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(54) **TRANSFORMABLE AERIAL VEHICLE**

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CPC B64D 47/08; A63H 27/12; B64C 1/28; B64C 2201/127; B64C 25/12; B64C 27/52
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

1,919,121	A	7/1933	Etienne
1,950,915	A	3/1934	Lado-Bordowsky

(Continued)

FOREIGN PATENT DOCUMENTS

CN	1639500	A	7/2005
CN	102180267	A	9/2011

(Continued)

OTHER PUBLICATIONS

International search report and written opinion dated Apr. 3, 2014 for PCT/CN2014/090470.

(Continued)

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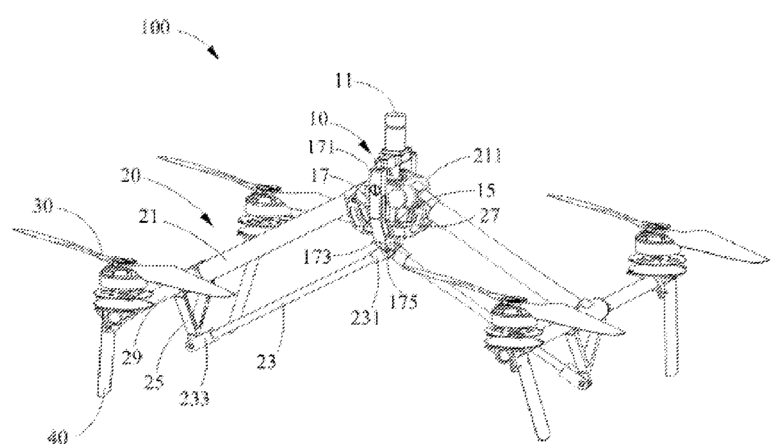
(57) **ABSTRACT**

Systems, devices, and methods for a transformable aerial vehicle are provided. In one aspect, a transformable aerial vehicle includes: a central body and at least two transformable frames assemblies respectively disposed on the central body, each of the at least two transformable frame assemblies having a proximal portion pivotally coupled to the central body and a distal portion; an actuation assembly mounted on the central body and configured to pivot the at least two frame assemblies to a plurality of different vertical angles relative to the central body; and a plurality of propulsion units mounted on the at least two transformable frame assemblies and operable to move the transformable aerial vehicle.

24 Claims, 16 Drawing Sheets



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B64C 27/08 (2006.01)
B64C 39/02 (2006.01)
G05D 1/04 (2006.01)

(52) **U.S. Cl.**
CPC *B64C 2201/024* (2013.01); *B64C 2201/127* (2013.01); *B64C 2201/14* (2013.01); *B64C 2201/165* (2013.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

2,157,963	A *	5/1939	Mercier	B64C 25/10 244/102 R
2,478,847	A	8/1949	Stuart	
3,185,409	A *	5/1965	Jacobsen	B64C 1/063 244/102 R
3,873,049	A	3/1975	Horsdal	
3,889,902	A	6/1975	Madet	
4,161,843	A	7/1979	Hui	
4,591,112	A	5/1986	Piasecki et al.	
6,655,631	B2	12/2003	Austen-Brown	
6,719,244	B1	4/2004	Gress	
6,978,969	B1	12/2005	Neal	
7,128,293	B2	10/2006	Isley	
7,364,114	B2	4/2008	Wobben	
7,699,260	B2	4/2010	Hughey	
7,959,104	B2	6/2011	Kuntz	
7,997,526	B2	8/2011	Greenley	
8,167,234	B1	5/2012	Moore	
8,172,173	B2	5/2012	Carlson	
8,187,049	B2	5/2012	Corsiglia et al.	
8,292,215	B2	10/2012	Olm et al.	
8,328,130	B2 *	12/2012	Goossen	B64C 27/20 244/17.11
8,342,441	B2	1/2013	Yoeli	
8,453,962	B2	6/2013	Shaw	
8,602,348	B2	12/2013	Bryant	
8,646,720	B2	2/2014	Shaw	
8,931,730	B2	1/2015	Wang et al.	
2002/0104922	A1	8/2002	Nakamura	
2007/0158494	A1	7/2007	Burrage	
2010/0051740	A1	3/2010	Yoeli	
2011/0017865	A1	1/2011	Achtelik et al.	
2011/0315806	A1	12/2011	Piasecki et al.	
2012/0261523	A1	10/2012	Shaw	
2012/0273608	A1	11/2012	Jess et al.	
2012/0298793	A1	11/2012	Weddendorf et al.	
2013/0206915	A1	8/2013	Desaulniers	
2014/0034775	A1	2/2014	Hutson	
2014/0151496	A1	6/2014	Shaw	
2014/0263823	A1	9/2014	Wang et al.	
2015/0012154	A1	1/2015	Senkel et al.	

FOREIGN PATENT DOCUMENTS

CN	102381471	A	3/2012
CN	102490896	A	6/2012
CN	101992854	B	11/2012
CN	203047530	U	7/2013
CN	203246584	U	10/2013
CN	203306225	U	11/2013
CN	103921933	A	7/2014
WO	WO 2009/095696	A2	8/2009
WO	WO 2010/068194	A1	6/2010
WO	WO 2011/131733	A2	10/2011

OTHER PUBLICATIONS

Notice of allowance dated Oct. 28, 2014 for U.S. Appl. No. 14/167,679.
Notice of allowance dated Nov. 21, 2014 for U.S. Appl. No. 14/167,679.
Office action dated Jun. 25, 2014 for U.S. Appl. No. 14/167,679.
U.S. Appl. No. 14/639,550, filed Mar. 5, 2015, Wang et al.
International search report and written opinion dated Mar. 2, 2015 for PCT/CN2014/080845.
Office action dated Jul. 28, 2015 for U.S. Appl. No. 14/639,550.
European search report and opinion dated May 13, 2015 for EP Application No. 13826711.7.
Notice of allowance dated Oct. 28, 2015 for U.S. Appl. No. 14/639,550.

* cited by examiner

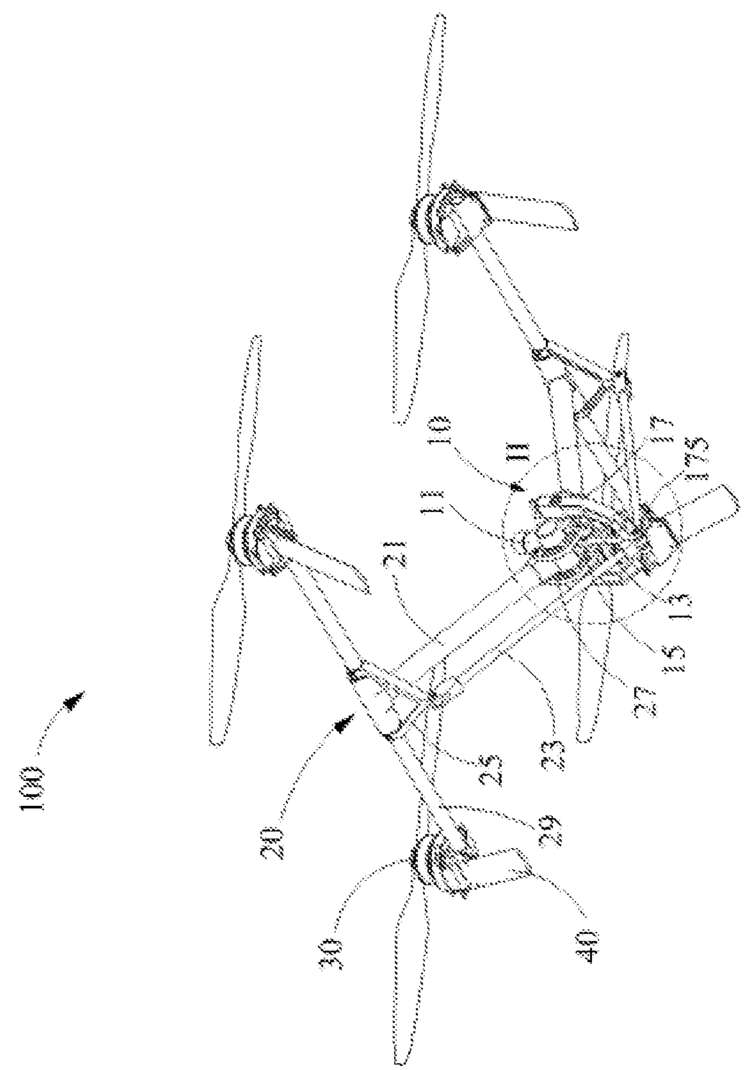

FIG. 1

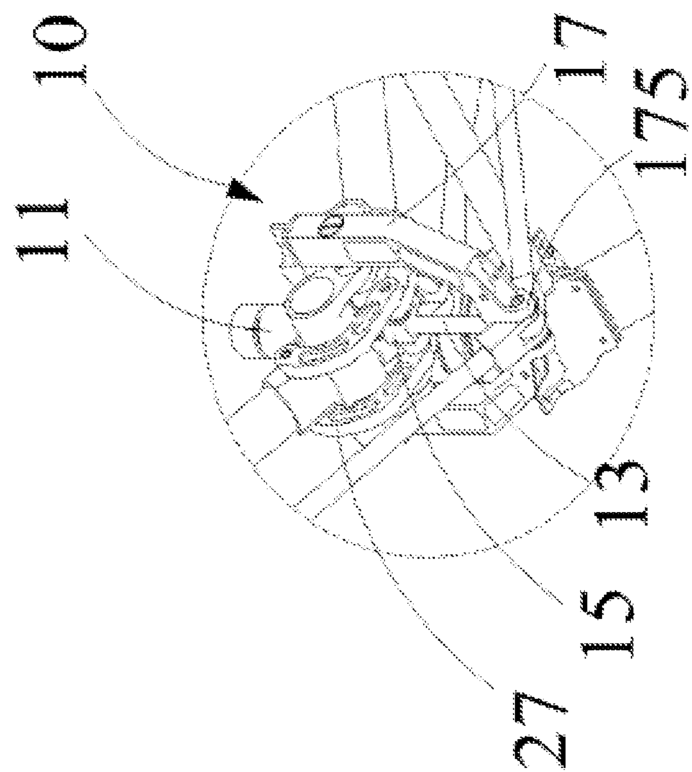

FIG. 2

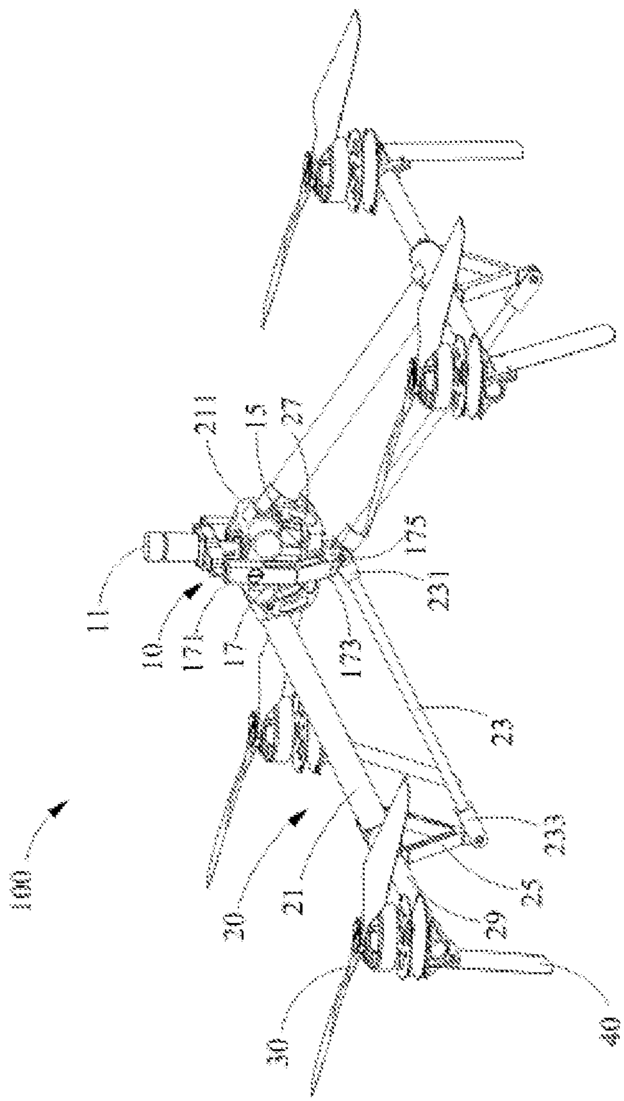

FIG. 3

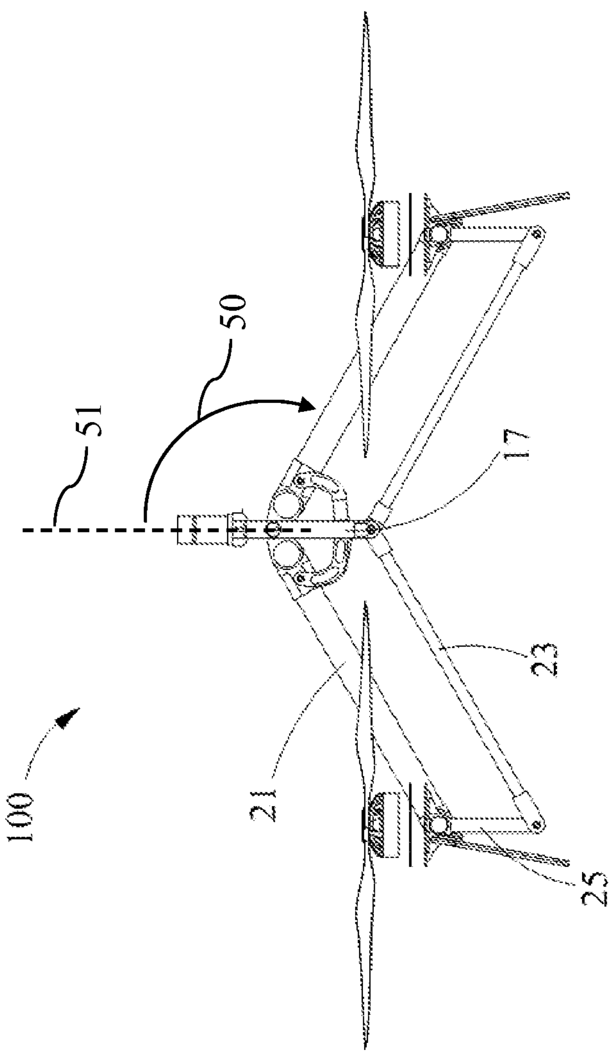

FIG. 4

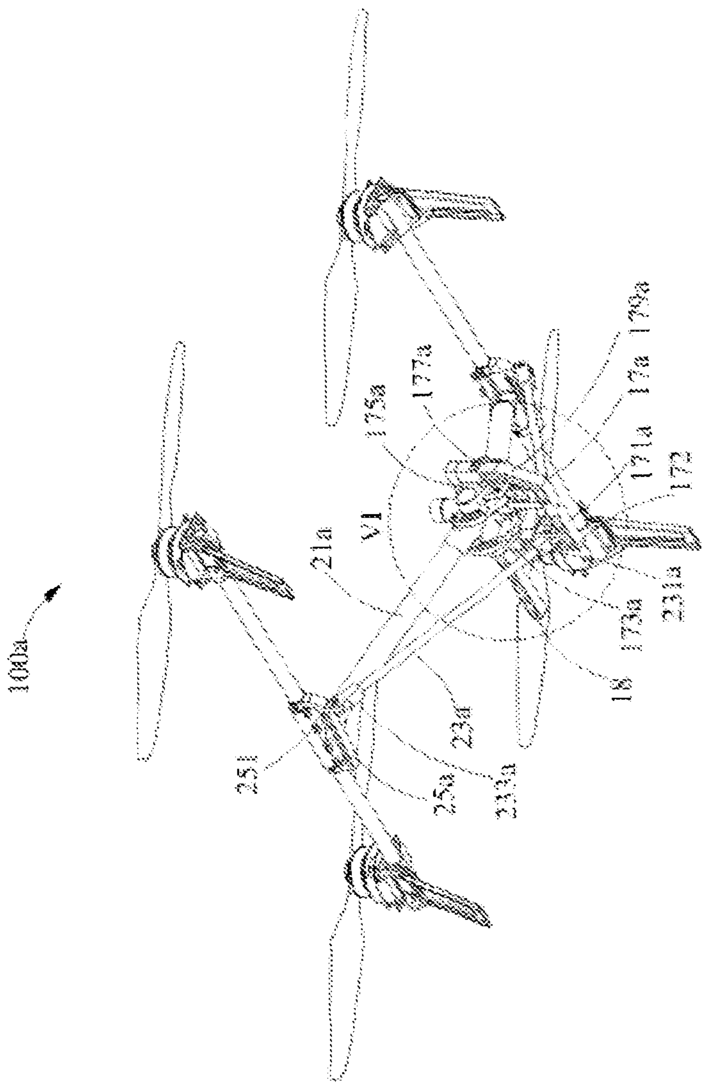
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FIG. 5

