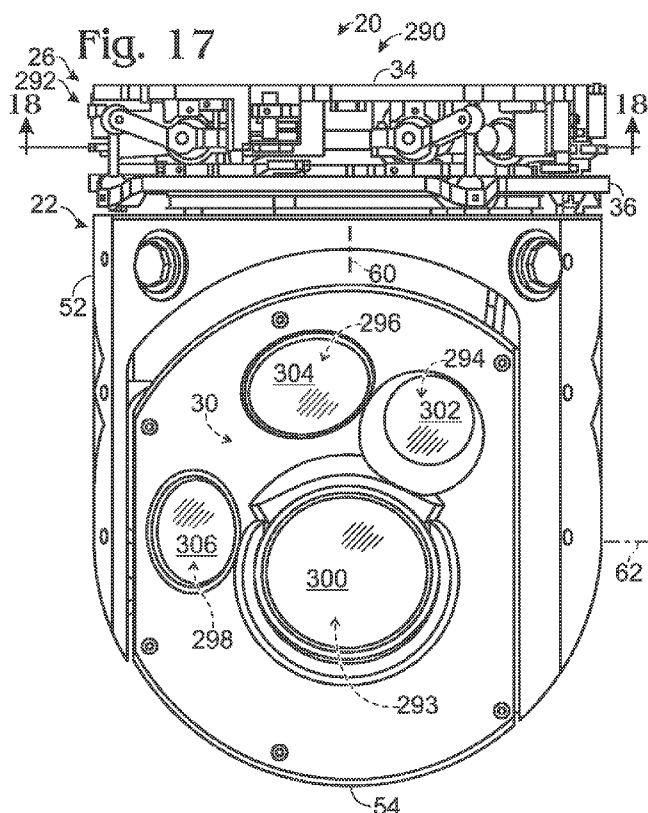




- (51) International Patent Classification:
F16M 11/14 (2006.01) *F16M 11/06* (2006.01)
- (21) International Application Number:
PCT/US2012/041327
- (22) International Filing Date:
7 June 2012 (07.06.2012)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
13/155,129 7 June 2011 (07.06.2011) US
61/563,282 23 November 2011 (23.11.2011) US
- (71) Applicant (for all designated States except US): **FLIR SYSTEMS, INC.** [US/US]; An Oregon Corporation, 27700 SW Parkway Avenue, Wilsonville, OR 97070 (US).
- (72) Inventor; and
- (75) Inventor/Applicant (for US only): **PETTERSSON, Daniel** [SE/SE]; Smedjegatan 41, S-632 20 Eskilstuna (SE).
- (74) Agent: **ABNEY, James, R.**; Kolisch Hartwell, PC, 520 SW Yamhill Street, Suite 200, Portland, OR 97204-1324 (US).
- (81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.
- (84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV,

[Continued on next page]

(54) Title: GIMBAL SYSTEM WITH A TRANSLATIONAL MOUNT



(57) Abstract: The present disclosure provides a gimbal system, including methods and apparatus, with a mounting portion connected to and supporting a gimbal assembly. The mounting portion may include a pair of frame members interconnected by a linkage portion. The linkage portion may include a plurality of bridge members that restrict pivotal motion of the frame members relative to one another about two or more orthogonal axes while permitting relative translational motion with three degrees of freedom.



MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, **Published:**
SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, — *with international search report (Art. 21(3))*
GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *of inventorship (Rule 4.17(iv))*

GIMBAL SYSTEM WITH A TRANSLATIONAL MOUNT

Cross-References to Related Applications

This application claims the priority of the following patent applications:
5 U.S. Patent Application Serial No. 13/155,129, filed June 7, 2011; and U.S. Provisional Patent Application Serial No. 61/563,282, filed November 23, 2011. Each of these priority documents is incorporated herein by reference in its entirety for all purposes.

Introduction

10 An aircraft may be equipped with a gimbal system including a camera. The gimbal system enables the camera to be accurately pointed as the attitude and location of the aircraft changes during flight. Accordingly, the camera can be panned and tilted to survey a wide field of view or to monitor a specific target from the flying aircraft. The camera may provide a line of sight
15 not available to the pilot and/or may detect optical radiation, such as infrared radiation, that is invisible to the human eye.

Aircraft vibration can degrade camera performance. Images from the camera can be unsteady and/or blurred if the field of view of the camera is not stabilized during flight. In particular, small, vibration-induced changes to the
20 angular orientation of the camera, relative to the aircraft, can produce unacceptably large shifts in the field of view, especially if the camera is being used to view a distant scene.

The gimbal system may stabilize the camera through servomechanisms that include gyroscopes and motors. The
25 servomechanisms can sense small, vibration-induced changes to the camera's orientation and actively apply compensating forces or movements to stabilize the camera. However, such active compensation may need to be applied with great accuracy, high gain, and considerable speed, to effectively stabilize the image when aircraft vibration is transmitted to the camera. As a
30 result, active compensation can require sophisticated instrumentation and substantial power consumption and generally is effective only for low vibration frequencies.

A mechanical approach to filtering vibrations for a gimbal-oriented camera is disclosed in U.S. Patent No. 6,154,317 to Segerstrom et al., which is incorporated herein by reference. Segerstrom provides a stand that includes an upper frame disposed above a lower frame, with the upper frame
5 attached to a vehicle and the lower frame to a set of gimbals supporting a camera below the lower frame. The frames are connected by a set of springs and a coupling assembly. The coupling assembly permits the frames to move relative to each other, while maintaining the frames substantially parallel to each other. However, the mechanical configuration of the coupling assembly
10 imparts a systematic rotation to the lower frame about a horizontal axis as the separation between the frames changes. The systematic rotation is relatively small, but may be significant enough to produce a corresponding, undesirable angular change (e.g., pivotal vibration) in the line of sight of the camera, which can degrade image quality.

15 A more effective mounting system is needed to improve the mechanical stabilization of a gimbal-oriented camera or other payload.

Summary

The present disclosure provides a gimbal system, including methods and apparatus, with a mounting portion connected to and supporting a gimbal
20 assembly. The mounting portion may include a pair of frame members interconnected by a linkage portion. The linkage portion may include a plurality of bridge members that restrict pivotal motion of the frame members relative to one another about two or more orthogonal axes while permitting relative translational motion with three degrees of freedom.

Brief Description of the Drawings

25 Figure 1 is a view of an exemplary gimbal system including a gimbal assembly attached to an exterior of a support platform (namely, a helicopter) via a translational mount (a mounting portion), in accordance with aspects of the present disclosure.

30 Figure 2 is a schematic view of selected aspects of the gimbal system of Figure 1, particularly the translational mount and the gimbal assembly, in accordance with aspects of the present disclosure.

Figure 3 is a schematic bottom view of selected aspects of an exemplary translational mount for use in the gimbal system of Figures 1 and 2, particularly showing an upper frame member and an exemplary anti-tilt linkage assembly connected to the frame member, in accordance with aspects of the present disclosure.

Figure 4 is a schematic fragmentary sectional view of the mount of Figure 3, taken generally along the arcuate path indicated generally at 4—4 in Figure 3, in accordance with aspects of the present disclosure.

Figure 5 is another schematic fragmentary, sectional view of the mount of Figure 3, taken generally as in Figure 4, with the linkage assembly arranged in a different configuration and with a greater vertical distance between frame members of the mount, in accordance with aspects of the present disclosure.

Figure 6 is yet another schematic fragmentary sectional view of the mount of Figure 3, taken generally as in Figure 4, with the linkage assembly arranged in yet another different configuration and with a lesser vertical distance between the frame members and with a horizontal offset of the frame members relative to one another, in accordance with aspects of the present disclosure.

Figure 7 is a schematic illustration of a set of struts of an exemplary translational mount, with the struts in various configurations and with each strut pivotably attached at one end to a lower frame member and maintained at the other end in the same plane, in a fixed geometrical relationship to one another, in response to translational motion or rotational motion of the plane, in accordance with aspects of the present disclosure.

Figure 8 is a view of selected aspects of an exemplary embodiment of the translational mount of Figures 1 and 2, with the mount including a ring to synchronize movement of articulated bridge members connecting a pair of plates, and with the view taken in the absence of the top plate, in accordance with aspects of the present disclosure.

Figure 9 is a sectional view of the mount of Figure 8, taken generally along line 9–9 of Figure 8 in the presence of both plates, in accordance with aspects of the present disclosure.

Figure 10 is a sectional view of the mount of Figure 8, taken as in
5 Figure 9 with a different vertical distance between the plates of the mount, in accordance with aspects of the present disclosure.

Figure 11 is another sectional view of the mount of Figure 8, taken as in Figure 9 with a horizontal offset of the plates relative to each other, in accordance with aspects of the present disclosure.

10 Figure 12 is a magnified fragmentary view of the mount of Figure 8, taken generally around an anti-pivot device that restricts rotation of one plate relative to the other plate about a z-axis of the mount, in accordance with aspects of the present disclosure.

Figure 13 is another view of the anti-pivot device of Figure 8, taken
15 from a different perspective relative to Figure 12.

Figures 14 and 15 are top views of the mount of Figure 8 taken generally around the anti-pivot device of Figures 12 and 13, respectively before and after relative translational motion of the plates parallel to an xy plane, to help illustrate how relative rotation of the plates about the z-axis is
20 restricted by the anti-pivot device, in accordance with aspects of the present disclosure.

Figure 16 is a schematic, exploded view of selected aspects of an exemplary translational mount for use in the gimbal system of Figures 1 and 2, with the mount having a linkage assembly that is synchronized by gears, in
25 accordance with aspects of the present disclosure.

Figure 17 is a side view of an exemplary embodiment of an imaging unit for the gimbal system of Figure 1, with the unit including an embodiment of the gear-synchronized mount of Figure 16, in accordance with aspects of the present disclosure.

30 Figure 18 is a bottom view of selected aspects of the mount of Figure 17, taken generally along line 18–18 of Figure 17.

Figure 19 is a side view of selected aspects of the mount of Figure 17, taken generally along line 19–19 of Figure 18.

Figure 20 is an end view of a gear of the mount of Figure 17, taken generally along line 20–20 of Figure 19.

5 Figure 21 is a view of selected aspects of another exemplary embodiment of a gear-synchronized, translational mount for a gimbal system, in accordance with aspects of the present disclosure.

Figure 22 is a schematic bottom view of selected aspects of yet another exemplary translational mount for use in the gimbal system of Figures
10 1 and 2, particularly showing an upper frame member and an exemplary anti-tilt linkage assembly connected to the frame member and synchronized by gears, in accordance with aspects of the present disclosure.

Figure 23 is a fragmentary side view of the mount of Figure 22, taken generally along line 23–23 of Figure 22.

15 Figure 24 is a view of an embodiment of a mount having an exemplary anti-tilt linkage assembly synchronized by gears, in accordance with aspects of the present disclosure.

Figure 25 is a view of an exemplary translational mount having a frame linkage including a plurality of anti-pivot devices each a pair of frame
20 members and arranged orthogonally to one another, in accordance with aspects of the present disclosure.

Figure 26 is a schematic view of the mount of Figure 25, illustrating an exemplary arrangement of anti-pivot devices.

Detailed Description

25 The present disclosure provides a gimbal system, including methods and apparatus, with a mounting portion connected to and supporting a gimbal assembly. The mounting portion may include a pair of frame members interconnected by a linkage portion. The linkage portion may include a plurality of bridge members that restrict pivotal motion of the frame members
30 relative to one another about two or more orthogonal axes while permitting relative translational motion with three degrees of freedom.

An exemplary gimbal system is provided. The gimbal system may comprise a mounting portion including a first frame member and a second frame member. The frame members may be interconnected by a linkage portion including three or more bridge members each having a first pivotable connection to the first frame member and a second pivotable connection to the second frame member. Each bridge member also may have a pivot joint disposed at a position along the bridge member intermediate the first and second pivotable connections. The first pivotable connections of the bridge members may be hinge joints. The pivot joints of the bridge members collectively may define a plane that remains parallel to the first frame member as the bridge members pivot at the hinge joints. The gimbal system also may comprise a gimbal assembly connected to and supported by the mounting portion and including a plurality of gimbals supporting a payload that is orientable with respect to the mounting portion by rotation of the gimbals. In some embodiments, the bridge members may be coupled to each other by a same rigid coupling member that is pivotably connected via a distinct connection to each bridge member and that is movable relative to both frame members. In some embodiments, each bridge member has a first portion extending from the hinge joint to the pivot joint of such bridge member, and the first portions of the bridge members each define a variable angle of the same size with the first frame member. In some embodiments, at least one of the bridge members may be disposed in meshed engagement with one or more teeth of a gear such that pivotal motion of at least a portion of the at least one bridge member is coupled to pivotal motion of the gear. In some cases, a pair of bridge members may be in toothed engagement with each other.

Another exemplary gimbal system is provided. The gimbal system may comprise a mounting portion including a first frame member and a second frame member. The frame members may be interconnected by a linkage portion that includes a first, a second, and a third anti-pivot device. Each anti-pivot device may provide one or more bridge members. Each anti-pivot device may permit translational motion of the frame members relative to each other

with three degrees of translational freedom and may restrict pivotal freedom of the frame members relative to each other about a different axis, such that the anti-pivot devices collectively restrict at least two or three degrees of pivotal freedom as the frame members move relative to each other with three
5 degrees of translational freedom. The gimbal system also may comprise a gimbal assembly connected to and supported by the mounting portion and including a plurality of gimbals supporting a payload that is orientable with respect to the mounting portion by rotation of the gimbals.

