend downwards from the wave-actuated component and that, when the closure component is in the first state and the assembly is placed on a horizontal surface, separate the fins from the horizontal surface.

5. The wave-powered device of claim 1 wherein the winch comprises wiping elements that clean the tether when the tether is drawn through the winch.

6. The wave-powered device of claim 1 wherein:

the tether has a substantially flat configuration to reduce drag; and

the winch has a spool that rotates about an axis parallel to a longitudinal axis of the float so that the tether can be wound onto the spool without twisting.

7. The wave-powered device of claim 1 wherein:

the first-mentioned winch is relatively close to the fore end of the float;

the wave-powered device further comprises a second winch that is relatively close to the aft end of the float; and

the wave-powered device further includes a second tether attached to the second winch.

8. The wave-powered device of claim 1, and further comprising:

(1) wireless communications equipment;

(2) a computer system;

(3) a satellite-referenced position sensor

(4) a horizontal direction sensor that senses direction in a horizontal plane; and

(5) a steering actuator;

the computer system

(a) being linked to the communications equipment, the position sensor, the horizontal sensor and the steering actuator, and

(b) containing, or being programmable to contain, instructions to control the steering actuator in response to signals received from the communications equipment, or from the position sensor and the horizontal direction sensor, or from signals received from another sensor on the vehicle.

9. The wave-powered device of claim 1 wherein

the float is formed with a hollow configured to engage the wave-actuated component when the winch is in the first state.

10. The wave-powered device of claim 1 wherein

the tether has a substantially flat configuration to reduce drag;

the winch has a spool that rotates about an axis perpendicular to the pitch axis so that the tether can be wound onto the spool without twisting; and

the tether is not required to flex against its wide axis as the wave-powered device undergoes pitch motion.

11. A wave-powered water vehicle, comprising:

a) a first component that is a float that travels on or near the water surface;

b) a second component that is wave actuated and travels below the first component;

c) a flexible tether that connects the first and second components; and

(d) a winch, mounted so as to pivot about pitch axis of the tether, the winch being built into the first component, wherein the winch is operable to assume a first state in which the tether is wound onto the winch, whereby one of said components may be secured against the other, and a second state in which the tether is unwound from the winch, whereby one of said components can move away from the other.

12. The wave-powered water vehicle of claim 11 wherein the first component is formed with a hollow configured to engage the second component when the winch is in the first state.

13. A wave-powered water vehicle, comprising:

a float that travels on or near the water surface;

a wave-actuated component that travels below the float;

a flexible tether connecting the float and the wave-actuated component; and

a winch, mounted to the wave-powered water vehicle so as to pivot about pitch axis of the tether, the winch having:

a first state in which the tether is wound onto the winch to secure the float and the wave-actuated component together as an assembly that can be moved as a unit, and

a second state in which the tether is unwound from the winch to permit the wave-actuated component to move away from the float.

14. The wave-powered water vehicle of claim 13 wherein the winch is mounted on the float.

15. A wave-powered water vehicle, comprising:

a float that travels on or near the water surface, the float having a longitudinal roll axis and a transverse pitch axis;

a wave-actuated component that travels below the float;

a flexible tether connecting the float and the wave-actuated component, wherein the tether has a substantially flat configuration with wide and narrow axes to reduce drag when the tether is oriented with its narrow axis directed parallel to pitch axis of the tether; and

a winch, mounted to the wave-powered water vehicle so as to pivot about pitch axis, wherein the winch has a spool that rotates about an axis perpendicular to the pitch axis of the tether so that the tether can be wound onto the spool without twisting, and the winch is operable to assume first and second states where:

in the first state, the tether is wound onto the winch to secure the float and the wave-actuated component together as an assembly that can be moved as a unit, and

in the second state, the tether is unwound from the winch to permit the wave-actuated component to move away from the float.