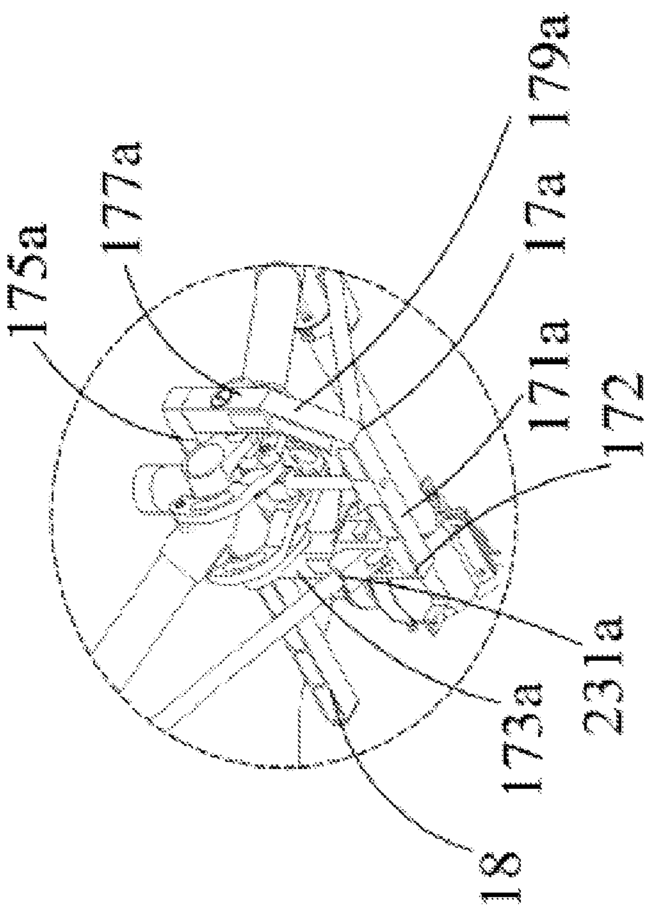

FIG. 6

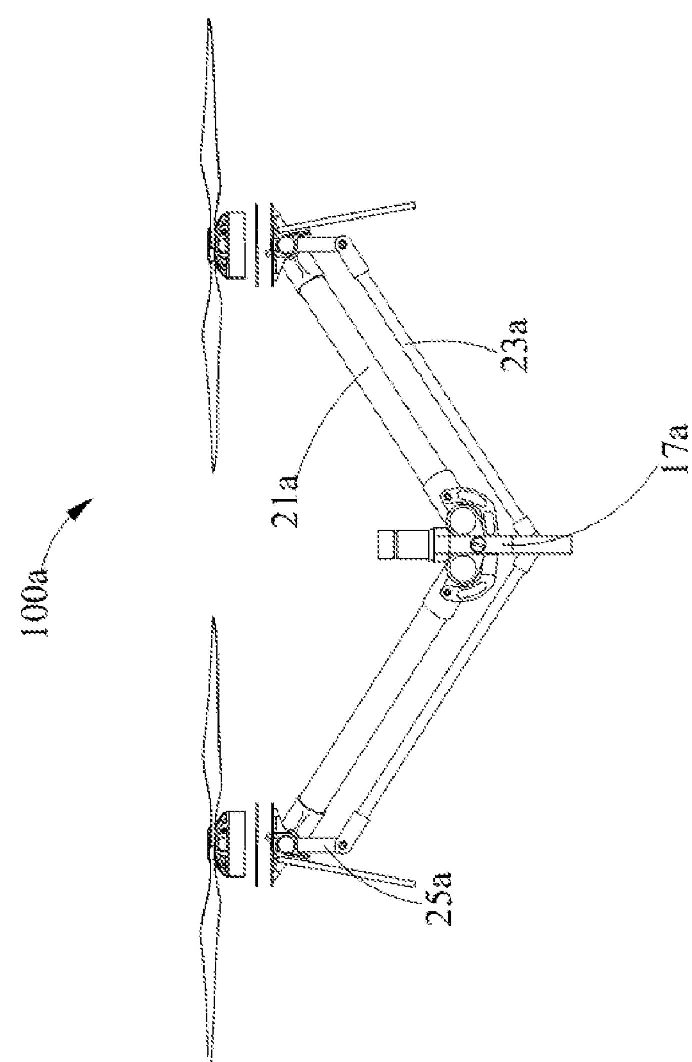

FIG. 7

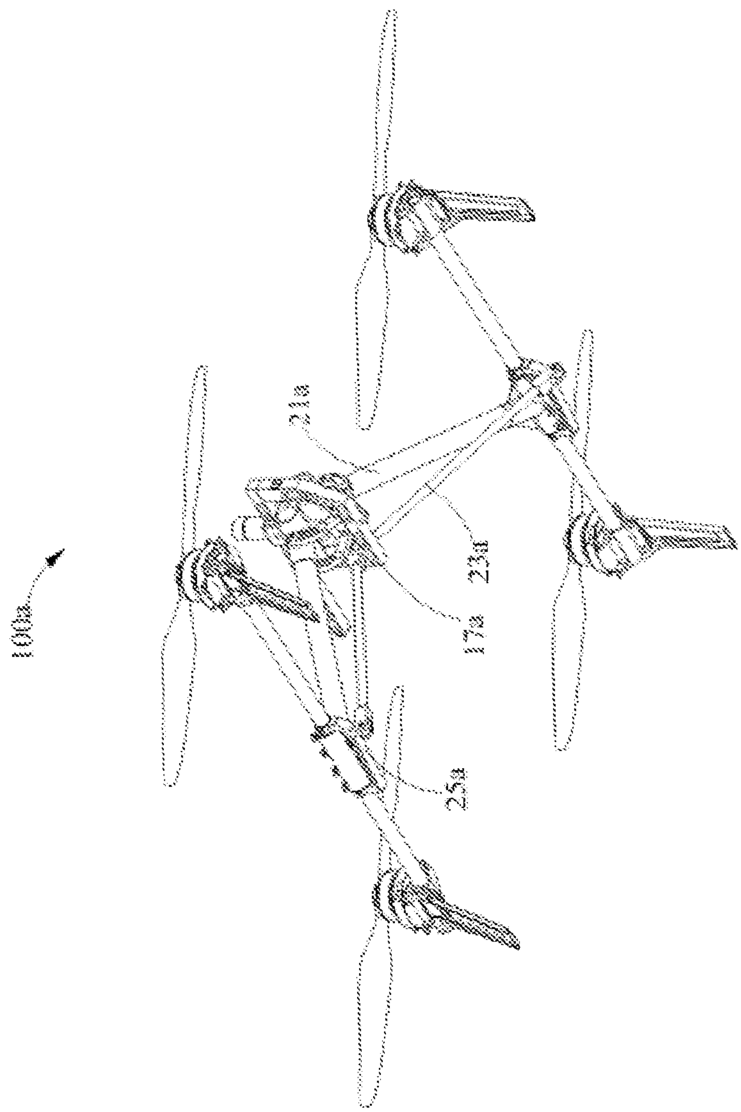

FIG. 8

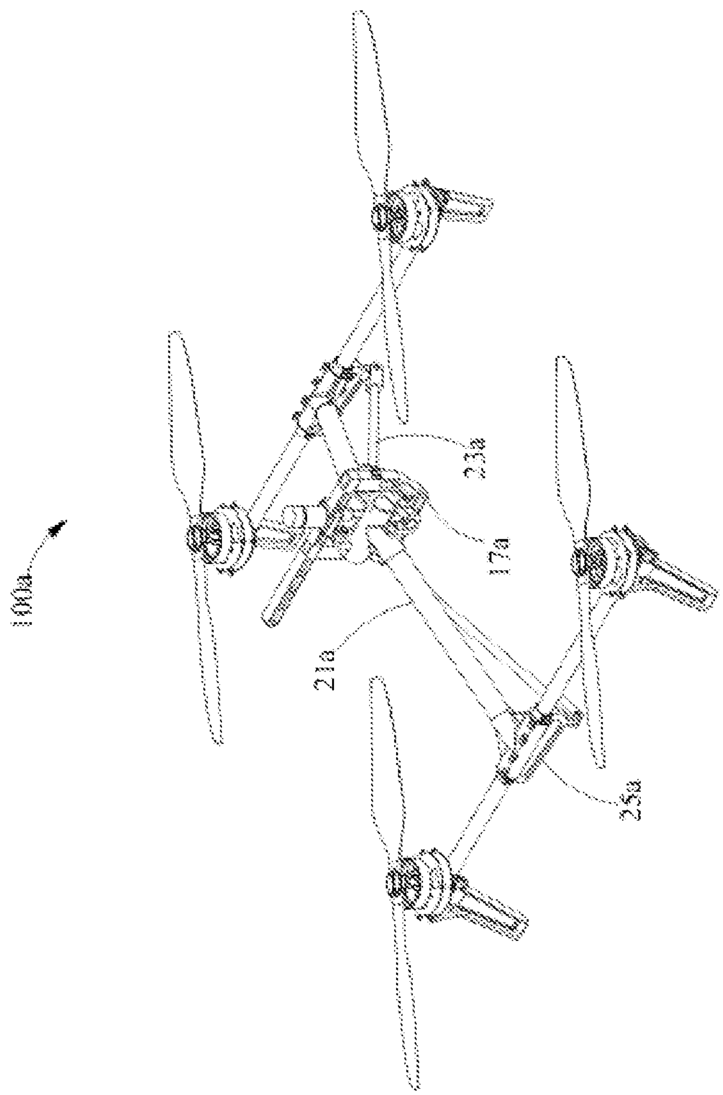

FIG. 9

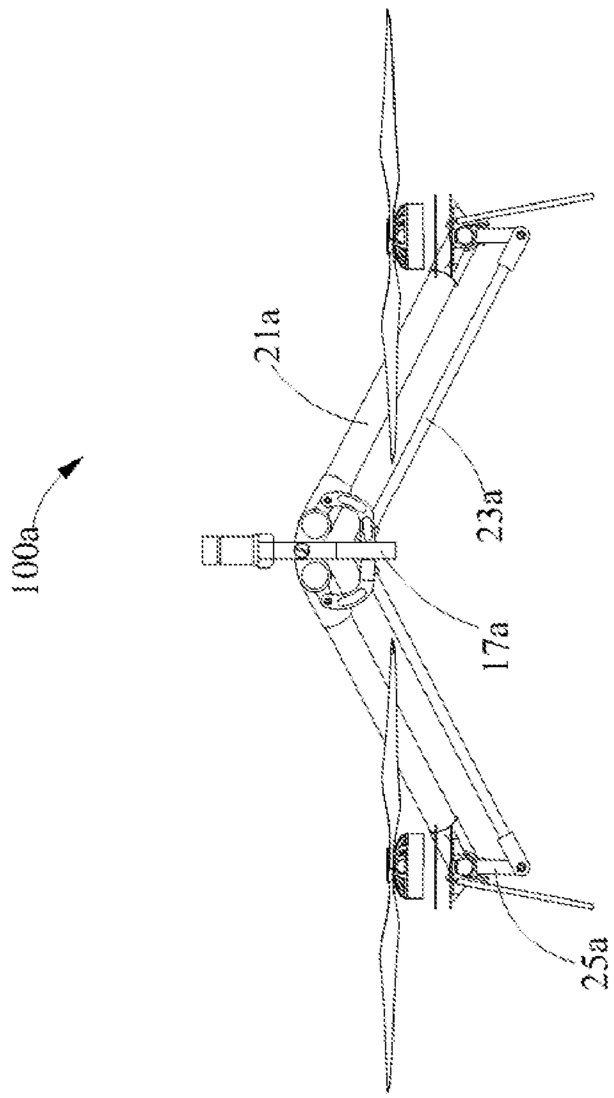

FIG. 10

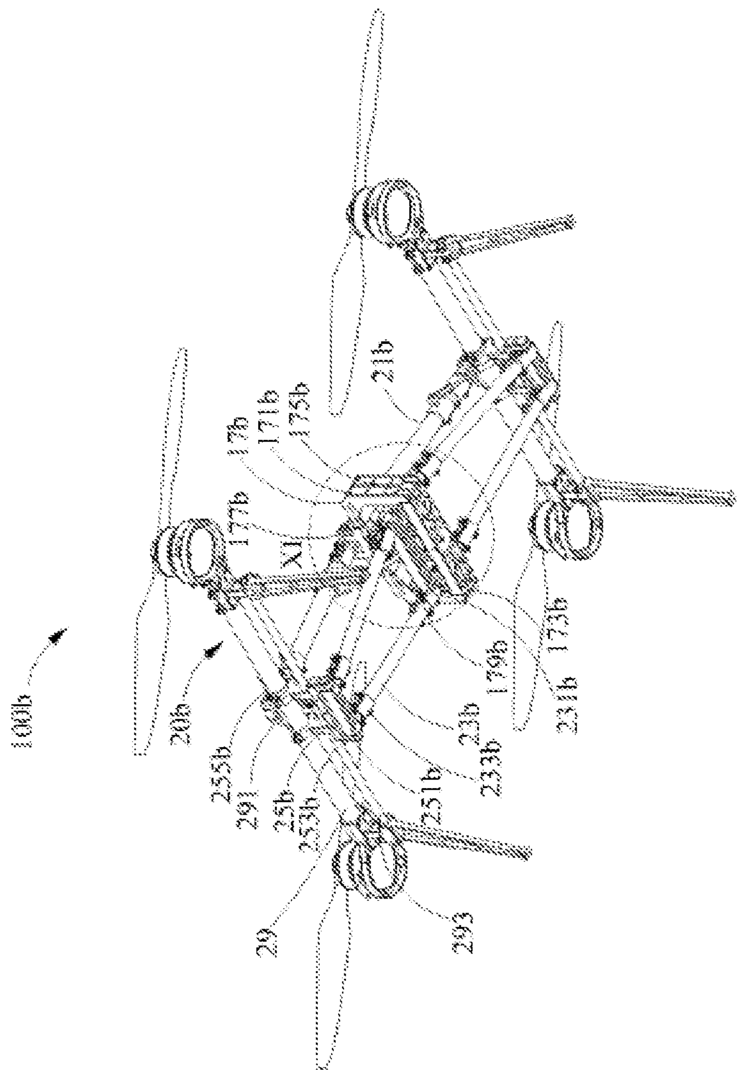
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FIG. 11