Yet another exemplary gimbal system is provided. The gimbal system
10 may comprise a mounting portion including a first frame member and a second frame member. The frame members may be interconnected by a linkage portion that restricts tilting of the frame members relative to one another while permitting the frame members to move relative to each other with three degrees of translational freedom. The frame members also may be
15 interconnected by an anti-pivot device that restricts pivotal motion of the frame members relative to each other about a central vertical axis. The gimbal system also may comprise a gimbal assembly connected to and supported by the mounting portion and including a plurality of gimbals supporting a payload that is orientable with respect to the mounting portion by rotation of the
20 gimbals. The anti-pivot device may include a central member connected to the second frame member by a pair of lateral members that are each pivotably connected to the central member and to the second frame member by a pair of spaced joints. The joints collectively may define vertices of a parallelogram that remains a parallelogram as the frame members move relative to each
25 other with three degrees of translational freedom.

Still another exemplary gimbal system is provided. The gimbal system may comprise a mounting portion including a first frame member and a second frame member. The frame members may be interconnected by an anti-pivot device that restricts pivotal motion of the frame members relative to
30 each other about a central vertical axis. The anti-pivot device may include a central member connected to the second frame member by a pair of lateral members that are each pivotably connected to the central member and to the

second frame member by a pair of spaced joints. The joints collectively may define vertices of a parallelogram that remains a parallelogram as the frame members move relative to each other with three degrees of translational freedom. The gimbal system also may comprise a gimbal assembly
5 connected to and supported by the mounting portion and including a plurality of gimbals supporting a payload that is orientable with respect to the mounting portion by rotation of the gimbals.

A method of using a gimbal system is provided. In the method, a gimbal system having any of the features disclosed herein may be mounted to
10 a vehicle via the mounting portion. The vehicle may be operated. The payload may be pointed at a target by controlled movement of the gimbals with respect to the mounting portion.

The mounts of the present disclosure may have advantages over other translational mounts, including a lower profile, fewer parts, a more compact
15 structure, less pivotal motion of frame members, better image quality of an associated image sensor, increased stability when pointing a payload at a target, or any combination thereof, among others.

Further aspects of the present disclosure are described in the following sections: (I) definitions, (II) overview of an exemplary gimbal system with a translational mount, (III) linkage portion with bridge members, (IV) payloads,
20 (V) support platforms, and (VI) examples.

I. Definitions

Technical terms used in this disclosure have the meanings that are commonly recognized by those skilled in the art. However, the following terms
25 may have additional meanings, as described below. The wavelength ranges identified in these meanings are exemplary, not limiting, and may overlap slightly, depending on source or context. The wavelength ranges lying between about 1 nm and about 1 mm, which include ultraviolet, visible, and infrared radiation, and which are bracketed by x-ray radiation and microwave
30 radiation, may collectively be termed optical radiation.

Ultraviolet radiation - Invisible electromagnetic radiation having wavelengths from about 100 nm, just longer than x-ray radiation, to about 400

nm, just shorter than violet light in the visible spectrum. Ultraviolet radiation includes (A) UV-C (from about 100 nm to about 280 or 290 nm), (B) UV-B (from about 280 or 290 nm to about 315 or 320 nm), and (C) UV-A (from about 315 or 320 nm to about 400 nm).

5 Visible light - Visible electromagnetic radiation having wavelengths from about 360 or 400 nanometers, just longer than ultraviolet radiation, to about 760 or 800 nanometers, just shorter than infrared radiation. Visible light may be imaged and detected by the human eye and includes violet (about 390-425 nm), indigo (about 425-445 nm), blue (about 445-500 nm),
10 green (about 500-575 nm), yellow (about 575-585 nm), orange (about 585-620 nm), and red (about 620-740 nm) light, among others.

Infrared (IR) radiation - Invisible electromagnetic radiation having wavelengths from about 700 nanometers, just longer than red light in the visible spectrum, to about 1 millimeter, just shorter than microwave radiation.
15 Infrared radiation includes (A) IR-A (from about 700 nm to about 1,400 nm), (B) IR-B (from about 1,400 nm to about 3,000 nm), and (C) IR-C (from about 3,000 nm to about 1 mm). IR radiation, particularly IR-C, may be caused or produced by heat and may be emitted by an object in proportion to its temperature and emissivity. Portions of the infrared range having
20 wavelengths between about 3,000 and 5,000 nm (i.e., 3 and 5 μ m) and between about 7,000 or 8,000 and 14,000 nm (i.e., 7 or 8 and 14 μ m) may be especially useful in thermal imaging, because they correspond to minima in atmospheric absorption and thus are more easily detected (particularly at a distance). The particular interest in relatively shorter wavelength IR radiation
25 has led to the following classifications: (A) near infrared (NIR) (from about 780 nm to about 1,000 nm), (B) short-wave infrared (SWIR) (from about 1,000 nm to about 3,000 nm), (C) mid-wave infrared (MWIR) (from about 3,000 nm to about 6,000 nm), (D) long-wave infrared (LWIR) (from about 6,000 nm to about 15,000 nm), and (E) very long-wave infrared (VLWIR)
30 (from about 15,000 nm to about 1 mm). Portions of the infrared range, particularly portions in the far or thermal IR having wavelengths between

about 0.1 and 1 mm, alternatively or additionally may be termed millimeter-wave (MMV) wavelengths.

II. Overview of an Exemplary Gimbal System with a Translational Mount

5

Figure 1 shows an exemplary gimbal system 20 including a gimbal assembly 22 attached to a support platform 24 via a translational mount 26 (interchangeably termed a mounting portion and/or a linear mount). In the present illustration, support platform 24 is a vehicle 28, namely, a helicopter.

10 The translational mount may restrict (i.e., impede and/or block) relative rotational motion of a pair of frame members of the mount with respect to one, two, or three degrees of pivotal freedom (i.e., about one, two, or three axes that are orthogonal to one another), while permitting three degrees of translational freedom of the frame members relative to each other. The mount
15 also may serve as a mechanical filter to reduce transmission of vibrations and other variable forces from the support platform to the gimbal assembly, and to resiliently position the gimbal assembly with respect to the support platform, toward an equilibrium position.

Figure 2 shows a schematic view of selected aspects of gimbal system
20 20. Gimbal assembly 22 may be connected to and supported by mount 26 (e.g., with the gimbal assembly located below or above the mount, among others) and may be pivotable collectively with respect to the mount (and the vehicle). The mount and/or a portion thereof may be relatively stationary with respect to vehicle 28, and the gimbal assembly may be relatively movable
25 with respect to the vehicle. System 20 also may be equipped with a payload 30 (e.g., including at least one or more optical devices, such as at least one light source and/or an optical sensor (e.g., an image sensor of a camera 32)) that is orientable with respect to mount 26 (and the vehicle) by rotation of gimbals of gimbal assembly 22 about a plurality of axes (e.g., at least two
30 nonparallel axes and/or a pair of orthogonal axes, among others).

Mount 26 may include first and second frame members 34, 36. In some cases, the frame members may be positioned as an upper frame member (34 or 36) and a lower frame member (36 or 34), which may be arranged along an

axis (e.g., spaced from one another along the indicated z-axis, which may be at least substantially vertical). For example, here, frame member 34 is an upper frame member and frame member 36 is a lower frame member. However, the frame members may switch their relative positions if the gimbal assembly is mounted above the vehicle (or other support platform), with frame member 34 adjacent the vehicle, and/or if the mount is inverted before attachment to the vehicle and gimbal assembly, such that frame member 36 is adjacent the vehicle. More generally, the frame members may be separated from each other along any axis determined, for example, by how the mount is attached to a support platform. In any event, frame member 34 may attach the mount to vehicle 28, and frame member 36 may connect the mount to gimbal assembly 22, or vice versa. A frame member may be secured to a support platform via attachment features of the frame member (and/or with one or more brackets, among others). For example, the frame member may define a set of apertures to receive fasteners. The apertures may have any suitable position, such as being disposed generally centrally or near a perimeter of the frame member.

Frame members 34, 36 may be connected movably to each other by any suitable combination of mechanisms. For example, the frame members may be interconnected by one or more spring elements 38 and/or one or more dampers 40 (e.g., to dissipate kinetic energy as heat). The frame members also may be interconnected by a linkage portion 42 having a plurality of articulated bridge members 44 and/or one or more anti-pivot devices 46 that permit translation motion while restricting pivotal motion of the frame members relative to one another. Anti-pivot device 46 may include one or more bridge members.

Spring elements 38 may be any elastic members that apply a restoring force when the frame members are displaced relative to one another from an equilibrium position, to urge the frame members back toward the equilibrium position. The spring elements may cushion gimbal assembly 22 from shocks and may filter vibrations of the vehicle according to frequency (e.g., a low-

pass filter that blocks higher-frequency vehicle vibration), to limit transmission of vibration from the vehicle to the gimbal assembly.

Spring elements 38 may be disposed at any suitable number of locations between frame members 34, 36. For example, mount 26 may
5 include at least three spring elements, at least one spring element for each bridge member, or the like. In any event, the spring elements may be configured to resiliently position frame member 36 (and gimbal assembly 22) along a z-axis that is orthogonal to a plane defined by a frame member. The spring elements also or alternatively may resiliently position frame member 36
10 (and gimbal assembly 22) along orthogonal horizontal axes (x- and y-axes).

Dampers 40 may, for example, include wire ropes. Alternatively, or in addition, one or more of the dampers may be integral to the spring elements.

Gimbal assembly 22 may comprise a series of two or more gimbals, such as first through fourth gimbals 52-58. Each gimbal is pivotably connected
15 to preceding and succeeding gimbals of the series, for example, via one or more axes. First gimbal 52 supports second through fourth gimbals 54-58 and payload 30 and is pivotably connected to and supported by frame member 36 for rotation about a first axis 60 (e.g., a first yaw, azimuthal, and/or vertical axis), which may extend at least generally centrally through
20 mount 26 and/or one or both frame members 34, 36. Second gimbal 54 supports third and fourth gimbals 56, 58 and payload 30 and is pivotably connected to and supported by first gimbal 52 for rotation about a second axis 62 (e.g., a first pitch, elevational, and/or horizontal axis), which may be orthogonal to first axis 60. Third gimbal 56 supports fourth gimbal 58 and
25 payload 30 and is pivotably connected to and supported by second gimbal 54 for rotation about a third axis 64 (e.g., a second pitch, elevational, and/or horizontal axis). Third axis 64 may be parallel to, and/or or coaxial with second axis 62 (or first axis 60 with the gimbal assembly in a neutral position). Fourth gimbal 58 supports payload 30 and is pivotably connected to and
30 supported by third gimbal 56 for rotation about a fourth axis 66 (e.g., a second yaw, azimuthal, and/or vertical axis). Fourth axis 66 may be parallel to, and/or coaxial with first axis 60 (or second axis 62) with the gimbal assembly in a

neutral position. The payload may (or may not) be fixed to the fourth gimbal. In some cases, rotation of first and second gimbals 52 and 54 may provide larger adjustments to the orientation of payload 30, and rotation of third and fourth gimbals 56 and 58 may provide smaller adjustments to the orientation
5 (or vice versa).

Rotation of each gimbal 52-58 may be driven by a drive mechanism, such as motors 68-74. Each motor may be attached to its corresponding gimbal or to the structure that supports the gimbal, or a combination thereof. For example, motor 68 may be attached to frame member 36 or first gimbal
10 52; motor 70 to first gimbal 52 or second gimbal 54; and so on. The angular orientation of the payload may be adjusted horizontally and vertically via rotation of gimbals 52-58, without changing the orientation of the support platform, and/or the payload may continue to point at a target as the attitude and location of the support platform changes, among others. Accordingly, the
15 gimbal system may allow one or more fixed and/or moving targets to be monitored or tracked over time from a fixed and/or moving support platform.

The gimbal system also may comprise one or more sensors to sense aspects of the vehicle, one or more gimbals, the payload, or a target. Exemplary sensors include an orientation sensor (e.g., a gyroscope that
20 measures angular position or rate of angular change, among others), an accelerometer, an optical sensor to detect optical radiation (e.g., an image sensor 76 in camera 32), or the like. At least one gimbal of the gimbal assembly and/or the payload may be attached to at least one gyroscope 78 to measure the orientation of the gimbal and/or payload. In some cases, the
25 gimbal system may include at least one inertial measurement unit (IMU) 80, which may be carried by gimbal assembly 22 (e.g., by payload 30 or fourth gimbal 58), and/or vehicle 28. The IMU may include sensors to measure acceleration along three orthogonal axes and angular position/change about three orthogonal axes. Measurements from unit 80 alone or in combination
30 with those from one or more other gyroscopes of the gimbal assembly may be used to aim the payload with respect to an inertial reference frame (e.g., the earth), as the vehicle travels with respect to the reference frame.

Gimbal system 20 also may comprise a processor 82, and a user control unit 84 to communicate inputs, such as user preferences, commands, etc., to the processor. The processor may be included in gimbal assembly 22 (and/or mount 26), vehicle 28, or a combination thereof, among others. The user control unit may be disposed in the vehicle, if the vehicle has a person onboard, or may be disposed elsewhere (e.g., on the ground) if the vehicle is unmanned.