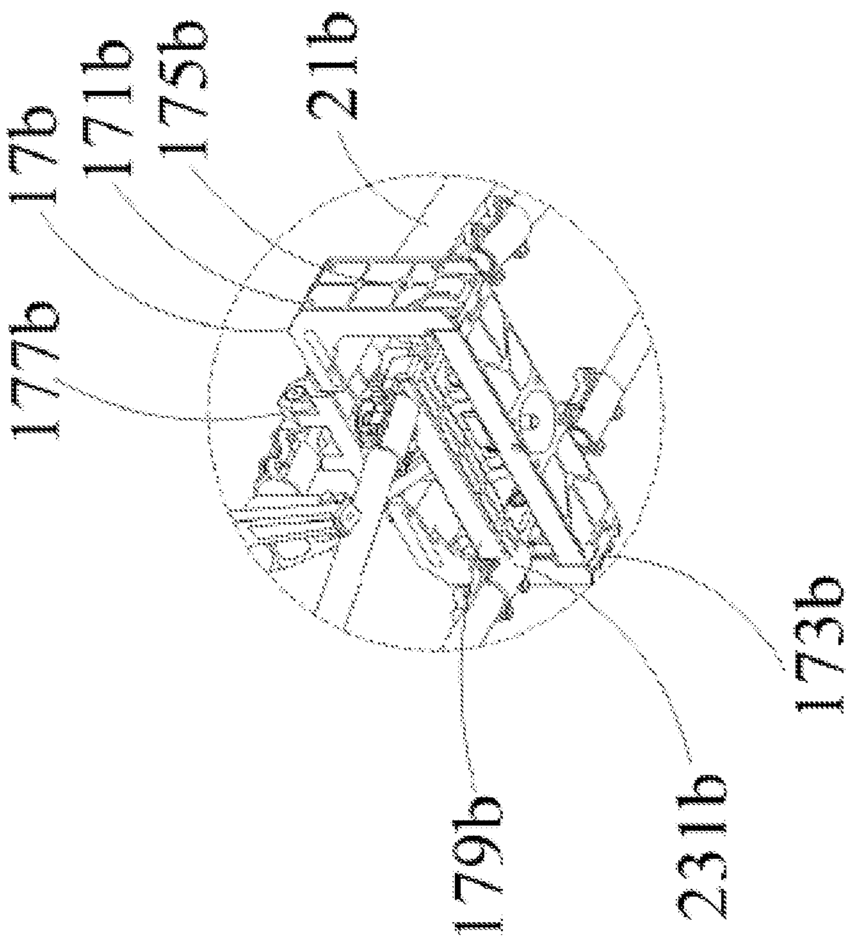

FIG. 12

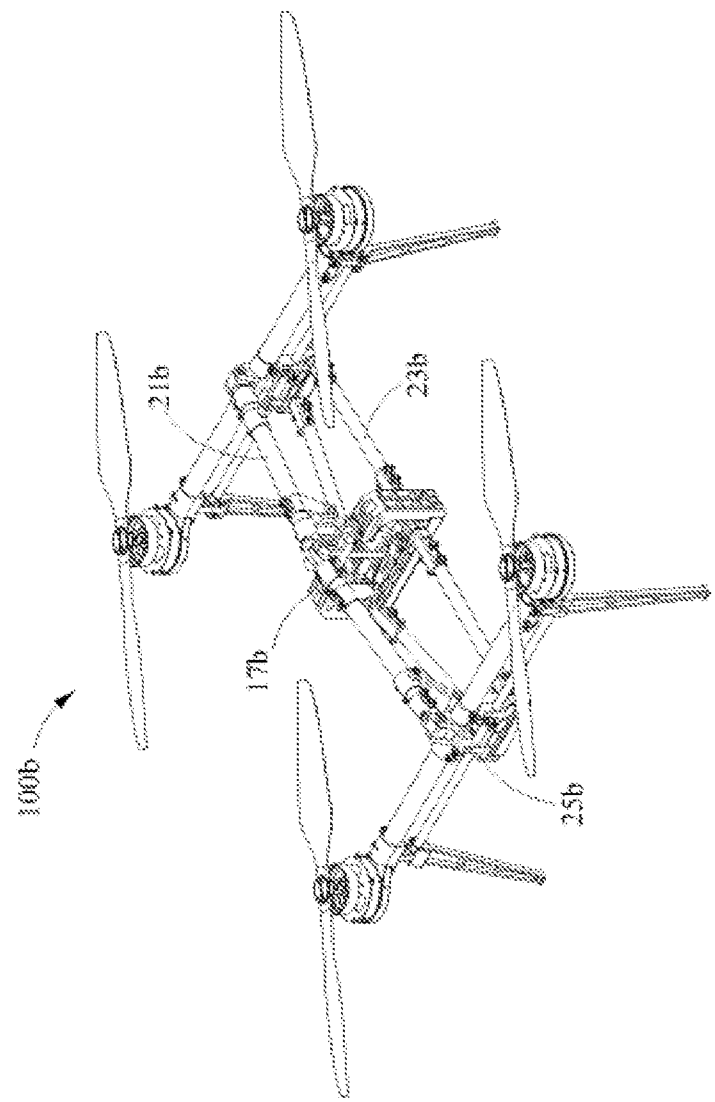

FIG. 13

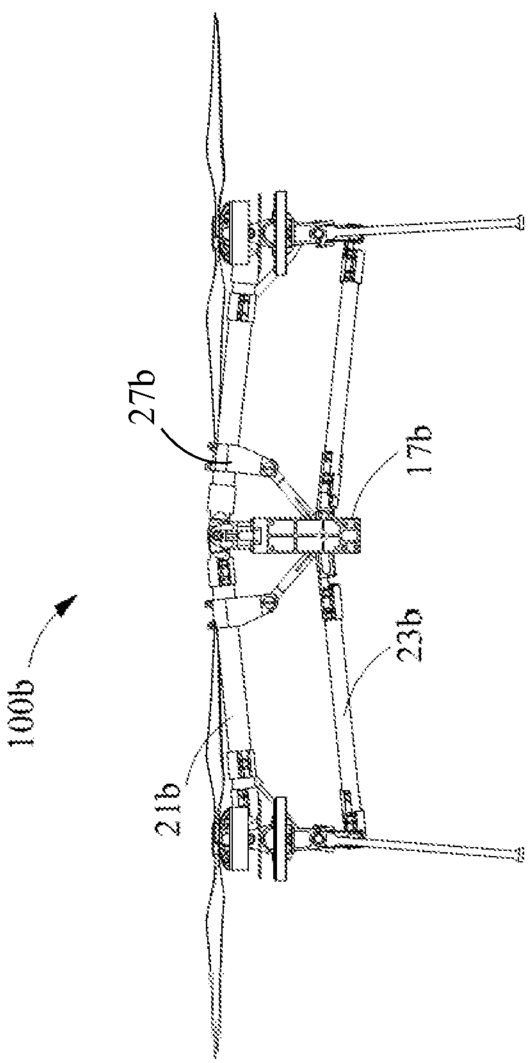

FIG. 14

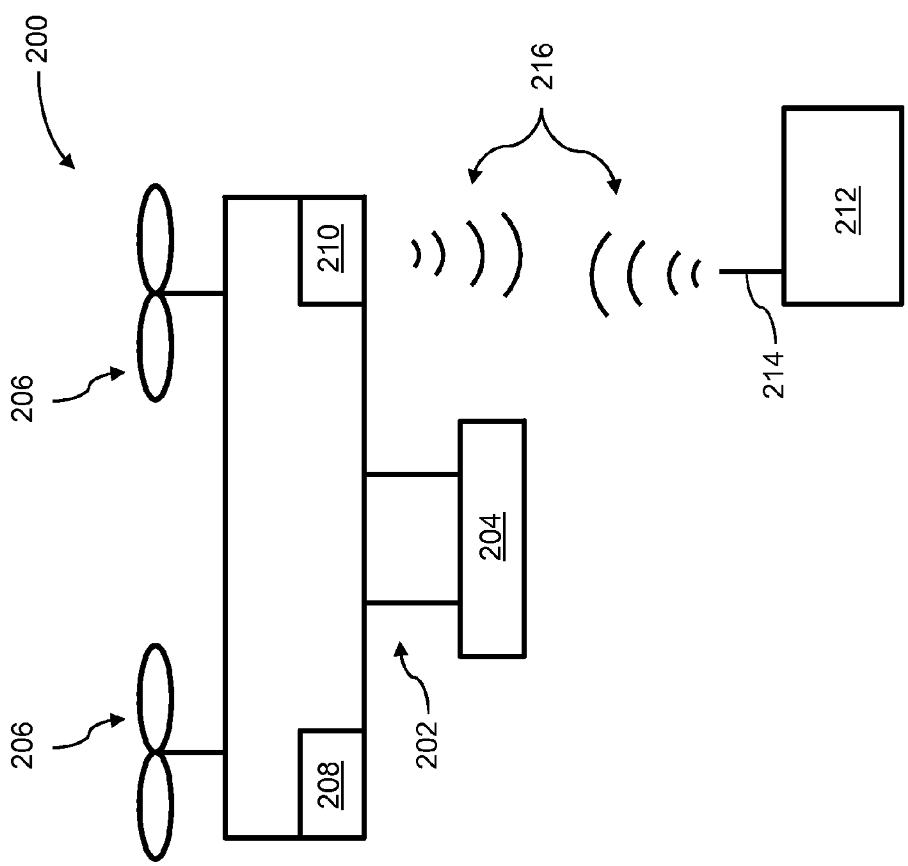

FIG. 15

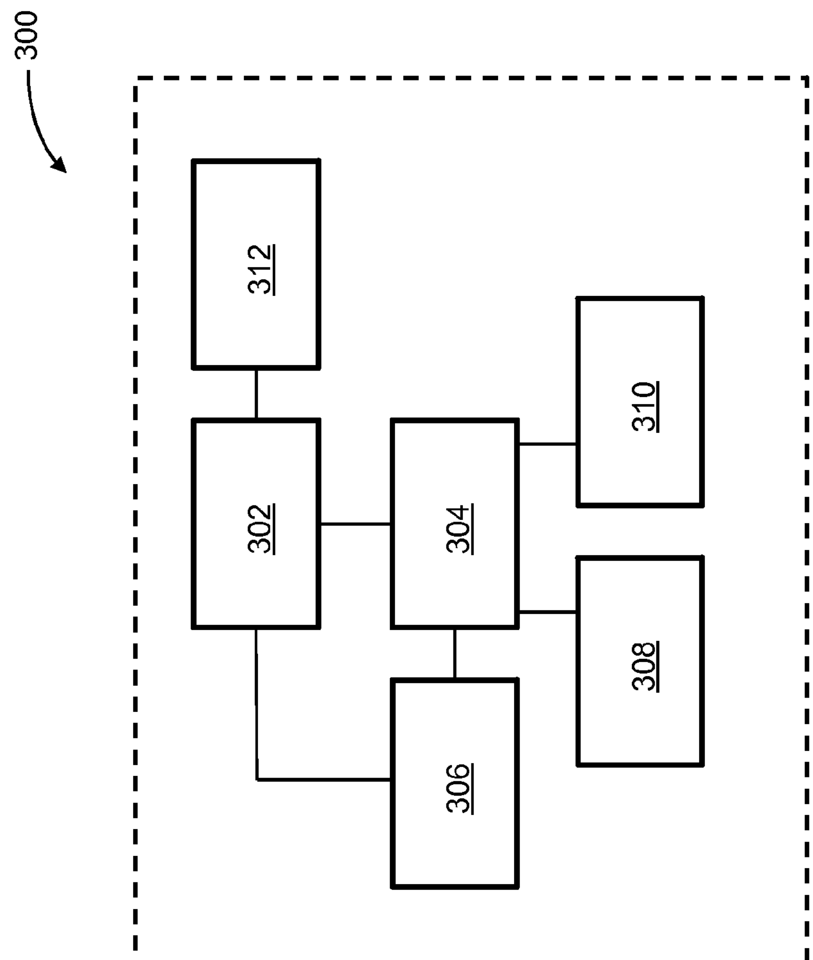

FIG. 16

TRANSFORMABLE AERIAL VEHICLE

CROSS-REFERENCE

This application is a continuation application of U.S. application Ser. No. 14/167,679, filed on Jan. 29, 2014, which is a continuation application of International Application No. PCT/CN2013/090470, filed Dec. 25, 2013, which claims the benefit of Chinese Application No. 201310008317.5, filed Jan. 10, 2013. The disclosures of these applications are hereby incorporated by reference in their entirety.

BACKGROUND

Unmanned vehicles can be used for performing surveillance, reconnaissance, and exploration tasks for military and civilian applications. Unmanned vehicles may be outfitted with a functional payload, such as sensors for collecting data from the surrounding environment. For example, remote-controlled unmanned aerial vehicles, which include fixed-wing aircraft and rotary-wing aircraft, can be used to provide aerial imagery of otherwise inaccessible environments.

The design of such unmanned vehicles involves tradeoffs between vehicle size, weight, payload capacity, energy consumption, and cost. Additionally, the vehicle design should provide sufficient functional space for the payload to operate. In some instances, existing unmanned aerial vehicle designs can be less than ideal for providing unobstructed viewing angles for a payload camera, such as when the visual space is obscured by the vehicle frame.

SUMMARY

A need exists for improvements in the structure and design of vehicles such as unmanned aerial vehicles. The present invention provides systems, devices and methods for a transformable aerial vehicle. In some embodiments, the systems, devices and methods described herein provide an aerial vehicle capable of transforming from a first configuration to a second configuration in order to increase the functional space of a coupled payload. Advantageously, the disclosed systems, devices and methods obviate the need for increasing the size of the aerial vehicle or providing additional mounting structures for the payload to increase the payload functional space.

In one aspect of the present disclosure, a transformable aerial vehicle is described. The transformable aerial vehicle includes: a central body; at least two transformable frame assemblies respectively disposed on the central body, each of the at least two transformable frame assemblies having a proximal portion pivotally coupled to the central body and a distal portion; an actuation assembly mounted on the central body and configured to pivot the at least two transformable frame assemblies to a plurality of different vertical angles relative to the central body; and a plurality of propulsion units mounted on the at least two transformable frame assemblies and operable to move the transformable aerial vehicle.

In another aspect of the present disclosure, a transformable aerial vehicle is described. The transformable aerial vehicle includes: a central body; at least two transformable frame assemblies respectively disposed on the central body, each of the at least two transformable frame assemblies having a proximal portion coupled to the central body and a distal portion; an actuation assembly configured to transform the at least two transformable frame assemblies between a first configuration and a second configuration; and a plurality of propulsion units mounted on the at least two transformable frame assemblies and operable to move the transformable aerial vehicle, wherein the first configuration includes the propulsion units being positioned above the central body and the second configuration includes the propulsion units being positioned below the central body.

In another aspect of the present disclosure, a transformable aerial vehicle is described. The transformable aerial vehicle includes: a central body coupled to a payload; at least two transformable frame assemblies respectively disposed on the central body, each of the at least two transformable frame assemblies having a proximal portion coupled to the central body and a distal portion; an actuation assembly mounted on the central body and configured to transform the at least two transformable frame assemblies between a first configuration and a second configuration, wherein the first configuration permits the at least two transformable frame assemblies to support the transformable aerial vehicle resting on a surface, and wherein the second configuration increases a functional space of the payload; and a plurality of propulsion units mounted on the at least two transformable frame assemblies and operable to move the transformable aerial vehicle.

In some embodiments, the transformable aerial vehicle in an unmanned aerial vehicle.

In some embodiments, the at least two transformable frame assemblies include a primary shaft and at least one secondary shaft extending parallel to the primary shaft, the primary shaft and the at least one secondary shaft respectively pivotally coupled to the central body, wherein the primary shaft and the at least one secondary shaft are coupled to each other such that actuation of the primary shaft by the actuation assembly produces a corresponding actuation of the at least one secondary shaft.

In some embodiments, the actuation assembly includes a linear actuator, and a portion of each of the at least two transformable frame assemblies is coupled to the linear actuator. The linear actuator can include a screw and nut mechanism, and the portion of each of the at least two transformable frame assemblies can be coupled to the nut.

In some embodiments, each of the plurality of propulsion units includes a rotor. The rotor can be oriented horizontally relative to the transformable aerial vehicle.

In some embodiments, the transformable aerial vehicle further includes a receiver, the receiver configured to receive user commands for controlling one or more of the actuation assembly and the plurality of propulsion units. The user commands can be transmitted from a remote terminal.