The processor may include any electronic device or set of electronic devices responsible for signal processing, manipulation of data, and/or communication between or among gimbal system components. The processor may be localized to one site or may be distributed to two or more spaced sites of the gimbal system. The processor may be programmed to receive user inputs from user control unit 84 and to control operation of and/or receive signals from any suitable system components, as indicated by dashed lines in Figure 2, for example, the motors, sensors (e.g., one or more optical devices, an IMU(s), gyroscopes, accelerometers, etc.), payload 30, a display 86 carried by vehicle 28, and so on. Accordingly, the processor may be in communication with the motors, sensors, and display, to receive signals from and/or send signals to these devices, and may be capable of controlling and/or responding to operation of these devices. Also, the processor may be responsible for manipulating (processing) image data (i.e., a representative video signal) received from camera 32 before the signal is communicated to display 86, to drive formation of visible images by the display.

Gimbal assembly 22 may include and/or be connected to a power supply. The power supply may include any mechanism for supplying power, such as electrical power, to the motors, sensors, payload, processor, etc. The power supply may be provided by the support platform, the mount, the gimbal apparatus, or a combination thereof, among others. Suitable power supplies may generate, condition, and/or deliver power, including AC and/or DC power, in continuous and/or pulsed modes. Exemplary power supplies may include batteries, AC-to-DC converters, DC-to-AC converters, and so on.

III. Linkage Portion with Bridge Members

This section describes an exemplary linkage portion 42 that may be included in translational mount 26 to reduce pivotal motion of frame members relative to one another, while permitting translational motion; see Figures 3-7.

5 Other linkage portions that may be suitable are described below in Section VI.

Linkage portion 42, interchangeably termed a linkage assembly, may be configured to permit three degrees of translational freedom of one frame member relative to the other frame member, such that the frame members can move translationally relative to one another with respect to three
10 orthogonal axes (x, y, and z). However, the linkage assembly may restrict at least two degrees of rotational freedom (e.g., restricting at least x and y rotational freedom). The restricted rotational freedom may be pivotal motion of one frame member relative to the other frame member about any axis in a plane parallel to a frame member. Such pivotal motion about a horizontal axis,
15 if permitted to occur substantially, causes one frame member to tilt relative to the other frame member, if initially parallel to each other. By restriction of these two degrees of rotational freedom, the linkage assembly can maintain the frame members substantially parallel to each other at all permitted relative positions of the frame members. In some examples, the mount may restrict
20 relative rotational motion of the frame members about a vertical axis using anti-pivot device 46 (e.g., see Examples 2 and 4). In other examples, without device 46, a small amount of tilting still may occur, due to pivotal motion about the z-axis (as described below in this Section).

Figures 3 and 4 show schematic bottom and sectional views,
25 respectively, of selected aspects of an exemplary embodiment 88 of translational mount 26 including linkage assembly 42 for use in the gimbal system of Figures 1 and 2. In the bottom view of Figure 3, lower frame member 36 is not visible.

Each frame member 34, 36 may define a plane 90, 92 (see Fig. 4). For
30 example, the frame member may be described generally as a plate and/or may include a plate portion. Planes 90, 92 of the frame members each may be described as an xy plane. The frame members may be interconnected by

linkage assembly 42, with the frame members and/or their defined planes parallel to each other and orthogonal to a central z-axis 94. The z-axis also or alternatively may be described as a separation axis. The frame members may be separated from each other by a variable separation distance 96 measured parallel to axis 94. In other words, the linkage assembly permits the frame members to change their separation distance from each other by moving closer together or farther apart, to respectively decrease or increase the separation distance. Also, the linkage assembly may permit the frame members to move to offset horizontal positions relative to each other in the xy plane.

Linkage assembly 42 may include three or more bridge members 44 that interconnect the frame members. The bridge members interchangeably may be termed spanning members, which each span a gap between the frame members. Each bridge member can be described as being articulated because the bridge member has at least one movable joint (e.g., a pivot joint) at which segments or portions of the bridge member are attached to each other. Each bridge member may be pivotably connected to each of the frame members, such as attached to the frame members at opposite ends of the bridge member. The bridge members may follow distinct, non-overlapping paths between the frame members.

Each bridge member may include an arm 98 that is attached to a strut 100 at a pivot joint 102. (Each arm and/or strut interchangeably may be termed a portion or segment.) Each arm 98 may have a pivotable connection 104, such as a hinge joint, that connects the arm to frame member 34. Also, each strut 100 may have a pivotable connection 106 that connects the strut to frame member 36. Pivot joint 102 may be disposed along the bridge member at a position along the bridge member that is intermediate pivotable connections 104, 106. Each bridge member can flex at pivot joint 102 to change the angle defined collectively by the arm and the strut, which, in turn, changes the distance between ends of the bridge member (i.e., between pivotable connections 104, 106 of the bridge member).

The bridge members may provide uniform separation between corresponding structures of the bridge members. For example, pivot joints 102 may be disposed at a uniform distance from their corresponding pivotable connections 104 and/or 106. Pivot joints 102 may define a plane 108 that
5 remains parallel to plane 90 and/or 92 as arms 98 pivot, and/or as frame members 34, 36 change their separation and/or undergo translational motion with three degrees of freedom.

Pivot joint 102 and pivotable connections 104, 106 of a bridge member each may permit any suitable range of pivotal motion about only one axis or
10 about orthogonal axes. In exemplary embodiments, pivot joint 102 and pivotable connection 106 each are spherical joints that permit motion about at least a pair of orthogonal axes, while pivotable connection 104 is a hinge joint that substantially restricts pivotal motion of each arm 98 to a single axis.

Arms 98 may undergo pivotal motion at hinge joint 104 to change the
15 separation between planes 90 and 108 and/or the separation between plane 90, 92 (and frame members 34, 36). In the present illustration, the arms may turn in a clockwise direction to increase separation distance 96 between frame members 34, 36 (compare Figs. 4 and 5), and in a counterclockwise direction to decrease separation distance 96 (assuming no change in the
20 orientation of struts 100).

Arms 98 may be arranged to all form the same angle 110 with frame member 34, at any given time, at any permitted separation of planes 90, 108 (and/or plane 90, 92) and/or with any permitted value of angle 110 (see Fig. 4).

25 Linkage assembly 42 may be equipped with a coupling member 120 that synchronizes pivotal motion of the arms. In any event, arms 98 may pivot at the same time and with the same rate of angular change. As a result, any change in angle 110 produced by pivotal motion of one of the arms may be matched by an equal angular change for each of the other arms. Coupling
30 member 120 may be pivotably connected to each arm 98 by an articulation 122 (a movable joint), which may be a spherical joint or a hinge joint, among others. Articulations 122 may be formed at corresponding positions of arms

98, such that each articulation 122 is positioned at the same, fixed distance from pivot joint 102 and at the same, fixed distance from pivotable connection 104.

Coupling member 120 may be rigid such that articulations 122 formed
5 between arms 98 and the coupling member have fixed positions relative to each other. The articulations may be held in a plane that remains parallel to plane 108 and/or to frame members 34 and/or 36 as the frame members move relative to each other.

Arm 98 and strut 100 each may have any suitable characteristics. The
10 arms may have a uniform length, and the struts may have a uniform length, which may be the same length or a different length from the arms. The arm and/or strut may (or may not) be elongate. The arm and/or strut may be structured as a plate, a bar, a rod, a disc, or a combination thereof, among others. The arm and the strut each may be substantially rigid.

15 Figures 4-6 shows various configurations of bridge members 44. In Figure 4, mount 88 is in an equilibrium configuration produced, for example, when the mount is attached to a stationary support platform (e.g., a vehicle with the engine shut off), without any tilt, and is loaded by the gimbal assembly. Additional forces exerted on the mount cause the frame members
20 to move relative to one another, which may be accompanied by pivotal motion of the arms and/or struts (compare Figs. 5 and 6). In the equilibrium configuration, struts 100 may (or may not) extend orthogonally to frame member 36 (see Figs. 4 and 5), and may pivot out of an orthogonal configuration to an oblique configuration with respect to frame member 36
25 (and/or frame member 34) in response to relative movement of the frame members (see Fig. 6). Also, arms 98 may have any suitable angular disposition in the equilibrium configuration of the mount. For example, the arms, and particularly an axis defined collectively by pivot joint 102 and connection 104, may form an oblique angle with plane 90 of frame member
30 34, which may increase and decrease in response to relative movement of the frame members. In other embodiments, pivot joint 102 and connection 104 of each bridge member collectively may define an axis oriented parallel to plane

90/frame member 34 in the equilibrium configuration of the mount. Movement of frame members 34, 36 relative to one another may produce a change in vertical separation distance 96, a horizontal offset 130, or both (see Fig. 6).

Figure 3 illustrates an exemplary radial arrangement of bridge members 44 for mount 88. Arms 98 may be arranged along a circular path 136 centered on central z-axis 94 of the mount. Each pivotable connection 104 may be a hinge joint defining a hinge axis 138. Hinge axes 138 may be nonparallel to one another, such as arranged radially with respect to z-axis 94. The bridge members may or may not be equally spaced from each other.

10 In some cases, corresponding points on the bridge members may define a regular polygon (i.e., a polygon with all sides having the same length and all angles being the same), such as an equilateral triangle, a square, a regular pentagon, a regular hexagon, or the like. In some cases, pivot joints 102 may form the vertices of a first polygon, connections 104 the vertices of a second

15 polygon, connections 106 the vertices of a third polygon, and articulations 122 the vertices of a fourth polygon. Each polygon may have a fixed size and shape as the frame members move relative to each other with any permitted relative motion. Also, or in addition, all or any combination of the first, second, third, and fourth polygons may be equivalent to each other (i.e., having the

20 same size and shape).

Coupling member 120 may extend around central orthogonal axis 94 to articulations 122 formed with each arm 98. The coupling member may extend completely around central axis 94, to form a closed coupling member (i.e., a closed loop, such as a ring), or may extend less than completely around

25 central axis 94, to form an open coupling member having distinct ends 140. The coupling member may have curved sides (e.g., a ring), straight sides (e.g., a polygonal coupling member, which may be triangular, rectangular, etc.), or a combination thereof.

Figure 7 shows a schematic representation of a lower portion of a

30 simplified mount 26. The mount has a rectangular frame member 36 attached to a set of four struts 100 at pivotable connections 106 (compare with Figs. 3 and 4). The upper end of each strut, which forms part of pivot joint 102, is

disposed in plane 108, with the upper ends arranged in a fixed geometrical relationship to one another. More particularly, pivotable connections 106 collectively define a first polygon, in this case, a square, that is equivalent (equal in size and shape) to a second polygon defined by pivot joints 102. The
5 fixed geometrical relationship is determined and maintained by arms 98 and/or coupling member 120 (see Figs. 3-6).

Various permitted configurations of the struts are illustrated. Configuration A shows struts 100 arranged orthogonally to frame member 36 and plane 108 (as in Figs. 4 and 5). Configuration B shows struts 100 oriented
10 obliquely to frame member 36 (and plane 92) and plane 108 and parallel to one another (as in Fig. 6). Configuration B is produced from Configuration A by translational motion, indicated at 150, of plane 108 relative to plane 92, and decreases the separation distance between the planes from the maximum separation distance of Configuration A. Configuration C shows a
15 “twisted” arrangement of struts 100. The configuration can result from rotation 160 of plane 108 with respect to plane 92 about central axis 94, while the planes remain parallel to one another. Arms 98, if arranged with radial hinge axes, also may be generally oriented in the same type of “twisted” arrangement.

20 In contrast to parallel Configurations A-C, nonparallel (tilted) Configuration B+C may be produced by a combination of the translational motion that produces Configuration B with the twisting motion that generates Configuration C. Access of mount 26 to Configuration B+C generally does not produce a substantial tilt of frame members 34, 36 relative to one another
25 during use of the gimbal system and can be restricted further by a z-axis anti-pivot device 46 (e.g., see Example 2).

In some embodiments, struts 100 may move from the orthogonal arrangement of Configuration A, in the equilibrium configuration of the mount, to twisted arrangements produced by rotation about axes parallel to the frame
30 members, as arms 98 rotate in the opposite direction from the equilibrium configuration (e.g., see Example 1). In other words, a plane or polygon defined by pivot joints 102 may rotate in a first direction as the separation

distance of frame members 34, 36 is increased, and then in a second, opposite direction as the separation distance is decreased from the equilibrium separation distance. Also, the struts may alternate between a clockwise twist and a counterclockwise twist, or vice versa, as the separation distance of the frame members decreases and increases from the equilibrium separation distance.

IV. Payloads

A payload is any device or collection of devices that is carried and aimed by a gimbal assembly. The payload may include one or more detectors and/or emitters, among others. A detector may create a signal representative of detected energy and/or force, such as electromagnetic radiation, an electric field, a magnetic field, a pressure or pressure difference (e.g., sonic energy), a temperature or temperature difference (e.g., thermal energy), a particle or particles (e.g., high energy particles), movement (e.g., an inertial measurement device), and/or the like. An emitter generally comprises any mechanism for emitting a suitable or desired signal, such as electromagnetic radiation (e.g., via a laser), sonic energy, and/or the like. The payload generally is in communication with a processor that sends signals to and/or receives signals from the payload. The payload may be connected (generally via a processor) to a display, such that signals from the payload may be formatted into a visible form for viewing on the display. In some cases, the payload may contain high heat-emitting components, such as lasers, radars, millimeter-wave (MMW) imagers, light detection and ranging (LIDAR) imagers, mine-detection sensors, and/or inertial measurement units (IMUs).

In some embodiments, the payload may form a detection portion of an imaging system. An imaging system generally comprises any device or assembly of devices configured to generate an image, or an image signal, based on received energy, such as electromagnetic radiation. Generally, an imaging system detects spatially distributed imaging energy (e.g., visible light and/or infrared radiation, among others) and converts it to a representative signal. Imaging may involve optically forming a duplicate, counterpart, and/or other representative reproduction of an object or scene, especially using a

mirror and/or lens. Detecting may involve recording such a duplicate, counterpart, and/or other representative reproduction, in analog or digital formats, especially using film and/or digital recording mechanisms. Accordingly, an imaging system may include an analog camera that receives
5 radiation (e.g., optical radiation) and exposes film based on the received radiation, thus producing an image on the film. Alternatively, or in addition, an imaging system may include a digital camera that receives radiation (e.g., optical radiation) and generates a digital image signal that includes information that can be used to generate an image that visually portrays the
10 received radiation. Alternatively, or in addition, an imaging system may include an active component such as a laser to illuminate a scene and form an image from one or more reflections of the laser. "Imaging energy," as used herein, may include any type of energy, particularly electromagnetic energy, from which an image can be generated, including but not limited to ultraviolet
15 radiation, visible light, and infrared radiation.

Suitable detectors for an imaging system may include (1) array detectors, such as charge-coupled devices (CCDs), charge-injection devices (CIDs), complementary metal-oxide semiconductor (CMOS) arrays, photodiode arrays, microbolometers, and the like, and/or (2) arrays of point
20 detectors, such as photomultiplier tubes (PMTs), photodiodes, pin photodiodes, avalanche photodiodes, photocells, phototubes, and the like. Detectors may be sensitive to the intensity, wavelength, polarization, and/or coherence of the detected imaging energy, among other properties, as well as spatial and/or temporal variations thereof.

25 The imaging system also may include optics (i.e., one or more optical elements). Exemplary optical elements may include (1) reflective elements (such as mirrors), (2) refractive elements (such as lenses), (3) transmissive or conductive elements (such as fiber optics or light guides), (4) diffractive elements (such as gratings), and/or (5) subtractive elements (such as filters),
30 among others.

The imaging system also may contain gyroscopes and/or other elements arranged to form an inertial measurement unit (IMU) on an optical

bench. The IMU may be used to assess the pointing angle of the line-of-sight, as well as geo-location, geo-referencing, geo-pointing, and/or geo-tracking in earth coordinates.

In some embodiments, an imaging system may be capable of
5 generating image signals based on two or more different types or wavebands of imaging energy. For example, the imaging system may be configured to generate a first image signal representative of visible light and a second image signal representative of infrared radiation. Visible light and infrared radiation are both types of electromagnetic radiation (see Definitions);
10 however, they are characterized by different wavebands of electromagnetic radiation that may contain or reflect different information that may be used for different purposes. For example, visible light may be used to generate an image signal that in turn may be used to create a photograph or movie showing how a scene appears to a human observer. In contrast, infrared
15 radiation may be used to generate an image signal that in turn may be used to create a heat profile showing heat intensity information for a scene. More generally, the imaging system may be used with any suitable set of first and second (or first, second, and third (and so on)) image signals, using any suitable wavelength bands. These suitable image signals may include first
20 and second visible wavebands, first and second infrared wavebands, mixtures of visible, infrared, and/or ultraviolet wavebands, and so on, depending on the application.

In some examples, an imaging system may form composite images. The composite images may be straight combinations of two or more other
25 images. However, in some cases, one or both of the images may be processed prior to or during the process of combining the images. Composite images may be formed for use in firefighting, aeronautics, surveillance, and/or the like, for example, by superimposing infrared images of hot spots, runway lights, persons, and/or the like on visible images.

30 The payload alternatively, or in addition, may include non-imaging systems, such as laser rangefinders, laser designators, laser communication devices, polarimeters, hyperspectral sensors, and/or the like.

In some examples, second gimbal 54 supports and encloses payload 30. The payload may include a plurality of optical devices, such as an infrared camera, a video camera for visible light (e.g., a closed-circuit television camera), a laser rangefinder, a light source that serves as a pointer and/or illuminator, or any combination thereof. The second gimbal also may be equipped with one or more optical windows that allow optical radiation to enter or exit the second gimbal, such that the optical radiation can travel to and/or from each optical device of the payload.

V. Support Platforms

The gimbal system of the present disclosure may include a gimbal assembly connected to a support platform by a translational mount. A support platform, as used herein, generally refers to any mechanism for supporting and/or conveying a translational mount and a gimbal assembly. The support platform may be movable or fixed in relation to the earth, and may be disposed on the ground, in the air or space, or on and/or in water, among others. In any case, the support platform may be selected to complement the function of the mount and gimbal assembly, and particularly the payload thereof.

The support platform may be movable, such as a vehicle with or without motive power. Exemplary vehicles include a ground vehicle (e.g., a car, truck, motorcycle, tank, etc.), a watercraft (e.g., a boat, submarine, carrier, etc.), an aircraft (e.g., a fixed-wing piloted aircraft, pilotless remote-controlled aircraft, helicopter, missile, dirigible, aerostat balloon, rocket, etc.), or the like. In some cases, the support platform may include a crane or mast, which may provide hydraulic positioning of the support platform.

The support platform may be fixed in position. Exemplary fixed support platforms may include a building, an observation tower, a wall, a mast, and/or an observation platform, among others.

A gimbal system with a movable or fixed support platform may be used for any suitable application(s). Exemplary applications for a gimbal system include navigation, targeting, search and rescue, law enforcement, firefighting, force protection, and/or surveillance, among others.

VI. Examples

The following examples describe selected aspects of exemplary translational mounts for gimbal systems. These examples are intended for illustration and should not be interpreted as limiting the entire scope of the present disclosure.

Example 1. Exemplary Translational Mount with a Coupling Ring

This example describes an exemplary embodiment 170 of mount 26; see Figures 8-11.

Mount 170 has four bridge members 44 constructed and arranged generally as described above for mount 88 (which has only three bridge members). Bridge members 44 are connected to each other intermediate their ends by a closed ring 172 that functions as coupling member 120 to synchronize movement of the bridge members (and particularly arms 98 thereof). In other embodiments, mount 170 may have any combination of the features disclosed herein for other mounts 26.

Figure 8 shows mount 170 in the absence of the upper frame member. Each bridge member has an arm 98 and a strut 100 connected to each other at pivot joint 102, which may include a spherical bearing. The lower end of each bridge member formed by strut 100 is connected to lower frame member 36 via a spherical bearing at pivotable connection 106. An end of the strut may be disposed in an aperture 174 formed in a floor 176 of frame member 36. Alternatively, the end of the strut may be attached to a bracket that projects from floor 176, among others. The upper end of each bridge member includes a pivot pin 178 that attaches arm 98 to the upper frame member, to form a hinge joint. The pivot pins are arranged radially such that each defines a radial pivot axis 180 that intersects central z-axis 94. Each pivot axis 180 may be parallel to a plane defined by frame member 34. Each arm 98 is attached to ring 172 via a spherical bearing 182.

The frame members of mount 170 also are connected to each other via anti-pivot device 46, which may be described as an anti-yaw linkage assembly. Device 46 restricts relative pivotal motion of one frame member

relative to the other about any vertical axis parallel to central axis 94. The anti-pivot device is described below in Section VI.

Figure 9 shows a sectional view of mount 170. Each frame member 34, 36 includes a plate portion or plate 190, 192. The frame member also may have various brackets (such as a hinge bracket 194), housings, and/or flanges 196 projecting from and fixed to the plate portion. Frame members 34, 36 are resiliently positioned relative to one another by a plurality of spring elements (six in this case) each disposed in a respective housing formed by frame member 34. The housing may, for example, be cylindrical. The spring element may be formed of any suitable elastic material, such as metal (e.g., a coil spring or leaf spring), an elastomer, or a combination thereof, among others. In some cases, the spring element may have a central or compression axis oriented orthogonally to a plane defined by the frame member. The spring elements collectively apply restoring forces that urge the frame members toward an equilibrium position, whenever the plates are displaced from the equilibrium position (along and/or about any axis or axes). The spring elements may permit relative translational motion of the plates with three degrees of freedom.

Mount 170 may have a range of translational motion determined at least in part by one or more stops 198. For example, the permitted range of motion can be a total of less than about five or two centimeters, or about one centimeter, with respect to each orthogonal axis. In an exemplary embodiment, intended only for illustration, the range of motion can be about 4 mm from the equilibrium position in each direction for an x-axis and a y-axis and about 6 mm in each direction for a z-axis.

Figure 10 shows a change in the separation of plates 190, 192 associated with rotation of arms 98 and struts 100 in opposite directions. The connection between ring 172 and arms 98 causes the ring to move relative to plates 190, 192 as the arm pivots via hinge joint 104. For example, clockwise motion of arm 98 in the present illustration is coupled to an increase in the separation distance between the plates. The clockwise motion also can be coupled to pivotal motion of ring 172 in a first rotational direction about a

central orthogonal axis of the mount and motion of the ring toward plate 190 and away from plate 192, as shown in Figure 10. In contrast, counterclockwise motion of arm 98 from the configuration of Figure 9 can be coupled to a decrease in the separation distance between the plates. The
5 counterclockwise motion also can be coupled to pivotal motion of ring 172 in an opposite, second rotational direction about the central orthogonal axis and movement of the ring closer to both plates (also see Figs. 4 and 5).

Figure 11 shows horizontal offset 130 of plates 190, 192 relative to each other produced by rotation of struts 100 while arms 98 stay at the same
10 position (also see Fig. 6).

Example 2. Exemplary Anti-Pivot Device for a Translational Mount

This example describes an exemplary anti-pivot device 46 for restricting relative pivotal motion of frame members 34, 36 about all axes (e.g., any z-axis) orthogonal to the planes defined by the frame members; see
15 Figures 12-15.

Figures 12 and 13 show anti-pivot device 46 of mount 170 (see Fig. 8) connected to frame member 36. The anti-pivot device is disposed between frame members 34, 36 and is connected pivotably to both (see below). In some embodiments, the anti-pivot device may be described as providing one
20 or more bridge members.

The anti-pivot device may include a plurality of pivotably connected, rigid structural members: a central member 210, axial members 212, 214, and lateral members 216, 218 (interchangeably termed arm members). Central member 210 may be a plate and/or may be at least generally cross-shaped or
25 T-shaped.

The central member may be pivotably connected to axial members 212, 214 by a pair of hinge joints 220 disposed at spaced positions along a first axis 222 (see Fig. 12). First axis 222 may be parallel to a plane (e.g., an xy plane) defined by each frame member and remains parallel to the plane as
30 the frame members move translationally relative to one another through their whole range of relative translational motion. Each hinge joint 220 has a pivot axis arranged parallel to z-axis 94 of the mount (see Fig. 13).

Central member 210 may be pivotably connected to lateral members 216, 218 by a pair of pivot joints 224 (e.g., with at least two degrees of pivotal freedom (such as spherical joints)) (see Fig. 12). The pivot joints may be arranged along a second axis 226 that is transverse and/or orthogonal to first axis 222. Second axis 226 may be kept substantially parallel to the plane defined by each frame member, by the action of anti-tilt linkage assembly 42 of mount 170 (e.g., see Example 1).

The anti-pivot device may be connected to frame members 34, 36 via axial members 212, 214 and lateral members 216, 218. Axial members 212, 214 each may be connected pivotably to frame member 34 by hinge joints 228. Lateral members 216, 218 may be pivotably connected to frame member 36 by pivot joints 230 formed between an end of each lateral member and a bracket 232 of frame member 36. (Pivot joints 230 (such as spherical joints) may have at least two degrees of pivotal freedom.) In other embodiments, the position of joints 228 and 230 may be inverted (i.e., joints 228 providing connection to frame member 36 and joints 230 providing connection to frame member 34).

Anti-pivot device 46 utilizes a series of pivotable connections to allow relative translational motion of frame members 34, 36 with three degrees of freedom, while restricting relative pivotal freedom of the plates about any axis parallel to central axis 94. For example, frame member 36 can move in an xy plane relative to frame member 34 by rotation of axial members 212, 214 and/or by pivotal motion of lateral members 216, 218 about vertical axes defined by spherical joints 224, 230. Also, frame member 36 can change its separation from frame member 34 by rotation of lateral members 216, 218 about horizontal axes defined by spherical joints 224, 230. However, anti-pivot device 46 restricts relative pivotal motion of the frame members about all vertical axes because central member 210 (and axis 222) cannot pivot with respect to either plate about any vertical axis. In particular, the central member is restricted from pivoting by the fixed length of lateral members 216, 218. In order for central member 210 to pivot about a vertical axis, one lateral member would need to decrease in length and the other lateral member

would need to increase in length, but both lateral members are rigid enough to resist a change in length.

Figures 14 and 15 show anti-pivot device 46 respectively before and after translational motion of frame member 34 relative to frame member 36 in x and y directions to illustrate why no relative pivotal motion of the frame members can occur about any vertical axis. Frame member 34 is presented as fragmentary and in phantom outline, to simplify the presentation, and is attached to axial members 212, 214 with fasteners 250 (see Fig. 14). Frame axis 252 represents an arbitrary fixed reference axis defined by the plane of frame member 36, and is parallel to first axis 222 of central member 210 before translational motion.

When axial members 212, 214 turn, and/or lateral members 216, 218 pivot, central member 210, first axis 222, and thus frame member 34, are each repositioned translationally in an xy plane relative to frame member 36. First axis 222 and reference axis 252 remain parallel.