In some embodiments, the transformable aerial vehicle further includes a payload coupled to the central body. The payload can include an image capturing device.

In some embodiments, the actuation assembly is configured to pivot the at least two transformable frame assemblies between a first vertical angle and a second vertical angle. At the first vertical angle, the at least two transformable frame assemblies may be angled downwards relative to the central body, and at the second vertical angle, the at least two transformable frame assemblies may be angled upwards relative to the central body.

In some embodiments, the at least two transformable frame assemblies are transformed into the first configuration during a first phase of operation of the transformable aerial vehicle and transformed into the second configuration during a second phase of operation of the transformable aerial vehicle. The first phase of operation may include the transformable aerial vehicle flying in air, and the second phase of operation may include the transformable aerial vehicle taking off from a surface and/or landing on the surface.

In some embodiments, the payload includes an image capturing device, and the functional space includes an unobstructed field of view of the image capturing device.

In some embodiments, the at least two transformable frame assemblies each include a support member configured to support the transformable aerial vehicle resting on a surface.

In some embodiments, in the first configuration, the at least two transformable frame assemblies are angled downwards relative to the central body, and in the second configuration angle, the at least two transformable frame assemblies are angled upwards relative to the central body.

In another aspect, a method for controlling a transformable aerial vehicle is provided. The method includes: providing the aforementioned transformable aerial vehicle; and driving the actuation assembly mounted on the central body to pivot the at least two transformable frame assemblies to a plurality of different vertical angles relative to the central body.

In another aspect, a method for controlling a transformable aerial vehicle is provided. The method includes: providing the aforementioned transformable aerial vehicle; and driving the actuation assembly mounted on the central body to transform the at least two transformable frame assemblies between the first configuration and the second configuration.

It shall be understood that different aspects of the invention can be appreciated individually, collectively, or in combination with each other. Various aspects of the invention described herein may be applied to any of the particular applications set forth below or for any other types of movable objects. Although the systems, devices, and methods described herein are generally presented in the context of aerial vehicles, this is not intended to be limiting, as the following embodiments can be applied to any suitable movable object. Any description herein of an aerial vehicle may apply to and be used for any movable object, such as any vehicle. Additionally, the systems, devices, and methods disclosed herein in the context of aerial motion (e.g., flight) may also be applied in the context of other types of motion, such as movement on the ground or on water, underwater motion, or motion in space.

Other objects and features of the present invention will become apparent by a review of the specification, claims, and appended figures.

INCORPORATION BY REFERENCE

All publications, patents, and patent applications mentioned in this specification are herein incorporated by reference to the same extent as if each individual publication, patent, or patent application was specifically and individually indicated to be incorporated by reference.

BRIEF DESCRIPTION OF THE DRAWINGS

The novel features of the invention are set forth with particularity in the appended claims. A better understanding of the features and advantages of the present invention will be obtained by reference to the following detailed description that sets forth illustrative embodiments, in which the principles of the invention are utilized, and the accompanying drawings of which:

FIG. **1** illustrates a transformable unmanned aerial vehicle in a flight configuration, in accordance with embodiments;

FIG. **2** is a closer view of the region II of FIG. **1**, in accordance with embodiments;

FIG. **3** illustrates the transformable unmanned aerial vehicle of FIG. **1** in a landing configuration, in accordance with embodiments;

FIG. **4** is a side view of the transformable unmanned aerial vehicle of FIG. **1** in a landing configuration, in accordance with embodiments;

FIG. **5** illustrates another example of a transformable unmanned aerial vehicle in a flight configuration, in accordance with embodiments;

FIG. **6** is a closer view of the region VI of FIG. **5**, in accordance with embodiments;

FIG. **7** is a side view of the transformable unmanned aerial vehicle of FIG. **5** in a flight configuration, in accordance with embodiments;

FIG. **8** illustrates the transformable unmanned aerial vehicle of FIG. **5** in a landing configuration, in accordance with embodiments;

FIG. **9** also illustrates the transformable unmanned aerial vehicle of FIG. **5** in a landing configuration, in accordance with embodiments;

FIG. **10** is a side view of the transformable unmanned aerial vehicle of FIG. **5** in a landing configuration, in accordance with embodiments;

FIG. **11** illustrates yet another example of a transformable unmanned aerial vehicle in a landing configuration, in accordance with embodiments;

FIG. **12** is a closer view of the region XI of FIG. **11**, in accordance with embodiments;

FIG. **13** also illustrates the transformable unmanned aerial vehicle of FIG. **11** in a landing configuration, in accordance with embodiments; and

FIG. **14** is a side view of the transformable unmanned aerial vehicle of FIG. **11** in a landing configuration, in accordance with embodiments;

FIG. **15** illustrates an aerial vehicle including a carrier and a payload, in accordance with embodiments; and

FIG. **16** is a schematic illustration by way of block diagram of a system for controlling an aerial vehicle, in accordance with embodiments.

DETAILED DESCRIPTION

The present invention provides systems, devices and methods for a transformable aerial vehicle. The systems, devices, and methods described herein can be used to transform an aerial vehicle between a plurality of different configurations. Each configuration can be optimized for a specified function of the aerial vehicle. For example, a configuration may provide increased functional space for a payload coupled to the aerial vehicle, such as an increased field of view for a camera mounted onto the aerial vehicle. When desired, a configuration may provide support for the aerial vehicle when resting on a surface, such as by means of support members configured to raise the body of the aerial vehicle off the ground.

In one aspect, the present invention provides a transformable aerial vehicle having one or more of the unique features disclosed below. In one embodiment, a transformable aerial vehicle comprises: a central body; at least two transformable frame assemblies respectively disposed on the central body, each of the at least two transformable frame assemblies having a proximal portion pivotally coupled to the central body and a distal portion; an actuation assembly mounted on the central body and configured to pivot the at least two transformable frame assemblies to a plurality of different vertical angles relative to the central body; and a plurality of propulsion units mounted on the at least two transformable frame assemblies and operable to move the transformable aerial vehicle.

A transformable aerial vehicle of the present invention can include a central body and at least two transformable frame assemblies disposed respectively on the central body. A plurality of propulsion units can be mounted on the transformable frame assemblies and coupled thereby to the central body. The propulsion units can be used to enable the transformable aerial vehicle to take off, land, hover, and move in the air with respective to up to three degrees of freedom of translation and up to three degrees of freedom of rotation. The propulsion units can be mounted on any suitable portion of the transformable frame assemblies, such as at or near the distal portions of the transformable frame assemblies.

The proximal portions of the transformable frame assemblies can be pivotally coupled to the central body, thus enabling the transformable frame assemblies to transform by pivoting relative to the central body. For example, in some embodiments, the transformable frame assemblies can be pivoted through a plurality of vertical angles relative to the central body (e.g., a vertical angle **50** measured from the line **51**, as depicted in FIG. **4**). The transformation of the transformable frame assemblies can be actuated by a suitable actuation assembly mounted on the central body and coupled to the transformable frame assemblies. Advantageously, this approach allows the vertical angle of the transformable frame assemblies to be adjusted as needed during operation of the transformable aerial vehicle.

In another embodiment, the present invention provides an alternative transformable aerial vehicle having the following features. The transformable aerial vehicle comprises: a central body coupled to a payload; at least two transformable frame assemblies respectively disposed on the central body, each of the at least two transformable frame assemblies having a proximal portion pivotally coupled to the central body and a distal portion; an actuation assembly mounted on the central body and configured to pivot the at least two transformable frame assemblies between a first configuration and a second configuration, wherein the first configuration permits the at least two transformable frame assemblies to support the transformable aerial vehicle resting on a surface, and wherein the second configuration increases a functional space of the payload; and a plurality of propulsion units mounted on the at least two transformable frame assemblies and operable to move the transformable aerial vehicle.

The central body, transformable frame assemblies, propulsion units, and actuation assembly disclosed above are equally applicable to this embodiment. Where desired, such transformable frame assemblies can be modified to be transformable to a first configuration supporting the transformable aerial vehicle resting on a surface (e.g., the ground). For example, the transformable frame assemblies can include a plurality of support members suitable for supporting the transformable aerial vehicle such that the central body does not contact the surface.

In some instances, however, an alternative configuration may be more useful. For example, the central body of the transformable aerial vehicle can be modified to mount a payload. The payload can be coupled to any suitable portion of the central body, such as on top, underneath, on the front, on the back, or on the sides of the central body. The payload can be configured to perform a function or operation. The function or operation of the payload may require a certain amount of functional space. The functional space can be, for example, a space occupied, affected, manipulated, or otherwise used by the payload during its operation. In some instances, however, the functional space may be obstructed by a portion of the transformable aerial vehicle. For example, when in the first configuration, the transformable frame assemblies may extend into the functional space, thereby interfering with the operation of the payload.

Accordingly, the transformable frame assemblies can be modified to be transformable to a second configuration increasing the functional space of a coupled payload, thus enabling or enhancing the ability of the payload to perform its function. Furthermore, the actuation assembly can be modified to transform the transformable frame assemblies between the first and second configurations, thereby allowing the structure of the transformable aerial vehicle to be optimized for multiple functionalities.

In another embodiment, the present invention provides another alternative transformable aerial vehicle having the following features. The transformable aerial vehicle comprises: a central body coupled to a payload; at least two transformable frame assemblies respectively disposed on the central body, each of the at least two transformable frame assemblies having a proximal portion pivotally coupled to the central body and a distal portion; an actuation assembly mounted on the central body and configured to pivot the at least two transformable frame assemblies between a first configuration and a second configuration; and a plurality of propulsion units mounted on the at least two transformable frame assemblies and operable to move the transformable aerial vehicle, wherein the first configuration includes the propulsion units being positioned above the central body and the second configuration includes the propulsion units being positioned below the central body.

The central body, transformable frame assemblies, propulsion units, and actuation assembly disclosed above are equally applicable to this embodiment. Where desired, the transformable frame assemblies can be modified to be transformable between a first configuration and a second configuration, such that the propulsion units are positioned above the central body in the first configuration and below the central body in the second configuration. Advantageously, this approach allows the height of the propulsion units to be adjusted as needed during operation of the transformable aerial vehicle.

In a separate aspect, the present invention provides a method for controlling a transformable aerial vehicle. In one embodiment, the method comprises providing a transformable aerial vehicle, the transformable aerial vehicle comprising: a central body; at least two transformable frame assemblies respectively disposed on the central body, each of the at least two transformable frame assemblies having a proximal portion pivotally coupled to the central body and a distal portion; an actuation assembly mounted on the central body and configured to pivot the at least two transformable frame assemblies to a plurality of different vertical angles relative to the central body; and a plurality of propulsion units mounted on the at least two transformable frame assemblies and operable to move the transformable aerial vehicle. The method comprises driving the actuation assembly mounted on the central body to pivot the at least two transformable frame assemblies to a plurality of different vertical angles relative to the central body.

A method of controlling a transformable aerial vehicle can include providing a transformable aerial vehicle having transformable frame assemblies pivotally coupled to a central body and transformable between a plurality of different vertical angles, as described above. The method can include driving the actuation assembly with a suitable drive unit (e.g., a motor or engine) to transform the transformable frame assemblies between the plurality of different vertical angles. The driving of the actuation assembly can occur automatically (e.g., based on a state of the transformable aerial vehicle, such as the altitude, longitude, or latitude) or in response to a user command. The method can be applied, for example, to adjust the vertical angle of the transformable frame assemblies during the operation of the transformable aerial vehicle.

In another embodiment, the present invention provides an alternative method for controlling a transformable aerial vehicle having the following steps. The method comprises providing a transformable aerial vehicle, the transformable aerial vehicle comprising: a central body coupled to a payload; at least two transformable frame assemblies respectively disposed on the central body, each of the at least two transformable frame assemblies having a proximal portion pivotally coupled to the central body and a distal portion; an actuation assembly mounted on the central body and configured to pivot the at least two transformable frame assemblies between a first configuration and a second configuration, wherein the first configuration permits the at least two transformable frame assemblies to support the transformable aerial vehicle resting on a surface, and wherein the second configuration increases a functional space of the payload; and a plurality of propulsion units mounted on the at least two transformable frame assemblies and operable to move the transformable aerial vehicle. The method comprises driving the actuation assembly mounted on the central body to transform the at least two transformable frame assemblies between the first configuration and the second configuration.

A method of controlling a transformable aerial vehicle can include providing a transformable aerial vehicle having transformable frame assemblies transformable between a first configuration supporting the transformable aerial vehicle on a surface and a second configuration increasing the functional space of a payload, as disclosed above. The method can include driving the actuation assembly with a suitable drive unit to transform the transformable frame assemblies between the first and second configurations. For example, the actuation assembly can be driven to transform the transformable frame assemblies to the first configuration when the transformable aerial vehicle is taking off from a surface or landing on a surface. The actuation assembly can drive the transformation to the second configuration when the transformable aerial vehicle is in a state suitable for operating the payload, such as during flight.

In another embodiment, the present invention provides another alternative method for controlling a transformable aerial vehicle having the following steps. The method comprises providing a transformable aerial vehicle comprising: a central body coupled to a payload; at least two transformable frame assemblies respectively disposed on the central body, each of the at least two transformable frame assemblies having a proximal portion pivotally coupled to the central body and a distal portion; an actuation assembly mounted on the central body and configured to pivot the at least two transformable frame assemblies between a first configuration and a second configuration; and a plurality of propulsion units mounted on the at least two transformable frame assemblies and operable to move the transformable aerial vehicle, wherein the first configuration includes the propulsion units being positioned above the central body and the second configuration includes the propulsion units being positioned below the central body. The method comprises driving the actuation assembly mounted on the central body to transform the at least two transformable frame assemblies between the first configuration and the second configuration.

A method of controlling a transformable aerial vehicle can include providing a transformable aerial vehicle having transformable frame assemblies transformable between a first configuration, in which the propulsion units are positioned above the central body, and a second configuration, in which the propulsion units are positioned below the central body, as described above. The method can include driving the actuation assembly with a suitable drive unit to transform the transformable frame assemblies between the first and second configurations. As previously described, the driving of the actuation assembly can occur automatically or in response to a user command. The method can be applied, for example, to adjust the height of the propulsion units during the operation of the transformable aerial vehicle.

Referring now to FIGS. **1**-**4**, a transformable unmanned aerial vehicle (UAV) **100** can include a central body **10** and transformable frame assemblies **20** disposed respectively on the central body **10**. A plurality of propulsion units **30** are mounted respectively on the transformable frame assemblies **20**. The terms "propulsion support frames," "propulsion support assemblies," "transformable assemblies," and "transformable structures," may also be used to refer to the transformable frame assemblies **20**.

The central body **10** of the UAV **100** can be used to support a load, such as a carrier and/or payload as described in further detail elsewhere herein. The load can be coupled to any suitable portion of the central body **10**, such as the bottom or underside of the central body **10**. The coupling can be a rigid coupling, or it can permit motion of the load with respect to the central body.

The coupled load can be a payload configured to perform a function, such as a sensor, emitter, tool, instrument, manipulator, or any other functional device. For example, the payload may be an image capturing device. In some instances, the image capturing device may be a camera pointing downwards relative to the central body **10**. The camera can be configured to rotate relative to the central body **10** (e.g., via a carrier or other mounting platform) in order to capture images from a plurality of viewing angles. Any description herein of a camera payload can be applied to other types of payload devices.

The payload can be associated with a functional space. The functional space can be a space occupied, affected, manipulated, or otherwise used by the payload during its operation, as previously described herein. For example, the functional space of a sensor can be the space from which the sensor can collect data. In some instances, the functional space of a camera or other image capture device can be an unobstructed field of view or viewing angles of the camera. For a tool, instrument or manipulator mechanism, the functional space can be an unobstructed working range or movement range. For example, a functional space of an emitter (e.g., illumination source) may be an unobstructed area which may receive emissions (e.g., illumination) from the emitter. The functional space of a payload can be of a fixed size or a variable size. In some embodiments, the functional space can be increased or decreased. For example, the functional space may be increased or decreased by a transformation of the UAV **100**, as described in further detail below.