Joints 224 and 230, which are shown schematically in Figures 14 and 15, form vertices of a parallelogram. As frame members 34, 36 move relative to each other, joints 224, 230 are constrained to continuously define a parallelogram. For example, the parallelogram begins as a rectangle in Figure 14 and is converted into a parallelogram with different internal angles in Figure 15.

Example 3. Exemplary Translational Mounts with Toothed Engagement of Bridge Members

This example describes exemplary gimbal systems having a translational mount with a gear-synchronized linkage assembly; see Figures 16-24.

Figure 16 shows mount 26 having linkage assembly 42 synchronized by gears 260, 262. The mount is depicted in an exploded configuration, with linkage assembly 42 exploded from upper and lower frame members 34, 36.

Linkage assembly 42 may include a pair of bar assemblies 264, 266. Each of the bar assemblies may provide a pair of bridge members 44. Each bridge member may have an arm 98 and a strut 100, as described above in

Section II and Example 1. At least a pair of the arms may be included in or fixed to gears 260, 262.

Each bar assembly may be pivotably connected to upper frame member 34 at one or more positions. For example, each bar assembly may be pivotably connected to the upper frame at a pair of positions along the bar assembly, to define respective rotation axes 268, 270 for rotation of the bar assemblies. The rotation axes are spaced from each other and may be coplanar and/or parallel.

The bar assemblies may provide one or more pairs of gears 260, 262. The gears are meshed with each other via teeth that provide toothed engagement of the gears with each other. As a result, rotation of one of the bar assemblies through a given angle is matched by rotation of the other bar assembly in the opposite direction through the same angle. A pair of gears may be disposed at either or both paired end regions of the bar assemblies.

Each bar assembly 264, 266 may be equipped with a shaft 272, 274 and a pair of transverse members that form gears 260, 262 and/or arms 98. The transverse members may be fixed to opposing ends of each shaft. The opposing ends of each bar assembly may have similar or identical structure (e.g., see below) or may be structured differently from each other, as shown here.

Each bar assembly 264, 266 and/or each opposing end of the bar assembly may include at least one arm that projects transversely and/or at least generally radially from shaft 272, 274 (or from corresponding rotation axis 268 or 270). For example, in the depicted embodiment, one end of each bar assembly provides opposing arms that collectively form one of gears 260, 262. Also, the other end of each bar assembly provides only arm 98 (and no gear).

Figures 17-20 show an exemplary imaging unit 290 that may form at least part of gimbal system 20. The imaging unit includes an embodiment 292 of mount 26. Other structural elements and features of unit 290 that were described previously with respect to Figures 1 and 2 have been assigned the same reference numbers as in Figures 1 and 2.

Second gimbal 54 supports and encloses payload 30. The payload may include a plurality of optical devices, such as an infrared camera 293, a video camera for visible light (e.g., a closed-circuit television camera) 294, a laser rangefinder 296, a light source that serves as a pointer and/or illuminator 298, or any combination thereof. The second gimbal also may be equipped with one or more optical windows 300-306 that allow optical radiation to enter and/or exit the second gimbal, such that the optical radiation can travel to and/or from each optical device of the payload.

Figure 18 shows a bottom view of selected aspects of mount 292, particularly in the absence of lower frame member 36 and struts 100. Each spring element 42 may be disposed in a spring housing 320 formed by the upper frame and depending from the body thereof. The housing may, for example, be cylindrical.

Each bar assembly 264, 266 may be supported by, and may extend through, a pair of brackets 322 depending from upper frame member 34. Each bracket may hold a bearing 324 that facilitates rotation of the bar assembly by reducing friction.

Gears 260, 262 may be secured to each opposing end of shafts 272 and 274, such that the shaft and its pair of gears pivot collectively as a unit. Each gear may project transversely with respect to the shaft, in one or more directions. The gear has at least one tooth, and generally, a series of teeth 326. Also, the gear has at least one attachment site 328 for a strut 100 (see below). In the depicted embodiment, two pairs of gears 260, 262 are formed at the opposing ends of bar assemblies 264, 266.

Each gear may have any suitable shape. For example, the gear may be linear or may be bent, as shown here. In some cases, the gear may form opposing arms that extend obliquely relative to each other from a rotation axis of the bar assembly. In the present illustration, the body of the gear extends orthogonally from the rotation axis, and arm 98 extends obliquely to the rotation axis and obliquely to the long axis of the gear. Arm 98 may be bifurcated to form a receiver for an end of strut 100.

Shafts 272, 274 may have any suitable shape. The shaft may be straight or may be bent at one or more positions. For example, a central region along the shaft may be laterally offset from a rotation axis of the shaft. The use of a shaft with an offset central region may provide more space
5 between the shafts for accommodating other components of the mount and/or gimbal apparatus.

Figure 19 shows a side view of mount 292, with each spring housing 320 shown in phantom outline to simplify the presentation. A respective strut 100 extends from pivot joint 102 of each bridge member 44 to pivotable
10 connection 106 at lower frame member 36. Each end of strut 100 forms part of a joint that permits pivotal motion about orthogonal axes. Coupled rotation of bar assemblies 264, 266 via gears 260, 262 maintains all four pivot joints 102 in a coplanar arrangement and equidistant from upper frame member 34 (and/or a plane defined by the upper frame member). As a result, the coupled
15 rotation is associated with translational motion of the lower frame (and gimbal apparatus), which may be, among others, linear motion along an axis that is orthogonal to the rotation axes of the bar assemblies.

Teeth 326 formed at the end of each gear 260, 262 may be arranged along an arcuate path having a radius corresponding to the distance from the
20 rotation axis of the gear to the teeth. The arcuate path may extend along any suitable portion of an imaginary, complete circle of the same radius centered on the rotation axis, such as less than about 60, 45, or 30 degrees, among others. The sets of teeth formed by meshed gears may be complementary to each other and interdigitated with each other.

Figure 20 shows an end view of gear 260, particularly teeth 326 thereof. Each gear may be a helical gear. Accordingly, a crest or land 340 of each tooth may define a tooth axis 342 that extends obliquely to rotation axis 268 of the gear. The crest also may extend along a segment of a helical path. The teeth of corresponding meshed gear 262 (e.g., see Fig. 19) have crests
25 that extend substantially parallel to the teeth of gear 260 to permit interdigitation of the respective sets of teeth. Coupled rotation of the first pair of meshed helical gears 260, 262 may create a force directed parallel to
30

rotation axes 268, 270. The force can be balanced by an equal but opposite force created by the second pair of meshed helical gears 268, 270, if the positions of the gears are swapped in the second pair. Stated differently, the second pair of gears may be related to the first pair by rotation through a half turn about a vertical axis. In other embodiments, the gears may be spur gears, among others. However, the use of helical gears may, in some cases, provide smoother operation of the gears with less backlash.

Figure 21 shows another exemplary mount 360 having gears 260, 262. Mount 360 may be structured and may operate generally as described for mount 292 (e.g., see Figs. 17-19). However, bar assemblies 264, 266 of mount 360 may utilize shorter gears 260, 262. In particular, each strut may be attached to a gear to form pivot joint 102 between the gear's pivot axis and teeth 326.

Figure 22 shows a schematic bottom view of selected aspects of yet another exemplary translational mount 380 with bridge members 44 synchronized by gears 260, 382. The gears may be arranged along a circular path centered about central vertical axis 94 of the mount. Hinge joints 104, 384 may be arranged with their pivot axes 138 extending radially with respect to axis 94.

Each gear 260, 382 may extend along an arcuate path, as shown here. Alternatively, the gear may extend along a linear path. In any event, gears 260, 382 collectively may extend completely around axis 94, as shown here, or may extend a majority of the distance, but not completely around the axis, to form a gap.

Figure 23 shows a side view of mount 380. The linkage assembly of the mount may utilize a plurality of articulated bridge members 44 that interconnect frame members 34, 36. The present illustration shows three bridge members, although four or more bridge members may be used.

Each bridge member 44 may include arm 98 and strut 100 pivotably connected to each other by a pivot joint. The arm may be provided by gear 260, which may be pivotably connected to frame member 34 by hinge joint 104 to permit pivotal motion about the hinge joint. Hinge joints 104 may be

disposed in the same plane. Each gear 260 may be in meshed engagement with another gear 260 that includes another arm 98 and/or may be in meshed engagement with a coupling gear 382, as shown here. The coupling gear may be pivotably connected to frame member 34, such as with at least one hinge joint 384. The coupling gear may include at least one set of teeth 362. Coupling gears 382 may synchronize pivotal motion of arms 98, such that the arms rotate at the same angular rate.

Gears 260, 382 may be elongate. The gears each may define a long axis and/or a plane that is parallel to frame member 34 at a permitted orientation of the gear, such as in an equilibrium configuration of the mount.

Figure 24 shows an embodiment 410 of mount 26 for the gimbal system of Figures 1 and 2. Mount 410 has frame members 34, 36 interconnected by an anti-tilt linkage assembly formed by eight bridge members 44, although fewer or more bridge members may be utilized by the mount. Each bridge member has a gear 260 pivotably connected to a strut 100 at pivot joint 102 and pivotably mounted to upper frame member 34 via a pivotable connection 104, such as a hinge joint. Gear 260 has opposing ends each disposed in tooth engagement with adjacent gears 260 via teeth 362. Strut 100 is connected to gear 260 at a position intermediate pivotable connection 104 and an end of the gear. The strut forms a pivotable connection 106 with lower frame member 36. Each of pivot joint 102 and pivotable connection 106 may permit pivotal motion about orthogonal axes and/or in orthogonal planes. In other embodiments, one or more of gears 260 may be in meshed engagement with only one gear. Alternatively, or in addition, struts 100 may be equally spaced around the perimeter of the mount.

Further aspects of linkage assemblies with gears are described in the references listed above under Cross-References, which are incorporated herein by reference.

Example 4. Exemplary Translational Mount with a Plurality of Anti-Pivot Devices

This example describes an exemplary translational mount for use in a
5 gimbal system, with the mount having a plurality of anti-pivot devices 46 (see
Example 2) to restrict rotation about transverse axes; see Figures 25 and 26.

Figure 25 shows an exemplary embodiment 440 of mount 26 having
frame members 34, 36 interconnected by a plurality of anti-pivot devices 46.
Devices 46 may be arranged transversely (e.g., orthogonally) to each other, to
10 restrict rotation about different axes, such as at least two or three orthogonal
axes. In other words, devices 46 can restrict two or three degrees of pivotal
freedom of frame members 34, 36 relative to each other.

One or more anti-pivot devices 46 may be positioned to restrict rotation
about each orthogonal axis. For example, at least one centrally located device
15 46, indicated by an arrow at 442, can restrict rotation about the z-axis. Also,
one or at least a pair of parallel devices 46, indicated by arrows at 444, may
be arranged orthogonally to central device 442, on opposite sides thereof, to
restrict rotation about an x-axis. Furthermore, one or at least a pair of parallel
devices 46, indicated by arrows at 446, may be arranged orthogonally to
20 central device 442 and to devices 444, to restrict rotation about a y-axis.
Accordingly, the devices collectively can restrict three degrees of pivotal
freedom.

Each device 46 may be attached to frame members 34, 36 via a pair of
brackets 448, 450. Bracket 448 is fixed to a plate portion of frame member
25 36, and bracket 450 is fixed to a plate portion of frame member 34. Each
bracket projects orthogonally from the plane defined by the frame member.
Each device 46 may be attached to bracket 448 via axial members 212, 214
and to bracket 450 via brackets 232, or vice versa (see Figs. 12-15).

Figure 26 shows a schematic representation of mount 440 of Figure
30 25. Restricted pivotal motion about each of the x-, y-, and z-axis is indicated.

Example 5. Selected Embodiments I

This example describes selected embodiments of the present
disclosure, presented as a series of numbered paragraphs.

1. A gimbal system, comprising: (A) a mounting portion including a first frame member and a second frame member interconnected by a linkage assembly including a plurality of articulated bridge members each forming a first pivotable connection with the first frame member and a second pivotable connection with the second frame member and having a pivot joint disposed at a position along the bridge member intermediate the first and second pivotable connections, the bridge members being coupled to each other such that the pivot joints collectively define a plane that remains parallel to both frame members as the frame members move relative to each other with three degrees of translational freedom; and (B) a gimbal assembly connected to and supported by the mounting portion and including a plurality of gimbals supporting a payload that is orientable with respect to the mounting portion by rotation of the gimbals.

2. The gimbal system of paragraph 1, wherein each first pivotable connection is a hinge joint.

3. The gimbal system of paragraph 2, wherein the bridge members are connected to the first frame member by a plurality of hinge joints arranged radially.

4. The gimbal system of paragraph 1, wherein a same rigid coupling member forms a distinct pivotable connection with each of the bridge members, and wherein the rigid coupling member is movable with respect to both frame members.

5. The gimbal system of paragraph 4, wherein each bridge member includes a swing member and a strut connected to each other by the pivot joint of the bridge member, wherein the swing member is connected to the first frame member to form the first pivotable connection, and wherein the distinct pivotable connection is formed between the swing member and the coupling member.

6. The gimbal system of paragraph 4, wherein the coupling member extends around a central axis of the mounting portion that is orthogonal to the frame members.

7. The gimbal system of paragraph 6, wherein the coupling member extends completely around the central axis.

8. The gimbal system of paragraph 6, wherein the coupling member extends along a circular path centered about the central axis.