The propulsion units **30** can be used to enable the UAV **100** to take off, land, hover, and move in the air with respective to up to three degrees of freedom of translation and up to three degrees of freedom of rotation. In some embodiments, the propulsion units **30** can include one or more rotors. The rotors can include one or more rotor blades coupled to a shaft. The rotor blades and shaft can be driven to rotate by a suitable drive mechanism, such as a motor. Although the propulsion units **30** of the unmanned aerial vehicle **100** are depicted as four rotors, any suitable number, type, and/or arrangement of propulsion units can be used. For example, the number of rotors may be one, two, three, four, five, six, seven, eight, or more. The rotors may be oriented vertically, horizontally, or at any other suitable angle with respect to the UAV **100**. The angle of the rotors may be fixed or variable. The distance between shafts of opposite rotors can be any suitable distance, such as less than or equal to 2 m, less than equal to 5 m. Optionally, the distance can be within a range from 40 cm to 1 m, from 10 cm to 2 m, or from 5 cm to 5 m. The propulsion units **30** can be driven by any suitable motor, such as a DC motor (e.g., brushed or brushless) or an AC motor. In some embodiments, the motor can be adapted to mount and drive a rotor blade.

The transformable frame assemblies **20** can be used to couple the propulsion units **30** to the central body **10**. The proximal portion of each transformable frame assembly **20** can be coupled to the central body **10**, and the propulsion units **30** can be mounted on any suitable portion of the transformable frame assemblies **20**, such as at or near the distal portions of the transformable frame assemblies **20**. Alternatively, the propulsion units **30** can be mounted at or near the proximal end. The propulsion units **30** can be mounted at or near a point within about $\frac{1}{10}$, $\frac{1}{5}$, $\frac{1}{4}$, $\frac{1}{3}$, $\frac{1}{2}$, $\frac{3}{4}$, $\frac{2}{3}$, $\frac{4}{5}$, or $\frac{9}{10}$ along the length of the transformable frame assembly **20** as measured from the distal end. The UAV **100** can include any suitable number of transformable frame assemblies **20**, such as one, two, three, four, or more. In some embodiments, the UAV **100** includes at least two transformable frame assemblies **20**. The transformable frame assemblies **20** can be situated symmetrically or asymmetrically around the central body **10**. Each transformable frame assembly **20** can be used to support a single propulsion unit, or multiple propulsion units. The propulsion units **30** can be evenly distributed among the transformable frame assemblies **20**. Alternatively, each transformable frame assembly **20** can have a different number of propulsion units **30**.

In some embodiments, the transformable frame assemblies **20** can support the propulsion units using via a cross bar or other similar support structure. For example, a transformable frame assembly **20** can include a cross bar located at the distal end or near the distal end of the transformable frame assembly **20**. The cross bar may be arranged at a suitable angle relative to the transformable frame assembly **20**, such as extending perpendicular or approximately perpendicular to the transformable frames assembly **20**. The cross bar can be coupled to the transformable frame assembly **20** via any suitable portion of the cross bar, such as at or near the midpoint of the cross bar. The cross bar can be configured to support a plurality of propulsion units **30** (e.g., one, two, three, four, or more propulsion units). The propulsion units **30** may be mounted onto any suitable portion of the cross bar. For example, the propulsion units **30** may be disposed on or near each of the ends of the cross bar. The propulsion units **30** may be distributed symmetrically on the cross bar, such as with one propulsion unit at each end of the cross bar. Alternatively, the propulsion units **30** may be distributed asymmetrically on the cross bar.

Optionally, one or more of the transformable frame assemblies **20** can include a support member **40**. The support member **40** can be a linear, curved, or curvilinear structure. In some instances, each of the transformable frame assemblies **20** has a corresponding support member **40**. The support member **40** can be used to support the UAV **10** on a surface (e.g., before takeoff or after takeoff). For example, each support member **40** can contact the surface at one, two, three, four, or more points of contact. Optionally, the support member **40** is configured to support the UAV **100** on a surface upon landing or before takeoff such that the other portions of the transformable frame assemblies **20** and the central body **10** do not touch the surface. The support member **40** can be situated at any suitable of the transformable frame assemblies **20**, such as at or near the distal end or the proximal end. The support member **40** can be mounted at or near a point within about $\frac{1}{10}$, $\frac{1}{5}$, $\frac{1}{4}$, $\frac{1}{3}$, $\frac{1}{2}$, $\frac{3}{4}$, $\frac{2}{3}$, $\frac{4}{5}$, or $\frac{9}{10}$ along the length of the transformable frame assembly **20** as measured from the distal end. In some embodiments, the support member **40** can be situated on the transformable frame assembly **20** near the propulsion unit **30**, such as under the propulsion unit **30**. The support member **40** may be coupled to the propulsion unit **30**. The support member **40** may be static. Alternatively, the support member **40** may be movable relative the transformable frame assembly **20**, such as by sliding, rotating, telescoping, folding, pivoting, extending, shrinking, and the like.

The transformable frame assemblies **20** can be configured to transform between a plurality of different configurations, such as between two, three, four, five, six, or more. The UAV **100** can be designed to transform between the plurality of different configurations in a fixed sequence. Alternatively, the UAV **100** may be able to transform between the plurality of different configurations in any order. Transforming from a first configuration to a second configuration may involve transforming through a plurality of intermediate or transitional configurations. The UAV **100** may be able to stop the transformation at an intermediate configuration, or may be able to stop the transformation only once the end configuration has been reached. A configuration can be maintained by the UAV **100** indefinitely, or only for a set amount of time. Some configurations may only be usable during certain phases of operation of the UAV **100** (e.g., when the UAV **100** is on the ground, during takeoff, during landing, or during flight). Alternatively, some configurations may be usable during any phase of operation. For example, it may be optimal for the transformable frame assemblies **20** to assume a first configuration during a first phase of operation (e.g., a landing configuration before takeoff and/or after landing) and a second configuration during a second phase of operation (e.g., a flight configuration during flight). Any number of configurations can be used during operation of the UAV **100**.

In some embodiments, each of the plurality of configurations provides a different functionality to the UAV **100**. For example, a first configuration can enable the UAV **100** to be supported on a surface by the support members **40**. In some instances, the first configuration may be a landing or surface-contacting configuration in which the UAV **100** may be supported on a surface with a payload or central body **10** not contacting the surface. A second configuration can increase a functional space of a payload coupled to the central body **10**. For example, the second configuration may be a flight configuration that reduces interference of one or more components of the UAV **100** with the functioning of the payload. The transformation of the UAV **100** to the second configuration can be used to move the transformable frame assemblies **20** out of the field of view of a payload camera in order to provide an unobstructed viewing angle (e.g., a 360° viewing angle) or increase a field of view. In another example, transformation of the UAV **100** to a second configuration may include moving the transformable frame assemblies **20** so they do not obstruct one or more types of sensors or emitters, or reduce interference with one or more types of sensors or emitters. Alternatively or in combination, the transformation to the second configuration can increase the available maneuvering space for a robotic arm coupled to the underside of the central body **10**. The functional space may be increased by a transformation achieving one or more of: removing an obstruction from the functional space, changing a shape of the functional space, changing a shape of a portion of the UAV **100**, or changing the position and/or orientation of the payload. In some instances, the functional space of the payload may be at least partially obstructed by the UAV **100** (e.g., by the transformable frame assemblies **20**) in the first configuration, and the obstruction can be removed by transforming to the second configuration.

The transformation of the transformable frame assemblies **20** can involve a motion of one or more portions of the transformable frame assemblies **20**, such as translating, rotating, folding, unfolding, telescoping, extending, or shrinking motions. The transformation can include a single type of motion, or a plurality of different type of motions. The transformable frame assemblies **20** may be mutually coupled such that they are transformed simultaneously, or they may be configured to be transformed independently. A transformation can involve transforming all of the transformable frame assemblies **20** or only some of the transformable frame assemblies **20**.

In some embodiments, the transformable frame assemblies **20** are pivotally coupled to the central body **10**, thereby enabling the transformable frame assemblies **20** to transform by rotation (about to up to three axes of rotation) relative to the central body **10**. For example, the transformable frame assemblies **20** can be pivoted through a plurality of vertical angles relative to the central body **10**. A vertical angle can be defined as an angle **50** formed by a portion of the transformable frame assembly **20** as measured from the line **51**, as depicted in FIG. **4**. The transformable frame assemblies **20** can be pivoted to a vertical angle less than 90° such that the distal portions are approximately positioned above the central body **10** (hereinafter "upwards," e.g., FIG. **1**). In some instances, the transformable frame assemblies **20** can be pivoted to a vertical angle greater than 90° such that the distal portions are approximately positioned below the central body **10** (hereinafter "downwards," e.g., FIGS. **3** and **4**). The transformable frame assemblies **20** can be pivoted to a vertical angle of 90° such that the distal portions are approximately even with the central body **10**. Above, below, and even with the central body **10** can be defined as above, below, or even with the vertical center of mass of the central body **10** or the vertical midpoint of the central body **10** (e.g., along line **51**). The vertical angles through which the transformable frame assemblies **20** can be pivoted can be within a range from 0° to 180°, 0° to 90°, 90° to 180°, 15° to 165°, 20° to 160°, 30° to 150°, or 45° to 135°. The transformable frame assemblies **20** may be capable of being transformed to any vertical angle within the range, or only to certain vertical angles within the range. The vertical angles can include a vertical angle permitting the transformable frame assemblies **20** to support the UAV **100** resting on a surface, and/or a vertical angle increasing a functional space of a coupled payload, as previously described herein.

In some instances, the position of the distal portions (e.g., above, below, or even with the central body **10**) can be varied through different configurations, potentially independently of the vertical angle of the transformable frame assemblies **20** as described above, such that the distal portions can be situated in any configuration relative to the central body **10**. For example, the distal portions can be positioned approximately above the central body **10** in a first configuration and positioned approximately below the central body **10** in a second configuration. This may be independent of the vertical angle of the transformable frame assemblies **20**. Conversely, the transformable frame assemblies **20** can be pivoted to a vertical angle less than 90° in a first configuration and to a vertical angle greater than 90° in a second configuration. In such arrangements, the distal portions of the transformable frame assemblies **20** may be positioned above, below, even with, or any combination thereof relative to the central body **10**. In some instances, transforming from a first configuration to a second configuration may cause the distal portions of the transformable frame assemblies **20** to be positioned higher with respect to the central body **10**, while the vertical angle of the transformable frame assemblies **20** as measured from the line **51** may be increased. Conversely, transforming from a first configuration to a second configuration may cause the distal portions of the transformable frame assemblies **20** to be positioned lower with respect to the central body **10**, while the vertical angle of the transformable frame assemblies **20** as measured from the line **51** may be decreased.

Furthermore, the transformable frame assemblies **20** can be configured to transform by translating (along up to three axes of translation), folding, unfolding, telescoping, extending, or shrinking, relative to the central body **10**. For example, the transformable frame assemblies **20** may be configured to slide upwards or downwards, or inward or outwards, relative to the central body **10**. In some instances, the transformable frame assemblies **20** may include one or more telescoping elements that can be extended or retracted in order to extend or shrink the length, width, and/or height of one or more portions of the transformable frame assemblies **20**. As described above, the transformations of the transformable frame assemblies **20** may occur completely independently from each other. Alternatively, one or more transformations may be coupled, such that one transformation produces a corresponding second transformation.

In some embodiments, one or more portions of the transformable frame assemblies **20** can be transformed independently from other portions of the transformable frame assemblies **20**. For example, the distal portions may be transformed independently of the proximal portions, and vice-versa. Different types of transformations (e.g., rotating, translating, folding, unfolding, telescoping, extending, or shrinking) can be applied to different portions of the transformable frame assemblies **20**. The different portions of the transformable frame assemblies **20** may be transformed simultaneously or sequentially. Certain configurations may require transforming all portions of the transformable frame assemblies **20**. Alternatively, certain configurations may require transforming only some of the portions of the transformable frame assemblies **20**.

The transformation of the UAV **100** can be controlled by a suitable control system (e.g., the system **300**) mounted on the UAV **100** (e.g., on the central body **10**). In some embodiments, the control system can be configured to automatically control the transformation of the UAV **100**, based on one or more of: position of the UAV, orientation of UAV, current configuration of the UAV, time, or sensing data acquired by a sensor of the UAV or by the payload. For example, the UAV **100** can include one or more sensors adapted to sense when the UAV **100** is about to land (e.g., based on position, velocity, and/or acceleration data), and the control system can automatically transform the UAV **100** into a landing configuration. Similarly, the UAV **100** can include one or more sensors adapted to sense when the UAV **100** is at a suitable altitude for aerial photography, and the control system can automatically transform the UAV **100** into a flight configuration increasing the functional space of a camera payload, as described herein.

Alternatively or in combination, the control system can include a receiver or other communication module mounted on the UAV **100** for receiving user commands, such as from a remote terminal as described elsewhere herein. The user commands received by the receiver can be used to control an actuation assembly configured to actuate the transformable frame assemblies **20** (e.g., via control of a suitable drive unit, such as the drive unit **11** described in further detail below). For example, the commands can include commands to turn the drive unit on or off, drive the actuation assembly with the drive unit (e.g., in a clockwise or counterclockwise rotation), or maintain a current state of the actuation assembly. The commands can result in the UAV **100** transforming to a specified configuration or maintaining a current configuration. In some embodiments, the transformation of the UAV **100** can be indirectly triggered by a user command directed to another function of the UAV. For example, a user command for the UAV **100** to land may automatically cause the UAV **100** to transform into a landing configuration. Optionally, a user command for a camera payload to begin recording images may automatically cause the UAV **100** to transform a configuration increasing the functional space of the camera, as described herein.

The UAV **100** can utilize any configuration of the transformable frame assemblies **20** and the central body **10** suitable for enabling one or more of the transformations described herein. For example, the transformation of the transformable frame assemblies **20** can be actuated by a drive unit **11** of the central body **10** via a suitable actuation assembly (also known as a transformation actuation assembly). The drive unit **11** and actuation assembly can be coupled to a fixed assembly **17** of the central body **10**. A single drive unit and actuation assembly can be used to simultaneously transform all the transformable frame assemblies **20** of the UAV **100**. For example, a single motor or other suitable actuator can be used to transform a plurality of or all of the transformable frame assemblies **20** of the UAV **100**. Alternatively, a plurality of drive units and actuation assemblies can be used to separately transform each of the transformable frame assemblies **20**. Any suitable driving mechanism can be used for the drive unit **11**, such as a DC motor (e.g., brushed or brushless), AC motor, stepper motor, servo motor, and the like. The actuation assembly can use any suitable actuation element or combination of actuation elements to transform the UAV **100**. Examples of suitable actuation mechanisms include gears, shafts, pulleys, screws, nuts spindles, belts, cables, wheels, axles, and the like. In some embodiments, the actuation assembly can include a linear actuator driven by the drive unit **11** in a linear reciprocating motion relative to the drive unit **11**. For example, as illustrated in FIG. **2**, the actuation assembly can be a screw and nut mechanism, including a screw **13** and a nut **15**. The nut **15** can encircle the shaft of the screw **13** and be coupled to the screw **13** (e.g., via screw threading or interference fit). The drive unit **11** can be affixed to one end of the screw **13**. Accordingly, the drive unit **11** can drive the rotation of the screw **13** (e.g., clockwise or counterclockwise) and thereby cause the nut **15** to move up or down along the length of the screw **13**.

Alternatively or in combination, the actuation assembly can utilize a worm drive mechanism including a worm and worm gear (not shown). The worm can be coupled to the worm gear, such that rotation of the worm actuated by the drive unit **11** produces a corresponding rotation of the worm gear. The worm gear can be coupled to and operable to drive the screw **13** (e.g., via internal threading of the worm gear). Advantageously, the use of a worm drive mechanism as described herein can provide smoother drive transmission and improve drive reliability.

The fixed assembly **17** can be any structure suitable for accommodating the drive unit **11** and the actuation assembly, such as a frame, half-frame, or hollow structure. Although the fixed assembly **17** is depicted in FIGS. **1-4** as a hexagonal frame approximately bisected by the screw **13** and nut **15**, the fixed assembly **17** can be any suitable two-dimensional or three-dimensional shape. In some embodiments, the fixed assembly **17** includes an upper portion **171** and a lower portion **173**, with the upper portion **171** disposed coupled to the upper end of the screw **13** near the drive unit **11**, and the lower portion **173** coupled to the lower end of the screw **13** away from the drive unit **11**. Optionally, the upper and lower portions **171**, **173** can be coupled to the screw **13** with suitable bearings (e.g., angular contact ball bearings) or rotary joints such that the screw **13** can rotate (e.g., when driven by the drive unit **11**) with respect to the fixed assembly **17**.

Any suitable configuration of transformable frame assemblies **20** can be used in conjunction with suitable embodiments of the fixed assembly **17**, drive unit **11**, and actuation assembly, as described above. In some embodiments, as illustrated in FIGS. **1-4**, the transformable frame assemblies **20** each include a primary shaft **21** and a secondary shaft **23**. Optionally, the secondary shaft **23** can be arranged parallel to or approximately parallel to the primary shaft **21**. The actuation assembly can be operatively coupled to the primary shafts **21** and/or the secondary shafts **23**, thereby enabling transformation of the transformable frame assemblies **20** by actuation of the primary shafts **21** and/or secondary shafts **23**.

In some embodiments, the proximal end of primary shaft **21** is coupled to the nut **15** of the actuation assembly by means of one or more connectors **27**. For example, two connectors **27** can be pivotally coupled to opposite sides of the proximal end of the primary shaft **21** and fixedly coupled to the nut **15**. The connectors **27** can have any suitable geometry, such as a curved shape or a straight shape. The proximal end of the primary shaft **21** can also be coupled to the fixed assembly **17**, such as by a joint **211** extending perpendicular to the screw **13**. The joint **211** can be pivotally coupled to the primary shaft **21** and fixedly coupled to the fixed assembly **17** near the drive unit **11**. Accordingly, each primary shaft **21** of the transformable frame assemblies **20** can pivot with respect to the central body **10** about the joint **211**. Furthermore, as the nut **15** moves up or down along the screw **13**, corresponding forces exerted on the primary shafts **21** through the connectors **27** cause the primary shafts **21** to pivot upwards or downwards relative to the central body **10**, respectively.

The proximal end **231** of the secondary shaft **23** can be coupled to the lower portion **173** of the fixed assembly **17** (e.g., through coupling point **175**). Optionally, the proximal ends **231** of each secondary shaft **23** of the transformable frame assemblies **20** are coupled to each other at the coupling point **175**. The proximal ends **231** can be pivotally coupled such that the secondary shafts **23** can pivot with respect to the central body **10**.

In some embodiments, the primary shaft **21** is coupled to the secondary shaft **23**, such that an actuation of the primary shaft **21** (e.g., by the actuation assembly) produces a corresponding actuation of the secondary shaft **23**. The primary shaft **21** and the secondary shaft **23** can be directly coupled to each other or indirectly coupled to each other. For example, the primary shaft **21** and the secondary shaft **23** can be coupled to each other through a connector **25**. The connector **25** can be a Y-shaped structure, for example, with the two upper ends pivotally coupled to the distal end of the primary shaft **21** and the lower end pivotally coupled to the distal end **233** of the secondary shaft **23**. The Y-shaped connector **25** can provide increased stability to the transformable frame assembly **20**. Alternatively, the connector **25** can be any shape suitable for coupling the primary shaft **21** and the secondary shaft **23**, such as a straight shaft, curved shaft, and the like. In this configuration, as the primary shaft **21** pivots relative to the central body **10** (e.g., driven by actuation of the nut **15** as described above), forces exerted by the connector **25** on the secondary shaft **23** produce a corresponding pivoting motion of the secondary shaft **23**.

In some embodiments, a cross bar **29** is affixed to the distal end of the primary shaft **21**. The cross bar **29** can extend in a direction perpendicular to the primary shaft **21** and/or the screw **13**. The primary shaft **21** can be coupled to the cross bar **29** (e.g., at the midpoint of the cross bar **29**) by a suitable coupling, such as a pivotal coupling. In some instances, the connector **25** is coupled to the cross bar **29** by means of suitable openings situated on the upper ends of the Y-shaped structure. The cross bar **29** can be used for mounting the propulsion units **30** and the support members **40**. For example, the propulsion units **30** and the support members **40** can be coupled to the ends of the cross bar **29**, or at any other suitable portion of the cross bar **29**.

The elements of the transformable frame assemblies **20** and central body **10** may be arranged in any suitable geometry. For example, as illustrated in FIG. **3**, the transformable frame assembly **20** and the central body **10** can form a parallelogram or parallelogram-like shape. In this embodiment, the length of the primary shaft **21** (e.g., as measured between its proximal and distal couplings) is equal to or approximately equal to the length of the secondary shaft **23** (e.g., as measured between its proximal and distal couplings), and the length of the connector **25** (e.g., as measured between its upper and lower couplings) is equal to or approximately equal to the length of fixed assembly **17** (e.g., as measured between its coupling to the hinge **211** and the coupling point **175**). However, other geometries can also be used. In some instances, elements of the transformable frame assemblies **20** (e.g., primary shaft **21**, secondary shaft **23**, connector **25**) and the central body **10** (e.g., fixed assembly **17**, screw **13**) can be coupled to form triangular, square, rectangular, and other polygonal shapes. The elements may be linear, or one or more of the elements may be curved, such that a rounded, curved, or curvilinear shape is formed.

The UAV **100** can be transformed using the elements of the central body **10** and the transformable frame assemblies **20** described herein. In some embodiments, the UAV **100** can assume a first configuration (e.g., a takeoff/landing configuration) in which the drive unit **11** is off and the nut **15** is in the bottom position on the screw **13** closest to the proximal ends **231** of the secondary shafts **23**. In the first configuration, the transformable frame assemblies **20** are angled downwards with respect to the central body **10**, thereby enabling the support members **40** to contact the surface and support the UAV **100**.

To transform the UAV **100** to a second configuration (e.g., a flight configuration), the drive unit **11** can be turned on to drive the rotation of the screw **13** in a first direction (e.g., clockwise). Consequently, the nut **15** moves upward along the screw **13** towards the drive unit **11**, thereby transmitting an upward force to the primary shafts **21** through the connectors **27** that causes the primary shafts **21** to pivot upwards. As the primary shafts **21** and secondary shafts **23** are coupled by means of the connectors **25**, as previously described herein, the secondary shafts **23** are also pivoted upwards, and the vertical angle of the transformable assemblies **20** relative to the central body **10** is changed. The movement of the nut **15** is stopped once it reaches the uppermost position on the screw **13**, thereby maintaining the UAV **100** in the second configuration in which the transformable frame assemblies **20** are angled upwards with respect to the central body **10**.

In the second configuration, the upward tilt of the transformable assemblies **20** increases the space beneath the central body **10**. Accordingly, the second configuration can increase the functional space for a functional payload situated underneath the central body **10**, as previously described herein.

To return the UAV **100** to the first configuration, the drive unit **11** can be used to drive the screw **13** to rotate in the opposite direction (e.g., counterclockwise), so that the nut **15** moves downwards away from the drive unit **11**. Thus, a downward force is exerted on the primary shafts **21** through the connectors **27**, and subsequently on to the secondary shafts **23** through the connectors **25**. Consequently, the transformable frame assemblies **20** are pivoted downwards relative to the central body **10** to support the UAV **100** on a surface.

FIGS. **5-10** illustrate another exemplary transformable UAV **100***a*, in accordance with embodiments. The design principles of the UAV **100***a* are fundamentally the same as those of the UAV **100**, and any element of the UAV **100***a* not specifically described herein can be assumed to be the same as in the UAV **100**. The UAV **100***a* differs from the UAV **100** primarily in the structure of the fixed assembly **17***a* and the arrangement of the primary and secondary shafts **21***a*, **23***a*.

In some embodiments, the fixed assembly **17***a* of the UAV **100***a* forms a pentagon having a first side **171***a*, a second side **173***a*, a third side **175***a*, a fourth side **177***a*, and a fifth side **179***a*. The first side **171***a* can be perpendicular to the second side **173***a* and coupled to the lower end of the screw **13**. The third side **175***a* can be perpendicular to the second side **173***a* and coupled to the upper end of the screw **13**. The fourth side **177***a* can be oriented at an obtuse angle relative to the fifth side **179***a*, and the fifth side **179***a* can be oriented at an obtuse angle relative to the first side **171***a*. An extension **18** can be formed with the third side **175***a*, for example, in a direction extending parallel with the first side **171***a*. The extension **18** can include a plurality of interfaces **181** (e.g., card interfaces). The interface **181** can be used to releasably couple a payload (e.g., a camera or robotic arm) or a battery.

In some embodiments, the UAV **100***a* includes a pair of transformable frame assemblies each having a primary shaft **21***a* and a secondary shaft **23***a*. The proximal end of each primary shaft **21***a* can be coupled to the actuation assembly and the fixed assembly **17***a*, similar to the configuration of the UAV **100**. The proximal ends **231***a* of the secondary shafts **23***b* can be coupled to the fixed assembly **17***a* and to each other at a coupling point **172** of the fixed assembly **17***a*. Although the coupling point **172** is depicted in FIG. **6** as situated at the intersection of the first and second sides **171***a* and **173***a*, the coupling point **172** can be located on any suitable portion of the fixed assembly **17***a*.

The primary shaft **21***a* and the secondary shaft **23***a* can be coupled to each other by a connector **25***a*. Similar to embodiments of the UAV **100**, the connector **25***a* can also be pivotally coupled to a cross bar for mounting propulsion units and/or support members. In this embodiment, the distal end of the primary shaft **21***a* is coupled to the upper ends of the connector **25***a*, and the distal end **233***a* of the secondary shaft **23***a* is coupled to the lower end **251** of the connector. The lower end **251** can be offset from the centerline of the connector **25***a* and be positioned, for example, at a corner of the connector **25***a*, such that the distal end **233***a* of the secondary shaft **23***a* is offset to one side of the distal end of the primary shaft **21***a*. In some instances, the distal end **233***a* is positioned on one side of the primary shaft **21***a* and the proximal end **231***a* is positioned on the opposite side, thereby causing the primary shaft **21***a* and the secondary shaft **23***a* to be horizontally skewed relative to each other. The primary shaft **21***a* and the secondary shaft **23***a* can still be parallel with respect to a vertical plane (e.g., as depicted in FIGS. **7** and **10**). This skewed configuration decreases the vertical distance between the primary shaft **21***a* and the secondary shaft **23***a*, thereby enabling a more compact design for the UAV **100***a*.

Similar to the UAV **100**, the transformable frame assembly and the central body of the UAV **100***a* can form a parallelogram or parallelogram-like shape. In this embodiment, the length of the primary shaft **21***a* (e.g., as measured between its proximal and distal couplings) is equal to or approximately equal to the length of the secondary shaft **23***a* (e.g., as measured between its proximal and distal couplings), and the length of the connector **25***a* (e.g., as measured between its upper and lower couplings) is equal to or approximately equal to the length of fixed assembly **17** (e.g., as measured between its coupling to the primary shaft **21***a* and the coupling point **172**). However, other suitable geometries can also be used, as previously described herein.

The UAV **100***a* can be transformed in a manner similar to that of the UAV **100**, and any aspects of the transformation not specifically described herein can be assumed to be the same as for the UAV **100**. Briefly, the actuation assembly of the UAV **100***a* can actuate the coupled primary and secondary shafts **21***a* and **23***a* to be angled upwards with respect to the central body (e.g., FIGS. **5**, **7**) or angled downwards with respect to the central body (e.g., FIGS. **8-10**). The upwards configuration can be used to increase the functional space of a coupled payload, while the downwards configuration can be used to provide support to the UAV **100***a* when resting on a surface.

FIGS. **11-14** illustrate another exemplary transformable UAV **100***b*, in accordance with embodiments. The design principles of the UAV **100***b* are fundamentally the same as those of the UAV **100**, and any element of the UAV **100***b* not specifically described herein can be assumed to be the same as in the UAV **100**. The UAV **100***b* differs from the UAV **100** primarily in the structure of the fixed assembly **17***b* and the arrangement of the primary and secondary shafts **21***b*, **23***b*. In particular, each transformable frame assembly **20***b* of the UAV **100***b* includes a primary shaft **21***b* and two secondary shafts **23***b* that can be arranged to form a triangular prism or triangular prism-like shape.

In some embodiments, the fixed assembly **17***b* forms an approximately rectangular frame having a top side **171***b*, a bottom side **173***b*, and opposed lateral sides **175***b*. The proximal end of each of the pair of primary shafts **21***b* can be pivotally coupled to the fixed assembly **17***b* and to each other at the top side **171***b* (e.g., at coupling point **177***b*). The proximal end can also be coupled to an actuation assembly within the fixed assembly **17***b* by one or more connectors, as previously described herein with respect to the UAV **100**.

The proximal ends **231***b* of the secondary shafts **23***b* can be respectively pivotally coupled to any suitable portion of the fixed assembly **17***b*, such as at coupling points **179***b* situated within the fixed assembly **17***b* at the two ends of the bottom side **173***b* where it joins the lateral sides **175***b*. In some embodiments, the proximal ends **231***b* of each pair of secondary shafts **23***b* are symmetrically situated on opposite sides of the proximal end of the corresponding primary shaft **21***b*.

Each primary shaft **21***b* is coupled to the corresponding pair of secondary shafts **23***b* by means of a connector **25***b* and a cross bar **29**. The connector **25***b* can be approximately rectangular, with the length and width of the connector **25***b* being smaller than a corresponding length and width of the fixed assembly **17***b*. The connector **25***b* can include a bottom side **251***b* and two parallel opposite lateral sides **253***b*. The lateral sides **253***b* can extend upwards along a direction perpendicular to the bottom side **251***b*. The connector **25***b* can be pivotally coupled to the cross bar **29** passing through the rings **255***b* situated on the upward ends of the lateral sides **253***b*. The distal end of the primary shaft **21***b* can be pivotally coupled to the cross bar **29***b*, for example, by means of a hinge **291** mounted on the portion of the cross bar **29** between the rings **255***b*. The distal ends **233***b* of the secondary shafts **23***b* can be respectively pivotally coupled to the ends of the bottom side **251***b*. In some embodiments, the distal ends **233***b* of each pair of secondary shafts **23***b* are symmetrically situated on opposite sides of distal end of the corresponding primary shaft **21***b*. The length of the bottom side **251***b* can be smaller than the length of the bottom side **173***b*, such that the separation between distal ends **233***b* is smaller than the separation between the proximal ends **231***b*. Alternatively, the lengths can be equal or approximately equal, such that the separation between the distal and proximal ends **233***b*, **231***b* of the secondary shafts **23***b* are equal or approximately equal.

The cross bar **29** can be used to mount propulsion units and/or support members. In some embodiments, the cross bar **29** is parallel to the bottom side **251***b* of the connector **25***b*. Optionally, a reinforcing bar **293** can be situated underneath and parallel to the cross bar **29**, passing through the lateral sides **253***b* of the connector **25***b*. The ends of the reinforcing bar **293** can be coupled to propulsion units mounted on respective ends of the cross bar **29**, thereby increasing stability and support for the propulsion units.

Similar to the UAV **100**, the transformable frame assembly and the central body of the UAV **100***b* can form a parallelogram or parallelogram-like shape. In this embodiment, the length of the primary shaft **21***b* (e.g., as measured between its proximal and distal couplings) is equal to or approximately equal to the length of the secondary shafts **23***b* (e.g., as measured between their proximal and distal couplings), and the length of the connector **25***b* (e.g., as measured between its upper and lower couplings) is equal to or approximately equal to the length of fixed assembly **17** (e.g., as measured between the coupling points **177***b* and **179***b*). However, other suitable geometries can also be used, as previously described herein.