5 9. The gimbal system of paragraph 4, wherein the coupling member defines a plane that remains parallel to the first and second frame members as the frame members move relative to each other with three degrees of translational freedom.

10 10. The gimbal system of paragraph 4, wherein coupling member forms a set of distinct pivotable connections with the bridge members collectively, and wherein the distinct pivotable connections define a plane that remains parallel to the first and second frame members as the frame members move translationally relative to each other.

15 11. The gimbal system of paragraph 4, wherein the coupling member is shaped as a ring that is closed or open.

12. The gimbal system of paragraph 1, wherein at least one of the bridge members is disposed in meshed engagement with one or more teeth of a gear.

20 13. The gimbal system of paragraph 12, wherein the gear is elongated transverse to an axis of rotation of such gear.

14. The gimbal system of paragraph 12, wherein the bridge members are connected to the first frame member by a plurality of hinge joints arranged parallel to one another.

25 15. The gimbal system of paragraph 1, wherein a pair of the bridge members are disposed in meshed engagement with each other.

30 16. The gimbal system of paragraph 1, wherein the mounting portion includes a plurality of spring elements configured to resiliently position the gimbal assembly and one of the frame members relative to the other frame member with respect to each of the three degrees of translational freedom.

17. The gimbal system of paragraph 1, further comprising a processor programmed to control motor-driven rotation of the gimbals based on signals from one or more gyroscopes.

18. The gimbal system of paragraph 17, wherein the processor is
5 programmed to control motor-driven rotation of the gimbals based on signals from an inertial measurement unit.

19. The gimbal system of paragraph 18, wherein the one or more gyroscopes are included in the gimbal assembly.

20. The gimbal system of paragraph 17, wherein the processor is
10 included in the gimbal assembly, the mounting portion, or both.

21. The gimbal system of paragraph 1, wherein the payload includes a camera.

22. The gimbal system of paragraph 21, wherein the camera detects infrared radiation.

15 23. The gimbal system of paragraph 1, wherein rotation of the gimbals is motor-driven.

24. The gimbal system of paragraph 1, wherein each frame member includes a plate portion that defines a plane.

25. A gimbal system, comprising: (A) a mounting portion including a
20 first frame member and a second frame member interconnected by a linkage assembly including a plurality of articulated bridge members each connected to the first frame member by a radially arranged hinge joint and to the second frame member by a pivotable connection, each bridge member having a pivot joint disposed at a position along the bridge member intermediate the hinge
25 joint and the pivotable connection, wherein the frame members remain parallel to each other as the frame members move relative to each other with three degrees of translational freedom; and (B) a gimbal assembly connected to and supported by the mounting portion and including a plurality of gimbals supporting a payload that is orientable with respect to the mounting portion by
30 rotation of the gimbals.

26. A gimbal system, comprising; (A) a mounting portion including a first frame member and a second frame member interconnected by a linkage

assembly including a plurality of articulated bridge members each being connected to the first frame member by a first pivotable connection and to the second frame member by a second pivotable connection, each bridge member having a pivot joint disposed at a position along the bridge member intermediate the first and second pivotable connections, wherein the bridge members are coupled to each other by a same rigid coupling member that is pivotably connected to each bridge member and that is movable relative to both frame members, and wherein the frame members remain parallel to each other as the frame members move translationally relative to each other with three degrees of translational freedom; and (B) a gimbal assembly connected to and supported by the mounting portion and including a plurality of gimbals supporting a payload that is orientable with respect to the mounting portion by rotation of the gimbals.

27. A gimbal system, comprising: (A) a mounting portion including a first frame member and a second frame member interconnected by a linkage assembly including a plurality of articulated bridge members, each bridge member being connected to the first frame member by a first pivotable connection and to the second frame member by a second pivotable connection, each bridge member having a pivot joint disposed at a position along the bridge member intermediate the first and second pivotable connections, wherein the bridge members are coupled to each other by a same rigid coupling member that is pivotably connected to each bridge member and movable relative to both frame members, wherein the frame members are arranged parallel to each other and remain parallel as the frame members move relative to one another with three degrees of translational freedom, and wherein the linkage assembly blocks at least two degrees of rotational freedom of the frame members relative to each other; and (B) a gimbal assembly connected to and supported by the mounting portion and including a plurality of gimbals supporting a payload that is orientable with respect to the mounting portion by rotation of the gimbals.

28. A gimbal system, comprising; (A) a mounting portion including a first frame member and a second frame member interconnected by a first

linkage assembly that eliminates a first degree and a second degree of rotational freedom of the frame members relative to each other and also being interconnected by a second linkage assembly that eliminates a third degree of rotational freedom of the frame members relative to each other, the second

5 linkage assembly including a central structural member connected to the first frame member with two degrees of translational freedom parallel to the first frame member and no rotational freedom with respect to the first frame member and connected to the second frame member by a pair of lateral structural members that are each pivotably connected to the central structural

10 member and to the second frame member by a pair of spaced spherical joints, the spherical joints collectively defining vertices of a parallelogram that remains a parallelogram as the frame members move relative to each other with three degrees of translational freedom; and (B) a gimbal assembly connected to and supported by the mounting portion and including a plurality

15 of gimbals supporting a payload that is orientable with respect to the mounting portion by rotation of the gimbals.

Example 6. Selected Embodiments II

This example describes further selected embodiments of the present disclosure, presented as a series of numbered paragraphs.

20 1. A gimbal system, comprising: (A) a mounting portion including a first frame member and a second frame member interconnected by a linkage portion including three or more bridge members each having a first pivotable connection to the first frame member and a second pivotable connection to the second frame member and also having a pivot joint disposed at a position

25 along the bridge member intermediate the first and second pivotable connections, the first pivotable connections of the bridge members being hinge joints, the pivot joints of the bridge members collectively defining a plane that remains parallel to the first frame member as the bridge members pivot at the hinge joints; and (B) a gimbal assembly connected to and

30 supported by the mounting portion and including a plurality of gimbals supporting a payload that is orientable with respect to the mounting portion by rotation of the gimbals.

2. The gimbal system of paragraph 1, wherein the linkage portion restricts at least two degrees of pivotal freedom of the frame members relative to each other while permitting relative movement of the frame member with three degrees of translational freedom.

5 3. The gimbal system of paragraph 1 or 2, wherein the plane is a first plane, wherein the first frame member defines a second plane, and wherein each bridge member defines a variable angle of the same size with the second plane.

10 4. The gimbal system of any of paragraphs 1 to 3, wherein the hinge joints define pivot axes arranged radially with respect to a same axis.

5. The gimbal system of any of paragraphs 1 to 4, wherein each bridge member has a first portion extending from the first pivotable connection to the pivot joint of such bridge member, and wherein the first portions of the bridge members pivot in unison with the same rate of angular change.

15 6. The gimbal system of any of paragraphs 1 to 5, wherein the pivot joints of the bridge members collectively define a plane that remains parallel to both frame members as the frame members move relative to each other with three degrees of translational freedom.

20 7. The gimbal system of any of paragraphs 1 to 6, wherein a same rigid coupling member is connected pivotably to each of the bridge members individually, and wherein the rigid coupling member is movable with respect to both frame members.

25 8. The gimbal system of paragraph 7, wherein each bridge member includes a first segment and a second segment connected to each other by the pivot joint of such bridge member, wherein the first segment is connected to the first frame member via a hinge joint, and wherein the coupling member is pivotably connected to each bridge member via the first segment of such bridge member.

30 9. The gimbal system of paragraph 7 or 8, wherein the mounting portion defines a central axis that is orthogonal to both frame members, and wherein the coupling member extends around the central axis.

10. The gimbal system of paragraph 9, wherein the coupling member extends completely around the central axis.

11. The gimbal system of paragraph 9 or 10, wherein the coupling member extends along a circular path centered on the central axis.

5 12. The gimbal system of any of paragraphs 7 to 11, wherein the plane is a first plane, wherein the coupling member defines a second plane that remains parallel to the first frame member as the frame members move relative to each other with three degrees of translational freedom.

10 13. The gimbal system of any of paragraphs 7 to 12, wherein the plane is a first plane, wherein the coupling member is pivotably connected to the bridge members via a set of pivotable connections, and wherein the set of pivotable connections defines a second plane that remains parallel to the first frame member as the frame members move relative to each other with three degrees of translational freedom.

15 14. The gimbal system of paragraph 13, wherein the second plane remains parallel to both frame members as the frame members move relative to each other with three degrees of translational freedom.

15 15. The gimbal system of any of paragraphs 7 to 14, wherein the coupling member is shaped as a ring that is closed or open.

20 16. The gimbal system of any of paragraphs 1 to 15, wherein at least one of the bridge members is disposed in meshed engagement with one or more teeth of a gear such that pivotal motion of at least a portion of the at least one bridge member is coupled to pivotal motion of the gear.

25 17. The gimbal system of paragraph 16, wherein the gear is provided by a bridge member such that a pair of the bridge members are in toothed engagement with each other.

18. The gimbal system of paragraph 16 or 17, wherein the gear is disposed intermediate a pair of the bridge members and is disposed in toothed engagement with each bridge member of the pair.

30 19. The gimbal system of any of paragraphs 16 to 18, wherein the gear is elongated transverse to an axis of rotation of such gear.

20. The gimbal system of any of paragraphs 16 to 19, wherein the gear is curved in a plane parallel to the first frame member.

21. The gimbal system of any of paragraphs 16 to 20, wherein the gear has a pivot axis and a perimeter extending around the pivot axis, and
5 wherein a majority of the perimeter is toothless.

22. The gimbal system of any of paragraphs 16 to 21, wherein each bridge member has a segment extending from the first pivotable connection to the pivot joint of such bridge member, and wherein rotation of the gear is synchronized with equal angular motion of the segment of each bridge
10 member.

23. The gimbal system of any of paragraphs 16 to 22, wherein the bridge members are connected to the first frame member by a plurality of hinge joints having pivot axes arranged radially.

24. The gimbal system of any of paragraphs 16 to 22, wherein the
15 first pivotable connections define pivot axes arranged parallel to each other.

25. The gimbal system of any of paragraphs 1 to 24, wherein a pair of the bridge members are disposed in meshed engagement with each other.

26. The gimbal system of any of paragraphs 1 to 25, wherein the mounting portion includes a plurality of spring elements configured to
20 resiliently position the gimbal assembly and the second frame member relative to the first frame member, for each of the three degrees of translational freedom.

27. The gimbal system of any of paragraphs 1 to 26, further comprising a processor programmed to control motor-driven rotation of the
25 gimbals based on signals from one or more gyroscopes.

28. The gimbal system of paragraph 27, wherein the one or more gyroscopes are included in the gimbal assembly.

29. The gimbal system of paragraph 27 or 28, wherein the processor is programmed to control motor-driven rotation of the gimbals
30 based on signals from an inertial measurement unit.

30. The gimbal system of any of paragraphs 27 to 29, wherein the processor is included in the gimbal assembly, the mounting portion, or both.

31. The gimbal system of any of paragraphs 1 to 30, wherein the payload includes an image sensor.

32. The gimbal system of paragraph 31, wherein the image sensor detects infrared radiation.

5 33. The gimbal system of any of paragraphs 1 to 32, wherein rotation of the gimbals is motor-driven.

34. The gimbal system of any of paragraphs 1 to 33, wherein the plane is a first plane, and wherein the first frame member includes a plate portion that defines a second plane that remains parallel to the first plane.

10 35. The gimbal system of any of paragraphs 1 to 34, wherein the second pivotable connection of each bridge member has two or more degrees of pivotal freedom.

36. The gimbal system of any of paragraphs 1 to 35, wherein each pivot joint has two or more degrees of pivotal freedom.

15 37. The gimbal system of any of paragraphs 1 to 36, further comprising an anti-pivot device that permits translational motion of the frame members relative to each other with three degrees of translational freedom while restricting pivotal motion of the frame members relative to each other about a vertical axis.

20 38. A gimbal system, comprising: (A) a mounting portion including a first frame member and a second frame member interconnected by a linkage portion including three or more bridge members each connected to the first frame member by a first pivotable connection and to the second frame member by a second pivotable connection, each bridge member having a
25 pivot joint disposed at a position along the bridge member intermediate the first and second pivotable connections, wherein the bridge members are coupled to each other by a same rigid coupling member that is pivotably connected via a distinct connection to each bridge member and that is movable relative to both frame members; and (B) a gimbal assembly
30 connected to and supported by the mounting portion and including a plurality of gimbals supporting a payload that is orientable with respect to the mounting portion by rotation of the gimbals.

39. The gimbal system of paragraph 38, wherein the pivot joints of the bridge members collectively define a plane that remains parallel to the first frame member as the frame members move relative to each other.

40. The gimbal system of paragraph 39, wherein the plane remains
5 parallel to the first frame member as a separation distance between the bridge members increases and decreases.

41. The gimbal system of any of paragraphs 38 to 40, wherein the linkage portion restricts at least two degrees of pivotal freedom of the frame members relative to each other.

10 42. The gimbal system of paragraph 41, wherein the linkage portion restricts relative pivotal motion of the frame members about horizontal axes.