The UAV **100***b* can be transformed in a manner similar to that of the UAV **100**, and any aspects of the transformation not specifically described herein can be assumed to be the same as for the UAV **100**. Briefly, the actuation assembly of the UAV **100***b* can actuate the coupled primary and secondary shafts **21***b* and **23***b* to be angled upwards or downwards with respect to the central body. The upwards configuration can be used to increase the functional space of a coupled payload, while the downwards configuration can be used to provide support to the UAV **100***a* when resting on a surface (e.g., FIGS. **11**, **13**, and **14**).

Suitable elements of any of transformable aerial vehicles described herein may be combined with or substituted with suitable elements from any other embodiment. The elements of the transformable aerial vehicles described herein may be flexible elements or rigid elements, and can be fabricated using any suitable material or combination of materials. Suitable materials can include metals (e.g., stainless steel, aluminum), plastics (e.g., polystyrene, polypropylene), wood, composite materials (e.g., carbon fiber), and the like. The materials for the transformable aerial vehicles can be selected based on one or more of strength, weight, durability, stiffness, cost, processing characteristics, and other material properties. The couplings between elements described herein may involve interference fits, clearance fits, transition fits, and suitable combinations thereof. Pivotal couplings can include ball bearings, hinges, and other suitable rotary joints. Fixed couplings may utilize one or more fasteners, such as nails, screws, bolts, clips, ties, and the like. In some embodiments, the materials and couplings can be configured to enhance stability and reduce vibration of the transformable aerial vehicle during operation.

The systems, devices, and methods described herein can be applied to a wide variety of movable objects. As previously mentioned, any description herein of an aerial vehicle may apply to and be used for any movable object. A movable object of the present invention can be configured to move within any suitable environment, such as in the air (e.g., a fixed-wing aircraft or a rotary-wing aircraft), in the water (e.g., a ship or a submarine), on the ground (e.g., a motor vehicle or a train), under the ground (e.g., a subway), in space (e.g., a spaceplane, a satellite, or a probe), or any combination of these environments. The movable object may be capable of moving freely within the environment with respect to six degrees of freedom (e.g., three degrees of freedom in translation and three degrees of freedom in rotation). Alternatively, the movement of the movable object can be constrained with respect to one or more degrees of freedom, such as by a predetermined path, track, or orientation. The movement can be actuated by any suitable actuation mechanism, such as an engine or a motor. The actuation mechanism of the movable object can be powered by any suitable energy source, such as electrical energy, magnetic energy, solar energy, wind energy, gravitational energy, chemical energy, nuclear energy, or any suitable combination thereof.

In some instances, the movable object can be a vehicle. In addition to aerial vehicles, suitable vehicles may include water vehicles, space vehicles, or ground vehicles. The systems, devices, and methods disclosed herein can be used for any vehicle capable of lifting off from and landing on surfaces (e.g., an underwater surface such as a sea floor, an extraterrestrial surface such as an asteroid). A vehicle can be self-propelled, such as self-propelled through the air, on or in water, in space, or on or under the ground. A self-propelled vehicle can utilize a propulsion system, such as a propulsion system including one or more engines, motors, wheels, axles, magnets, rotors, propellers, blades, nozzles, or any suitable combination thereof.

The aerial vehicles of the present disclosure can include fixed-wing aircraft (e.g., airplane, gliders), rotary-wing aircraft (e.g., helicopters, rotorcraft), aircraft having both fixed wings and rotary wings, or aircraft having neither (e.g., blimps, hot air balloons). The aerial vehicle may be capable of moving freely within the environment with respect to six degrees of freedom (e.g., three degrees of freedom in translation and three degrees of freedom in rotation). Alternatively, the movement of the aerial vehicle can be constrained with respect to one or more degrees of freedom, such as by a predetermined path or track. The movement can be actuated by any suitable actuation mechanism, such as an engine or a motor. In some embodiments, the aerial vehicle can be a self-propelled aerial vehicle. Self-propelled aerial vehicles can be driven by a propulsion system as previously described herein. The propulsion system can be used to enable the aerial vehicle to take off from a surface, land on a surface, maintain its current position and/or orientation (e.g., hover), change orientation, and/or change position.

For example, the propulsion system can include one or more rotors. A rotor can include one or more blades (e.g., one, two, three, four, or more blades) affixed to a central shaft. The blades can be disposed symmetrically or asymmetrically about the central shaft. The blades can be turned by rotation of the central shaft, which can be driven by a suitable motor or engine. The blades can be configured to spin in a clockwise rotation and/or a counterclockwise rotation. The rotor can be a horizontal rotor (which may refer to a rotor having a horizontal plane of rotation), a vertically oriented rotor (which may refer to a rotor having a vertical plane of rotation), or a rotor tilted at an intermediate angle between the horizontal and vertical positions. In some embodiments, horizontally oriented rotors may spin and provide lift to the aerial vehicle. Vertically oriented rotors may spin and provide thrust to the aerial vehicle. Rotors oriented an intermediate angle between the horizontal and vertical positions may spin and provide both lift and thrust to the aerial vehicle. One or more rotors may be used to provide a torque counteracting a torque produced by the spinning of another rotor.

The aerial vehicle can be controlled remotely by a user or controlled locally by an occupant within or on the aerial vehicle. In some embodiments, the aerial vehicle is a UAV. An UAV may not have an occupant onboard the aerial vehicle. The aerial vehicle can be controlled by a human or an autonomous control system (e.g., a computer control system), or any suitable combination thereof. The aerial vehicle can be an autonomous or semi-autonomous robot, such as a robot configured with an artificial intelligence.

The aerial vehicle can have any suitable size and/or dimensions. In some embodiments, the aerial vehicle may be of a size and/or dimensions to have a human occupant within or on the vehicle. Alternatively, the aerial vehicle may be of size and/or dimensions smaller than that capable of having a human occupant within or on the vehicle. The aerial vehicle may be of a size and/or dimensions suitable for being lifted or carried by a human. Alternatively, the aerial vehicle may be larger than a size and/or dimensions suitable for being lifted or carried by a human. In some instances, the aerial vehicle may have a maximum dimension (e.g., length, width, height, diameter, diagonal) of less than or equal to about: 2 cm, 5 cm, 10 cm, 50 cm, 1 m, 2 m, 5 m, or 10 m. The maximum dimension may be greater than or equal to about: 2 cm, 5 cm, 10 cm, 50 cm, 1 m, 2 m, 5 m, or 10 m. For example, the distance between shafts of opposite rotors of the aerial vehicle may be less than or equal to about: 2 cm, 5 cm, 10 cm, 50 cm, 1 m, 2 m, 5 m, or 10 m. Alternatively, the distance between shafts of opposite rotors may be greater than or equal to about: 2 cm, 5 cm, 10 cm, 50 cm, 1 m, 2 m, 5 m, or 10 m.

In some embodiments, the aerial vehicle may have a volume of less than 100 cm×100 cm×100 cm, less than 50 cm×50 cm×30 cm, or less than 5 cm×5 cm×3 cm. The total volume of the aerial vehicle may be less than or equal to about: 1 cm^3, 2 cm^3, 5 cm^3, 10 cm^3, 20 cm^3, 30 cm^3, 40 cm^3, 50 cm^3, 60 cm^3, 70 cm^3, 80 cm^3, 90 cm^3, 100 cm^3, 150 cm^3, 200 cm^3, 300 cm^3, 500 cm^3, 750 cm^3, 1000 cm^3, 5000 cm^3, 10,000 cm^3, 100,000 cm^3, 1 m^3, or 10 m^3. Conversely, the total volume of the aerial vehicle may be greater than or equal to about: 1 cm^3, 2 cm^3, 5 cm^3, 10 cm^3, 20 cm^3, 30 cm^3, 40 cm^3, 50 cm^3, 60 cm^3, 70 cm^3, 80 cm^3, 90 cm^3, 100 cm^3, 150 cm^3, 200 cm^3, 300 cm^3, 500 cm^3, 750 cm^3, 1000 cm^3, 5000 cm^3, 10,000 cm^3, 100,000 cm^3, 1 m^3, or 10 m^3.

In some embodiments, the aerial vehicle may have a footprint (which may refer to the lateral cross-sectional area encompassed by the aerial vehicle) less than or equal to about: 32,000 cm^2, 20,000 cm^2, 10,000 cm^2, 1,000 cm^2, 500 cm^2, 100 cm^2, 50 cm^2, 10 cm^2, or 5 cm^2. Conversely, the footprint may be greater than or equal to about: 32,000 cm^2, 20,000 cm^2, 10,000 cm^2, 1,000 cm^2, 500 cm^2, 100 cm^2, 50 cm^2, 10 cm^2, or 5 cm^2.

In some instances, the aerial vehicle may weigh no more than 1000 kg. The weight of the aerial vehicle may be less than or equal to about: 1000 kg, 750 kg, 500 kg, 200 kg, 150 kg, 100 kg, 80 kg, 70 kg, 60 kg, 50 kg, 45 kg, 40 kg, 35 kg, 30 kg, 25 kg, 20 kg, 15 kg, 12 kg, 10 kg, 9 kg, 8 kg, 7 kg, 6 kg, 5 kg, 4 kg, 3 kg, 2 kg, 1 kg, 0.5 kg, 0.1 kg, 0.05 kg, or 0.01 kg. Conversely, the weight may be greater than or equal to about: 1000 kg, 750 kg, 500 kg, 200 kg, 150 kg, 100 kg, 80 kg, 70 kg, 60 kg, 50 kg, 45 kg, 40 kg, 35 kg, 30 kg, 25 kg, 20 kg, 15 kg, 12 kg, 10 kg, 9 kg, 8 kg, 7 kg, 6 kg, 5 kg, 4 kg, 3 kg, 2 kg, 1 kg, 0.5 kg, 0.1 kg, 0.05 kg, or 0.01 kg.

In some embodiments, an aerial vehicle may be small relative to a load carried by the aerial vehicle. The load may include a payload and/or a carrier, as described in further detail below. In some examples, a ratio of an aerial vehicle weight to a load weight may be greater than, less than, or equal to about 1:1. In some instances, a ratio of an aerial vehicle weight to a load weight may be greater than, less than, or equal to about 1:1. Optionally, a ratio of a carrier weight to a load weight may be greater than, less than, or equal to about 1:1. When desired, the ratio of an aerial vehicle weight to a load weight may be less than or equal to: 1:2, 1:3, 1:4, 1:5, 1:10, or even less. Conversely, the ratio of an aerial vehicle weight to a load weight can also be greater than or equal to: 2:1, 3:1, 4:1, 5:1, 10:1, or even greater.

In some embodiments, the aerial vehicle may have low energy consumption. For example, the aerial vehicle may use less than about: 5 W/h, 4 W/h, 3 W/h, 2 W/h, 1 W/h, or less. In some instances, a carrier of the aerial vehicle may have low energy consumption. For example, the carrier may use less than about: 5 W/h, 4 W/h, 3 W/h, 2 W/h, 1 W/h, or less. Optionally, a payload of the aerial vehicle may have low energy consumption, such as less than about: 5 W/h, 4 W/h, 3 W/h, 2 W/h, 1 W/h, or less.

In some embodiments, the aerial vehicle can be configured to carry a load. The load can include one or more of passengers, cargo, equipment, instruments, and the like. The load can be provided within a housing. The housing may be separate from a housing of the aerial vehicle, or be part of a housing for an aerial vehicle. Alternatively, the load can be provided with a housing while the aerial vehicle does not have a housing. Alternatively, portions of the load or the entire load can be provided without a housing. The load can be rigidly fixed relative to the aerial vehicle. Optionally, the load can be movable relative to the aerial vehicle (e.g., translatable or rotatable relative to the aerial vehicle).

In some embodiments, the load includes a payload. The payload can be configured not to perform any operation or function. Alternatively, the payload can be a payload configured to perform an operation or function, also known as a functional payload. For example, the payload can include one or more sensors for surveying one or more targets. Any suitable sensor can be incorporated into the payload, such as an image capture device (e.g., a camera), an audio capture device (e.g., a parabolic microphone), an infrared imaging device, or an ultraviolet imaging device. The sensor can provide static sensing data (e.g., a photograph) or dynamic sensing data (e.g., a video). In some embodiments, the sensor provides sensing data for the target of the payload. Alternatively or in combination, the payload can include one or more emitters for providing signals to one or more targets. Any suitable emitter can be used, such as an illumination source or a sound source. In some embodiments, the payload includes one or more transceivers, such as for communication with a module remote from the aerial vehicle. Optionally, the payload can be configured to interact with the environment or a target. For example, the payload can include a tool, instrument, or mechanism capable of manipulating objects, such as a robotic arm.

Optionally, the load may include a carrier. The carrier can be provided for the payload and the payload can be coupled to the aerial vehicle via the carrier, either directly (e.g., directly contacting the aerial vehicle) or indirectly (e.g., not contacting the aerial vehicle). Conversely, the payload can be mounted on the aerial vehicle without requiring a carrier. The payload can be integrally formed with the carrier. Alternatively, the payload can be releasably coupled to the carrier. In some embodiments, the payload can include one or more payload elements, and one or more of the payload elements can be movable relative to the aerial vehicle and/or the carrier, as described above.

The carrier can be integrally formed with the aerial vehicle. Alternatively, the carrier can be releasably coupled to the aerial vehicle. The carrier can be coupled to the aerial vehicle directly or indirectly. The carrier can provide support to the payload (e.g., carry at least part of the weight of the payload). The carrier can include a suitable mounting structure (e.g., a gimbal platform) capable of stabilizing and/or directing the movement of the payload. In some embodiments, the carrier can be adapted to control the state of the payload (e.g., position and/or orientation) relative to the aerial vehicle. For example, the carrier can be configured to move relative to the aerial vehicle (e.g., with respect to one, two, or three degrees of translation and/or one, two, or three degrees of rotation) such that the payload maintains its position and/or orientation relative to a suitable reference frame regardless of the movement of the aerial vehicle. The reference frame can be a fixed reference frame (e.g., the surrounding environment). Alternatively, the reference frame can be a moving reference frame (e.g., the aerial vehicle, a payload target).

In some embodiments, the carrier can be configured to permit movement of the payload relative to the carrier and/or aerial vehicle. The movement can be a translation with respect to up to three degrees of freedom (e.g., along one, two, or three axes) or a rotation with respect to up to three degrees of freedom (e.g., about one, two, or three axes), or any suitable combination thereof.

In some instances, the carrier can include a carrier frame assembly and a carrier actuation assembly. The carrier frame assembly can provide structural support to the payload. The carrier frame assembly can include individual carrier frame components, some of which can be movable relative to one another. The carrier actuation assembly can include one or more actuators (e.g., motors) that actuate movement of the individual carrier frame components. The actuators can permit the movement of multiple carrier frame components simultaneously, or may be configured to permit the movement of a single carrier frame component at a time. The movement of the carrier frame components can produce a corresponding movement of the payload. For example, the carrier actuation assembly can actuate a rotation of one or more carrier frame components about one or more axes of rotation (e.g., roll axis, pitch axis, or yaw axis). The rotation of the one or more carrier frame components can cause a payload to rotate about one or more axes of rotation relative to the aerial vehicle. Alternatively or in combination, the carrier actuation assembly can actuate a translation of one or more carrier frame components along one or more axes of translation, and thereby produce a translation of the payload along one or more corresponding axes relative to the aerial vehicle.

In some embodiments, the movement of the aerial vehicle, carrier, and payload relative to a fixed reference frame (e.g., the surrounding environment) and/or to each other, can be controlled by a terminal. The terminal can be a remote control device at a location distant from the aerial vehicle, carrier, and/or payload. The terminal can be disposed on or affixed to a support platform. Alternatively, the terminal can be a handheld or wearable device. For example, the terminal can include a smartphone, tablet, laptop, computer, glasses, gloves, helmet, microphone, or suitable combinations thereof. The terminal can include a user interface, such as a keyboard, mouse, joystick, touchscreen, or display. Any suitable user input can be used to interact with the terminal, such as manually entered commands, voice control, gesture control, or position control (e.g., via a movement, location or tilt of the terminal).

The terminal can be used to control any suitable state of the aerial vehicle, carrier, and/or payload. For example, the terminal can be used to control the position and/or orientation of the aerial vehicle, carrier, and/or payload relative to a fixed reference from and/or to each other. In some embodiments, the terminal can be used to control individual elements of the aerial vehicle, carrier, and/or payload, such as the actuation assembly of the carrier, a sensor of the payload, or an emitter of the payload. The terminal can include a wireless communication device adapted to communicate with one or more of the aerial vehicle, carrier, or payload.

The terminal can include a suitable display unit for viewing information of the aerial vehicle, carrier, and/or payload. For example, the terminal can be configured to display information of the aerial vehicle, carrier, and/or payload with respect to position, translational velocity, translational acceleration, orientation, angular velocity, angular acceleration, or any suitable combinations thereof. In some embodiments, the terminal can display information provided by the payload, such as data provided by a functional payload (e.g., images recorded by a camera or other image capturing device).

FIG. **15** illustrates an aerial vehicle **200** including a carrier **202** and a payload **204**, in accordance with embodiments. Alternatively, the payload **204** may be provided on the aerial vehicle **200** without requiring the carrier **202**. The aerial vehicle **200** may include propulsion mechanisms **206**, a sensing system **208**, and a transceiver **210**. The propulsion mechanisms **206** can include one or more of rotors, propellers, blades, engines, motors, wheels, axles, magnets, or nozzles, as previously described herein. The aerial vehicle may have one or more, two or more, three or more, or four or more propulsion mechanisms. The propulsion mechanisms may all be of the same type. Alternatively, one or more propulsion mechanisms can be different types of propulsion mechanisms. In some embodiments, the propulsion mechanisms **206** can enable the aerial vehicle **200** to take off vertically from a surface or land vertically on a surface without requiring any horizontal movement of the aerial vehicle **200** (e.g., without traveling down a runway). Optionally, the propulsion mechanisms **206** can be operable to permit the aerial vehicle **200** to hover in the air at a specified position and/or orientation.

For example, the aerial vehicle **200** can have multiple horizontally oriented rotors that can provide lift and/or thrust to the aerial vehicle. The multiple horizontally oriented rotors can be actuated to provide vertical takeoff, vertical landing, and hovering capabilities to the aerial vehicle **200**. In some embodiments, one or more of the horizontally oriented rotors may spin in a clockwise direction, while one or more of the horizontally rotors may spin in a counterclockwise direction. For example, the number of clockwise rotors may be equal to the number of counterclockwise rotors. The rotation rate of each of the horizontally oriented rotors can be varied independently in order to control the lift and/or thrust produced by each rotor, and thereby adjust the spatial disposition, velocity, and/or acceleration of the aerial vehicle **200** (e.g., with respect to up to three degrees of translation and up to three degrees of rotation).

The sensing system **208** can include one or more sensors that may sense the spatial disposition, velocity, and/or acceleration of the aerial vehicle **200** (e.g., with respect to up to three degrees of translation and up to three degrees of rotation). The one or more sensors can include global positioning system (GPS) sensors, motion sensors, inertial sensors, proximity sensors, or image sensors. The sensing data provided by the sensing system **208** can be used to control the spatial disposition, velocity, and/or orientation of the aerial vehicle **200** (e.g., using a suitable processing unit and/or control module, as described below). Alternatively, the sensing system **208** can be used to provide data regarding the environment surrounding the aerial vehicle, such as weather conditions, proximity to potential obstacles, location of geographical features, location of manmade structures, and the like.

The transceiver **210** enables communication with terminal **212** having a transceiver **214** via wireless signals **216**. In some embodiments, the communication can include two-way communication, with the terminal **212** providing control commands to one or more of the aerial vehicle **200**, carrier **202**, and payload **204**, and receiving information from one or more of the aerial vehicle **200**, carrier **202**, and payload **204** (e.g., position and/or motion information of the aerial vehicle, carrier or payload; data sensed by the payload such as image data captured by a payload camera). In some instances, control commands from the terminal may include instructions for relative positions, movements, actuations, or controls of the aerial vehicle, carrier and/or payload. For example, the control command may result in a modification of the location and/or orientation of the aerial vehicle (e.g., via control of the propulsion mechanisms **206**), or a movement of the payload with respect to the aerial vehicle (e.g., via control of the carrier **202**). The control command from the terminal may result in control of the payload, such as control of the operation of a camera or other image capturing device (e.g., taking still or moving pictures, zooming in or out, turning on or off, switching imaging modes, change image resolution, changing focus, changing depth of field, changing exposure time, changing viewing angle or field of view). In some instances, the communications from the aerial vehicle, carrier and/or payload may include information from one or more sensors (e.g., of the sensing system **208** or of the payload **204**). The communications may include sensed information from one or more different types of sensors (e.g., GPS sensors, motion sensors, inertial sensor, proximity sensors, or image sensors). Such information may pertain to the position (e.g., location, orientation), movement, or acceleration of the aerial vehicle, carrier and/or payload. Such information from a payload may include data captured by the payload or a sensed state of the payload. The control commands provided transmitted by the terminal **212** can be configured to control a state of one or more of the aerial vehicle **200**, carrier **202**, or payload **204**. Alternatively or in combination, the carrier **202** and payload **204** can also each include a transceiver configured to communicate with terminal **212**, such that the terminal can communicate with and control each of the aerial vehicle **200**, carrier **202**, and payload **204** independently.

FIG. **16** is a schematic illustration by way of block diagram of a system **300** for controlling an aerial vehicle, in accordance with embodiments. The system **300** can be used in combination with any suitable embodiment of the systems, devices, and methods disclosed herein. The system **300** can include a sensing module **302**, processing unit **304**, non-transitory computer readable medium **306**, control module **308**, and communication module **310**.

The sensing module **302** can utilize different types of sensors that collect information relating to the aerial vehicles in different ways. Different types of sensors may sense different types of signals or signals from different sources. For example, the sensors can include inertial sensors, GPS sensors, proximity sensors (e.g., lidar), or vision/image sensors (e.g., a camera). The sensing module **302** can be operatively coupled to a processing unit **304** having a plurality of processors. In some embodiments, the sensing module can be operatively coupled to a transmission module **312** (e.g., a Wi-Fi image transmission module) configured to directly transmit sensing data to a suitable external device or system. For example, the transmission module **312** can be used to transmit images captured by a camera of the sensing module **302** to a remote terminal.

The processing unit **304** can have one or more processors, such as a programmable processor (e.g., a central processing unit (CPU)). The processing unit **304** can be operatively coupled to a non-transitory computer readable medium **306**. The non-transitory computer readable medium **306** can store logic, code, and/or program instructions executable by the processing unit **304** for performing one or more steps. The non-transitory computer readable medium can include one or more memory units (e.g., removable media or external storage such as an SD card or random access memory (RAM)). In some embodiments, data from the sensing module **302** can be directly conveyed to and stored within the memory units of the non-transitory computer readable medium **306**. The memory units of the non-transitory computer readable medium **306** can store logic, code and/or program instructions executable by the processing unit **304** to perform any suitable embodiment of the methods described herein. For example, the processing unit **304** can be configured to execute instructions causing one or more processors of the processing unit **304** to analyze sensing data produced by the sensing module. The memory units can store sensing data from the sensing module to be processed by the processing unit **304**. In some embodiments, the memory units of the non-transitory computer readable medium **306** can be used to store the processing results produced by the processing unit **304**.

In some embodiments, the processing unit **304** can be operatively coupled to a control module **308** configured to control a state of the aerial vehicle. For example, the control module **308** can be configured to control the propulsion mechanisms of the aerial vehicle to adjust the spatial disposition, velocity, and/or acceleration of the movable object with respect to six degrees of freedom. Alternatively or in combination, the control module **308** can control one or more of a state of a carrier, payload, or sensing module.

The processing unit **304** can be operatively coupled to a communication module **310** configured to transmit and/or receive data from one or more external devices (e.g., a terminal, display device, or other remote controller). Any suitable means of communication can be used, such as wired communication or wireless communication. For example, the communication module **310** can utilize one or more of local area networks (LAN), wide area networks (WAN), infrared, radio, WiFi, point-to-point (P2P) networks, telecommunication networks, cloud communication, and the like. Optionally, relay stations, such as towers, satellites, or mobile stations, can be used. Wireless communications can be proximity dependent or proximity independent. In some embodiments, line-of-sight may or may not be required for communications. The communication module **310** can transmit and/or receive one or more of sensing data from the sensing module **302**, processing results produced by the processing unit **304**, predetermined control data, user commands from a terminal or remote controller, and the like.

The components of the system **300** can be arranged in any suitable configuration. For example, one or more of the components of the system **300** can be located on the aerial vehicle, carrier, payload, terminal, sensing system, or an additional external device in communication with one or more of the above. Additionally, although FIG. **16** depicts a single processing unit **304** and a single non-transitory computer readable medium **306**, one of skill in the art would appreciate that this is not intended to be limiting, and that the system **300** can include a plurality of processing units and/or non-transitory computer readable media. In some embodiments, one or more of the plurality of processing units and/or non-transitory computer readable media can be situated at different locations, such as on the movable object, carrier, payload, terminal, sensing module, additional external device in communication with one or more of the above, or suitable combinations thereof, such that any suitable aspect of the processing and/or memory functions performed by the system **300** can occur at one or more of the aforementioned locations.

While preferred embodiments of the present invention have been shown and described herein, it will be obvious to those skilled in the art that such embodiments are provided by way of example only. Numerous variations, changes, and substitutions will now occur to those skilled in the art without departing from the invention. It should be understood that various alternatives to the embodiments of the invention described herein may be employed in practicing the invention. It is intended that the following claims define the scope of the invention and that methods and structures within the scope of these claims and their equivalents be covered thereby.

What is claimed is:

1. A transformable aerial vehicle, the vehicle comprising:

a central body comprising a flight control system and supporting a payload beneath the central body;

at least two transformable frame assemblies respectively disposed on the central body, each of the at least two transformable frame assemblies having a proximal portion coupled to the central body and a distal portion;

an actuation assembly configured to transform the at least two transformable frame assemblies between a first configuration and a second configuration; and

a plurality of propulsion units operable to move the transformable aerial vehicle, wherein the plurality of propulsion units are mounted on the at least two transformable frame assemblies,

wherein the first configuration (1) permits the at least two transformable frame assemblies to support the transformable aerial vehicle resting on a surface with the payload not contacting the surface, (2) causes obstruction within a range of 360 degrees around the payload by the at least two transformable frame assemblies, and (3) positions the distal portion lower with respect to the central body,

wherein the second configuration (1) provides a 360 degree angle around the payload that is unobstructed by the at least two transformable frame assemblies, and (2) positions the distal portion higher with respect to the central body, and

wherein each of the plurality of propulsion units is configured to provide thrust along a thrust axis, said thrust axis being orthogonal to the surface in said first configuration.

2. The transformable aerial vehicle of claim **1**, wherein the first configuration and the second configuration provide different vertical angles (1) between the at least two transformable frame assemblies and (2) between each of the at least two transformable frame assemblies and the payload.

3. The transformable aerial vehicle of claim **2**, wherein the actuation assembly is configured to pivot the at least two transformable frame assemblies between the different vertical angles, wherein the different vertical angles include a first vertical angle and a second vertical angle.

4. The transformable aerial vehicle of claim **3**, wherein at the first vertical angle, each of the at least two transformable frame assemblies are angled downwards relative to the central body, and wherein at the second vertical angle, each of the first transformable frame assembly and the second transformable frame assembly are angled upwards relative to the central body.

5. The transformable aerial vehicle of claim **1**, wherein the transformable aerial vehicle is an unmanned aerial vehicle.

6. The transformable aerial vehicle of claim **1**, wherein each of the at least two transformable frame assemblies comprise a primary shaft and at least one secondary shaft extending parallel to the primary shaft, the primary shaft and the at least one secondary shaft respectively pivotally coupled to the central body, wherein the primary shaft and the at least one secondary shaft are coupled to each other such that the actuation of the primary shaft by the actuation assembly produces a corresponding actuation of the at least one secondary shaft.

7. The transformable aerial vehicle of claim **1**, further comprising a robotic arm, wherein the robotic arm is coupled to an underside of the central body and is configured to remove an obstruction from the functional space.

8. The transformable aerial vehicle of claim **1**, wherein each of the plurality of propulsion units comprises a rotor, and wherein each rotor is oriented horizontally relative to the transformable aerial vehicle.

9. The transformable aerial vehicle of claim **1**, further comprising a receiver configured to receive user commands for controlling one or more of the actuation assembly and the plurality of propulsion units.

10. The transformable aerial vehicle of claim **9**, wherein the user commands are transmitted from a remote terminal.

11. The transformable aerial vehicle of claim **1**, wherein the actuation assembly comprises a linear actuator, and a portion of each of the at least two transformable frame assemblies is coupled to the linear actuator.

12. The transformable aerial vehicle of claim **11**, wherein the linear actuator comprises a screw and nut mechanism, and the portion of the at least two transformable frame assemblies is coupled to the nut.

13. The transformable aerial vehicle of claim **1**, wherein the at least two transformable frame assemblies are transformed into the first configuration during a first phase of operation of the transformable aerial vehicle and transformed into the second configuration during a second phase of operation of the transformable aerial vehicle.

14. The transformable aerial vehicle of claim **13**, wherein the first phase of operation comprises the transformable aerial vehicle taking off from a surface and/or landing on the surface, and the second phase of operation comprises the transformable aerial vehicle flying in the air.

15. The transformable aerial vehicle of claim **1**, wherein the payload is movable relative to the central body via actuation of a carrier.

16. The transformable aerial vehicle of claim **1**, wherein the payload is an image capturing device.

17. A method for controlling a transformable aerial vehicle, said method comprising:

providing a transformable aerial vehicle comprising a central body comprising a flight control system and at least two transformable frame assemblies respectively disposed on the central body, each of the at least two transformable frame assemblies having a proximal portion coupled to the central body and a distal portion;

operating a plurality of propulsion units mounted on the at least two transformable frame assemblies to move the transformable aerial vehicle; and

driving an actuation assembly mounted on the central body to automatically transform the at least two transformable frame assemblies between a first configuration and a second configuration in response to a signal from one or more sensors in communication with the transformable aerial vehicle, wherein:

(a) the first configuration and the second configuration provide the at least two transformable frame assemblies at different vertical angles with respect to one another, and wherein the signal indicates whether (1) the UAV is about to land or (2) the UAV is at a suitable altitude for aerial photography;

(b) the first configuration permits the at least two transformable frame assemblies to support the transformable aerial vehicle resting on a surface when the signal indicates that the UAV is about to land, and wherein the second configuration increases the functional space beneath the central body when the signal indicates the UAV is at a suitable altitude for aerial photography; or

(c) the first configuration includes the plurality of propulsion units being positioned below the central body when the signal indicates that the UAV is about to land, and wherein the second configuration includes the plurality of propulsion units being positioned above the central body when the signal indicates the UAV is at a suitable altitude for aerial photography.

18. The method of claim **17**, wherein the one or more sensors are on-board the transformable aerial vehicle.

19. The method of claim **17**, wherein each of the plurality of propulsion units comprises a rotor that remains horizontal relative to the transformable aerial vehicle during the first configuration and the second configuration.

20. The method of claim **17**, wherein the transformable aerial vehicle comprises a connector configured to accept a payload coupled to the central body.

21. The method of claim **17**, wherein the one or more sensors indicate whether the UAV is about to land based on position, velocity, or acceleration data of the UAV.

22. The method of claim **17**, wherein the one or more sensors sense position, velocity or acceleration of the UAV with respect to up to three degrees of translation and up to three degrees of rotation.

23. The method of claim **17**, wherein the one or more sensors include a GPS sensor, a motion sensor, a proximity sensor, or an image sensor.

24. The method of claim **17**, wherein the one or more sensors include an inertial sensor.

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