43. A gimbal system, comprising: (A) a mounting portion including a first frame member and a second frame member interconnected by a linkage portion including three or more bridge members each connected to the first
15 frame member by a first pivotable connection and to the second frame member by a second pivotable connection, each bridge member having a pivot joint disposed at a position along the bridge member intermediate the first and second pivotable connections, wherein each first pivotable connection is a hinge joint, wherein each bridge member has a first portion
20 extending from the hinge joint to the pivot joint of such bridge member, and wherein the first portions of the bridge members each define a variable angle of the same size with the first frame member; and (B) a gimbal assembly connected to and supported by the mounting portion and including a plurality of gimbals supporting a payload that is orientable with respect to the mounting
25 portion by rotation of the gimbals.

44. A gimbal system, comprising: (A) a mounting portion including a first frame member and a second frame member interconnected by a linkage portion including three or more bridge members each connected to the first frame member by a first pivotable connection and to the second frame
30 member by a second pivotable connection, each bridge member having a pivot joint disposed at a position along the bridge member intermediate the first and second pivotable connections, wherein at least one of the bridge

members is disposed in meshed engagement with one or more teeth of a gear such that pivotal motion of at least a portion of the at least one bridge member is coupled to pivotal motion of the gear; and (B) a gimbal assembly connected to and supported by the mounting portion and including a plurality of gimbals supporting a payload that is orientable with respect to the mounting portion by rotation of the gimbals.

45. The gimbal system of paragraph 44, wherein the pivot joints of the bridge members collectively define a plane that remains parallel to the first frame member as the frame members move relative to each other.

10 46. The gimbal system of paragraph 44 or 45, wherein at least two of the bridge members are in toothed engagement with each other.

47. A gimbal system, comprising: (A) a mounting portion including a first frame member and a second frame member interconnected by a linkage portion including a first, a second, and a third device, each anti-pivot device permitting translational motion of the frame members relative to each other with three degrees of translational freedom and restricting pivotal motion of the frame members relative to each other about a different axis, such that the anti-pivot devices collectively restrict at least two degrees of pivotal freedom; and (B) a gimbal assembly connected to and supported by the mounting portion and including a plurality of gimbals supporting a payload that is orientable with respect to the mounting portion by rotation of the gimbals.

48. The gimbal system of paragraph 47, wherein the anti-pivot devices collectively restrict pivotal motion of the frame members relative to one another about three orthogonal axes.

25 49. A gimbal system, comprising: (A) a mounting portion including a first frame member and a second frame member interconnected by a linkage portion that restricts tilting of the frame members relative to one another and also being interconnected by an anti-pivot device that restricts pivotal motion of the frame members relative to each other about a central vertical axis; and
30 (B) a gimbal assembly connected to and supported by the mounting portion and including a plurality of gimbals supporting a payload that is orientable with respect to the mounting portion by rotation of the gimbals.

50. The gimbal system of paragraph 49, wherein the anti-pivot device includes a central member connected to the second frame member by a pair of lateral members that are each pivotably connected to the central member and to the second frame member by a pair of spaced joints, the joints collectively defining vertices of a parallelogram that remains a parallelogram as the frame members move relative to each other with three degrees of translational freedom.

51. A gimbal system, comprising: (A) a mounting portion including a first frame member and a second frame member interconnected by an anti-pivot device that restricts pivotal motion of the frame members relative to each other about a central vertical axis, the anti-pivot device including a central member connected to the second frame member by a pair of lateral members that are each pivotably connected to the central member and to the second frame member by a pair of spaced joints, the joints collectively defining vertices of a parallelogram that remains a parallelogram as the frame members move relative to each other with three degrees of translational freedom; and (B) a gimbal assembly connected to and supported by the mounting portion and including a plurality of gimbals supporting a payload that is orientable with respect to the mounting portion by rotation of the gimbals.

52. A method of using a gimbal system, comprising: (A) mounting a gimbal system of any of paragraphs 1 to 51 to a vehicle; and (B) operating the vehicle.

The disclosure set forth above may encompass multiple distinct inventions with independent utility. Although each of these inventions has been disclosed in its preferred form(s), the specific embodiments thereof as disclosed and illustrated herein are not to be considered in a limiting sense, because numerous variations are possible. The subject matter of the inventions includes all novel and nonobvious combinations and subcombinations of the various elements, features, functions, and/or properties disclosed herein. The following claims particularly point out certain combinations and subcombinations regarded as novel and nonobvious. Inventions embodied in other combinations and subcombinations of features,

functions, elements, and/or properties may be claimed in applications claiming priority from this or a related application. Such claims, whether directed to a different invention or to the same invention, and whether broader, narrower, equal, or different in scope to the original claims, also are regarded as

5 included within the subject matter of the inventions of the present disclosure.

WE CLAIM:

1. A gimbal system, comprising:

a mounting portion including a first frame member and a second frame member interconnected by a linkage portion including three or more bridge members each having a first pivotable connection to the first frame member and a second pivotable connection to the second frame member and also having a pivot joint disposed at a position along the bridge member intermediate the first and second pivotable connections, the first pivotable connections of the bridge members being hinge joints, the pivot joints of the bridge members collectively defining a plane that remains parallel to the first frame member as the bridge members pivot at the hinge joints; and

a gimbal assembly connected to and supported by the mounting portion and including a plurality of gimbals supporting a payload that is orientable with respect to the mounting portion by rotation of the gimbals.

2. The gimbal system of claim 1, wherein the linkage portion restricts at least two degrees of pivotal freedom of the frame members relative to each other while permitting relative movement of the frame member with three degrees of translational freedom.

3. The gimbal system of claim 1, wherein the plane is a first plane, wherein the first frame member defines a second plane, and wherein each bridge member defines a variable angle of the same size with the second plane.

4. The gimbal system of claim 3, wherein the hinge joints define pivot axes arranged radially.

5. The gimbal system of claim 1, wherein each bridge member has a first portion extending from the first pivotable connection to the pivot joint of

such bridge member, and wherein the first portions of the bridge members pivot in unison with the same rate of angular change.

6. The gimbal system of claim 1, wherein the pivot joints of the bridge members collectively define a plane that remains parallel to both frame members as the frame members move relative to each other with three degrees of translational freedom.

7. The gimbal system of claim 1, wherein a same rigid coupling member is connected pivotably to each of the bridge members individually, and wherein the rigid coupling member is movable with respect to both frame members.

8. The gimbal system of claim 7, wherein each bridge member includes a first segment and a second segment connected to each other by the pivot joint of such bridge member, wherein the first segment is connected to the first frame member via a hinge joint, and wherein the coupling member is pivotably connected to each bridge member via the first segment of such bridge member.

9. The gimbal system of claim 7, wherein the mounting portion defines a central axis that is orthogonal to both frame members, and wherein the coupling member extends around the central axis.

10. The gimbal system of claim 9, wherein the coupling member extends completely around the central axis.

11. The gimbal system of claim 9, wherein the coupling member extends along a circular path centered on the central axis.

12. The gimbal system of claim 7, wherein the plane is a first plane, wherein the coupling member defines a second plane that remains parallel to

the first frame member as the frame members move relative to each other with three degrees of translational freedom.

13. The gimbal system of claim 7, wherein the plane is a first plane, wherein the coupling member is pivotably connected to the bridge members via a set of pivotable connections, and wherein the set of pivotable connections defines a second plane that remains parallel to the first frame member as the frame members move relative to each other with three degrees of translational freedom.

14. The gimbal system of claim 13, wherein the second plane remains parallel to both frame members as the frame members move relative to each other with three degrees of translational freedom.

15. The gimbal system of claim 7, wherein the coupling member is shaped as a ring that is closed or open.

16. The gimbal system of claim 1, wherein at least one of the bridge members is disposed in meshed engagement with one or more teeth of a gear such that pivotal motion of at least a portion of the at least one bridge member is coupled to pivotal motion of the gear.

17. The gimbal system of claim 16, wherein the gear is provided by a bridge member such that a pair of the bridge members are in toothed engagement with each other.

18. The gimbal system of claim 16, wherein the gear is disposed intermediate a pair of the bridge members and is disposed in toothed engagement with each bridge member of the pair.

19. The gimbal system of claim 16, wherein the gear is elongated transverse to an axis of rotation of such gear.

20. The gimbal system of claim 16, wherein the gear is curved in a plane parallel to the first frame member.

21. The gimbal system of claim 16, wherein the gear has a pivot axis and a perimeter extending around the pivot axis, and wherein a majority of the perimeter is toothless.

22. The gimbal system of claim 16, wherein each bridge member has a segment extending from the first pivotable connection to the pivot joint of such bridge member, and wherein rotation of the gear is synchronized with equal angular motion of the segment of each bridge member.

23. The gimbal system of claim 16, wherein the bridge members are connected to the first frame member by a plurality of hinge joints having pivot axes arranged radially.

24. The gimbal system of claim 16, wherein the first pivotable connections define pivot axes arranged parallel to each other.

25. The gimbal system of claim 1, wherein a pair of the bridge members are disposed in meshed engagement with each other.

26. The gimbal system of claim 1, wherein the mounting portion includes a plurality of spring elements configured to resiliently position the gimbal assembly and the second frame member relative to the first frame member, for each of the three degrees of translational freedom.

27. The gimbal system of claim 1, further comprising a processor programmed to control motor-driven rotation of the gimbals based on signals from one or more gyroscopes.

28. The gimbal system of claim 27, wherein the one or more gyroscopes are included in the gimbal assembly.

29. The gimbal system of claim 27, wherein the processor is programmed to control motor-driven rotation of the gimbals based on signals from an inertial measurement unit.

30. The gimbal system of claim 27, wherein the processor is included in the gimbal assembly, the mounting portion, or both.

31. The gimbal system of claim 1, wherein the payload includes an image sensor.

32. The gimbal system of claim 31, wherein the image sensor detects infrared radiation.

33. The gimbal system of claim 1, wherein rotation of the gimbals is motor-driven.

34. The gimbal system of claim 1, wherein the plane is a first plane, and wherein the first frame member includes a plate portion that defines a second plane that remains parallel to the first plane.

35. The gimbal system of claim 1, wherein the second pivotable connection of each bridge member has two or more degrees of pivotal freedom.

36. The gimbal system of claim 1, wherein each pivot joint has two or more degrees of pivotal freedom.

37. The gimbal system of claim 1, further comprising an anti-pivot device that permits translational motion of the frame members relative to each

other with three degrees of translational freedom while restricting pivotal motion of the frame members relative to each other about a vertical axis.

38. A gimbal system, comprising:

a mounting portion including a first frame member and a second frame member interconnected by a linkage portion including three or more bridge members each connected to the first frame member by a first pivotable connection and to the second frame member by a second pivotable connection, each bridge member having a pivot joint disposed at a position along the bridge member intermediate the first and second pivotable connections, wherein the bridge members are coupled to each other by a same rigid coupling member that is pivotably connected via a distinct connection to each bridge member and that is movable relative to both frame members; and

a gimbal assembly connected to and supported by the mounting portion and including a plurality of gimbals supporting a payload that is orientable with respect to the mounting portion by rotation of the gimbals.

39. The gimbal system of claim 38, wherein the pivot joints of the bridge members collectively define a plane that remains parallel to the first frame member as the frame members move relative to each other.

40. The gimbal system of claim 39, wherein the plane remains parallel to the first frame member as a separation distance between the bridge members increases and decreases.

41. The gimbal system of claim 38, wherein the linkage portion restricts at least two degrees of pivotal freedom of the frame members relative to each other.

42. The gimbal system of claim 41, wherein the linkage portion restricts relative pivotal motion of the frame members about horizontal axes.

43. A gimbal system, comprising:

a mounting portion including a first frame member and a second frame member interconnected by a linkage portion including three or more bridge members each connected to the first frame member by a first pivotable connection and to the second frame member by a second pivotable connection, each bridge member having a pivot joint disposed at a position along the bridge member intermediate the first and second pivotable connections, wherein each first pivotable connection is a hinge joint, wherein each bridge member has a first portion extending from the hinge joint to the pivot joint of such bridge member, and wherein the first portions of the bridge members each define a variable angle of the same size with the first frame member; and

a gimbal assembly connected to and supported by the mounting portion and including a plurality of gimbals supporting a payload that is orientable with respect to the mounting portion by rotation of the gimbals.

44. A gimbal system, comprising:

a mounting portion including a first frame member and a second frame member interconnected by a linkage portion including three or more bridge members each connected to the first frame member by a first pivotable connection and to the second frame member by a second pivotable connection, each bridge member having a pivot joint disposed at a position along the bridge member intermediate the first and second pivotable connections, wherein at least one of the bridge members is disposed in meshed engagement with one or more teeth of a gear such that pivotal motion of at least a portion of the at least one bridge member is coupled to pivotal motion of the gear; and

a gimbal assembly connected to and supported by the mounting portion and including a plurality of gimbals supporting a payload that is orientable with respect to the mounting portion by rotation of the gimbals.

45. The gimbal system of claim 44, wherein the pivot joints of the bridge members collectively define a plane that remains parallel to the first frame member as the frame members move relative to each other.

46. The gimbal system of claim 44, wherein at least two of the bridge members are in toothed engagement with each other.

47. A gimbal system, comprising:

a mounting portion including a first frame member and a second frame member interconnected by a linkage portion including a first, a second, and a third device, each anti-pivot device permitting translational motion of the frame members relative to each other with three degrees of translational freedom and restricting pivotal motion of the frame members relative to each other about a different axis, such that the anti-pivot devices collectively restrict at least two degrees of pivotal freedom; and

a gimbal assembly connected to and supported by the mounting portion and including a plurality of gimbals supporting a payload that is orientable with respect to the mounting portion by rotation of the gimbals.

48. The gimbal system of claim 47, wherein the anti-pivot devices collectively restrict pivotal motion of the frame members relative to one another about three orthogonal axes.

49. A gimbal system, comprising:

a mounting portion including a first frame member and a second frame member interconnected by a linkage portion that restricts tilting of the frame members relative to one another and also being interconnected by an anti-pivot device that restricts pivotal motion of the frame members relative to each other about a central vertical axis; and

a gimbal assembly connected to and supported by the mounting portion and including a plurality of gimbals supporting a payload that is orientable with respect to the mounting portion by rotation of the gimbals.

50. The gimbal system of claim 49, wherein the anti-pivot device includes a central member connected to the second frame member by a pair of lateral members that are each pivotably connected to the central member and to the second frame member by a pair of spaced joints, the joints collectively defining vertices of a parallelogram that remains a parallelogram as the frame members move relative to each other with three degrees of translational freedom.

51. A gimbal system, comprising:

a mounting portion including a first frame member and a second frame member interconnected by an anti-pivot device that restricts pivotal motion of the frame members relative to each other about a central vertical axis, the anti-pivot device including a central member connected to the second frame member by a pair of lateral members that are each pivotably connected to the central member and to the second frame member by a pair of spaced joints, the joints collectively defining vertices of a parallelogram that remains a parallelogram as the frame members move relative to each other with three degrees of translational freedom; and

a gimbal assembly connected to and supported by the mounting portion and including a plurality of gimbals supporting a payload that is orientable with respect to the mounting portion by rotation of the gimbals.

52. A method of using a gimbal system, comprising:

mounting a gimbal system of any preceding claim to a vehicle; and
operating the vehicle.

1/15

Fig. 1

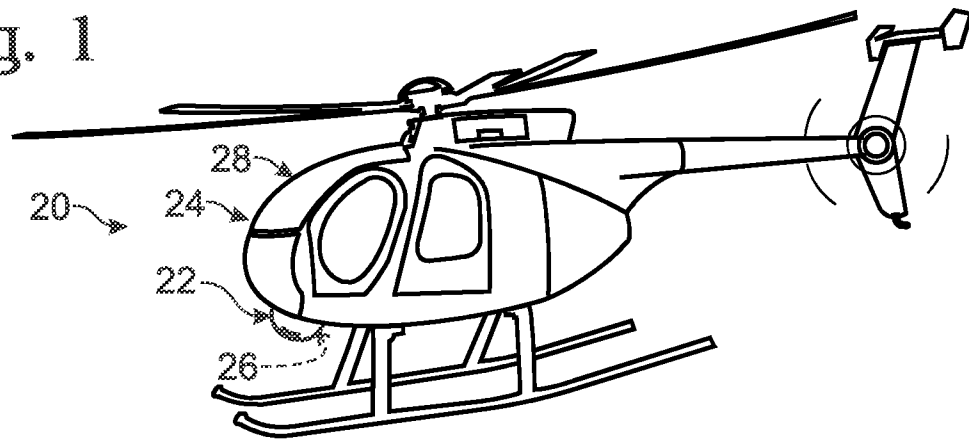
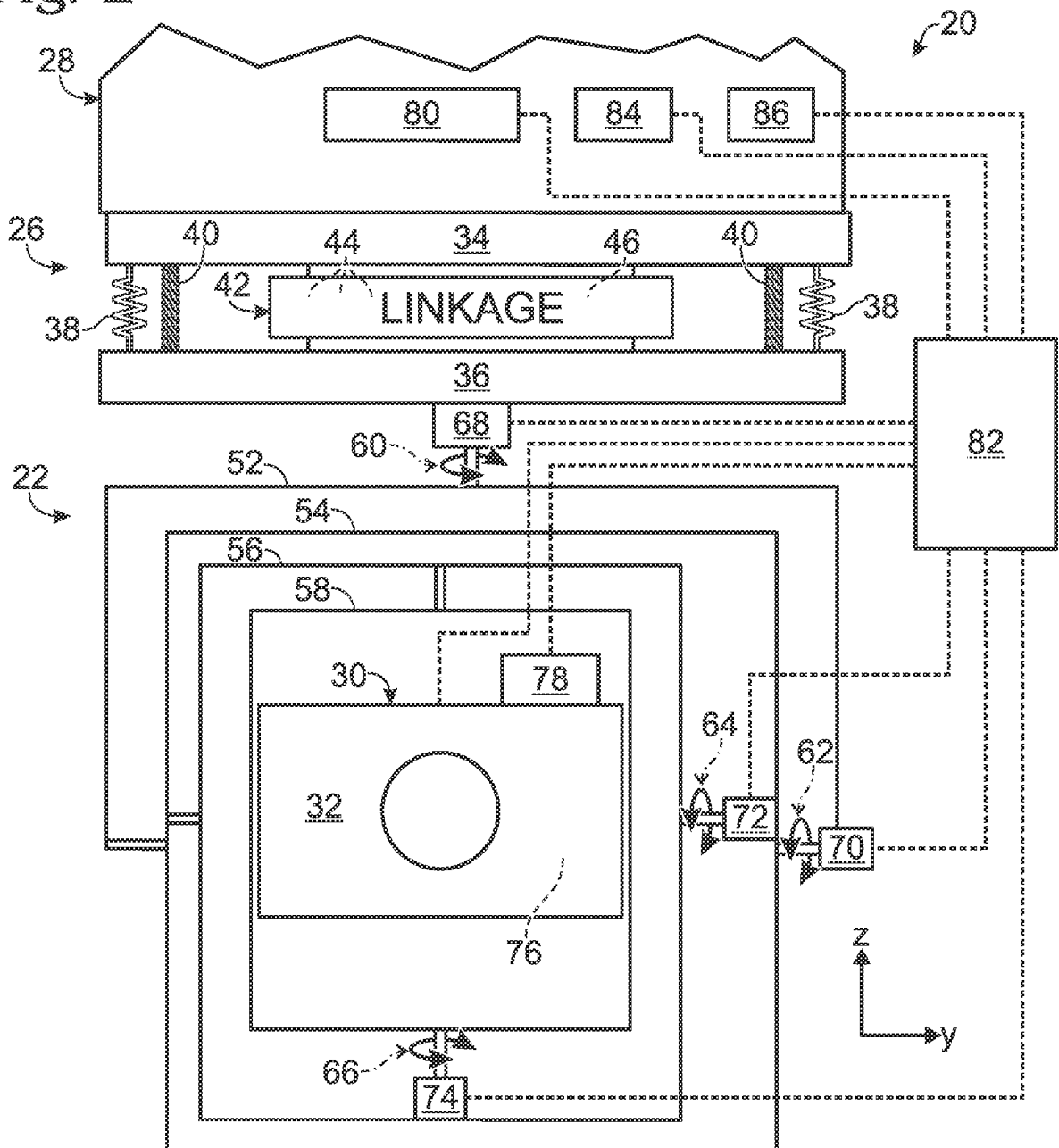
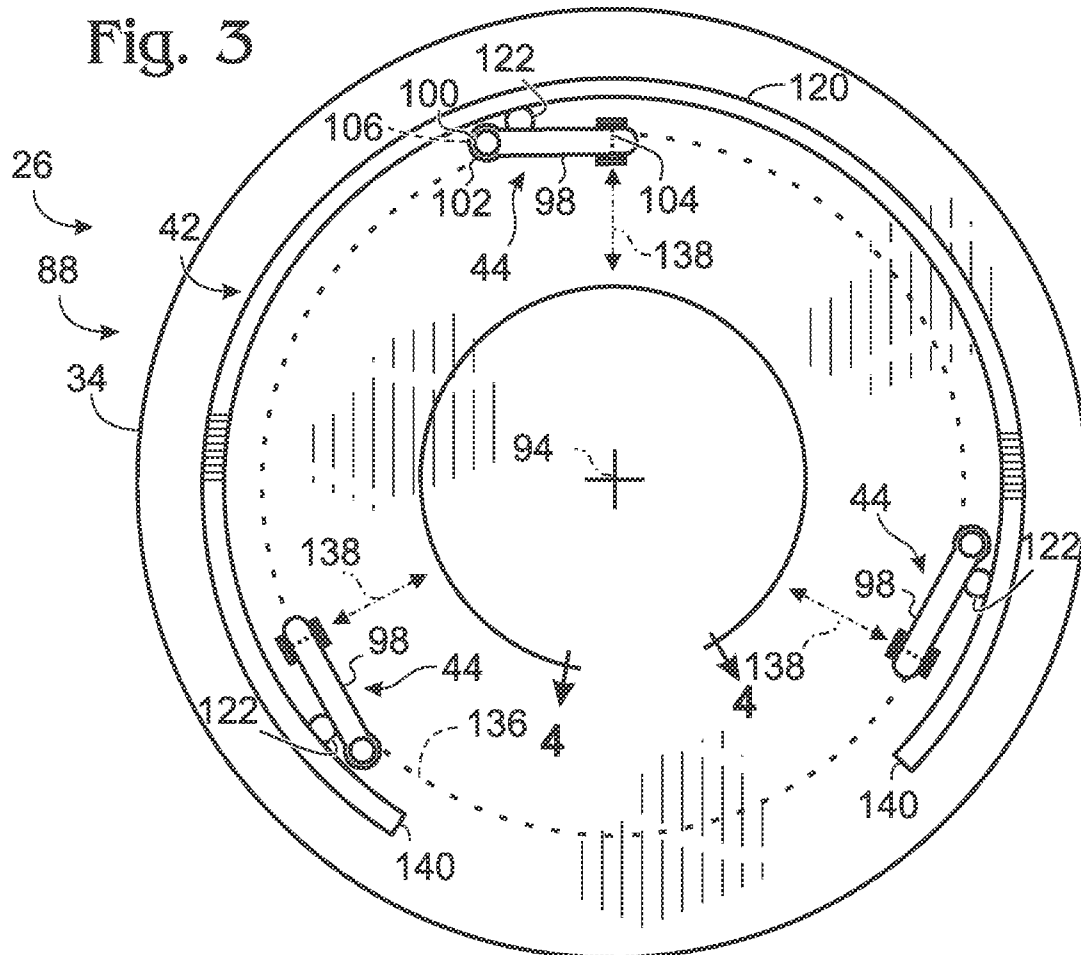
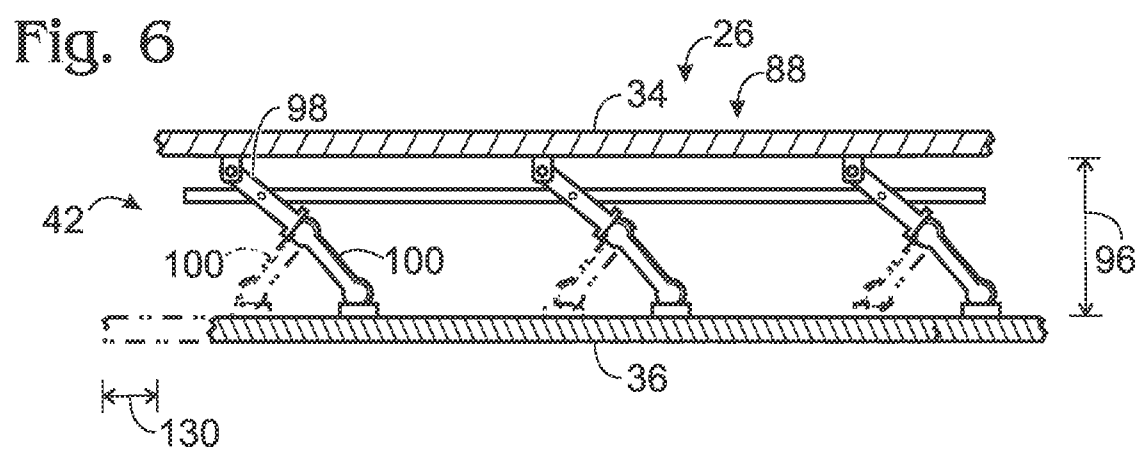
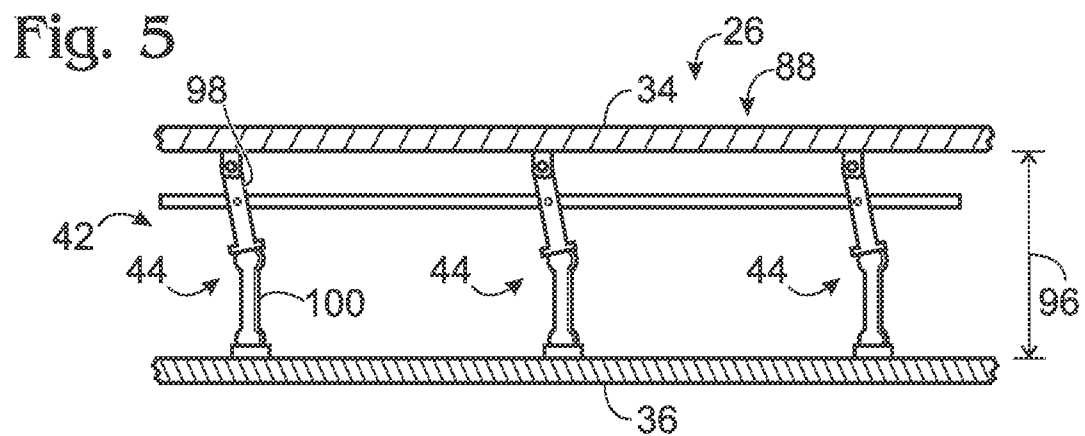
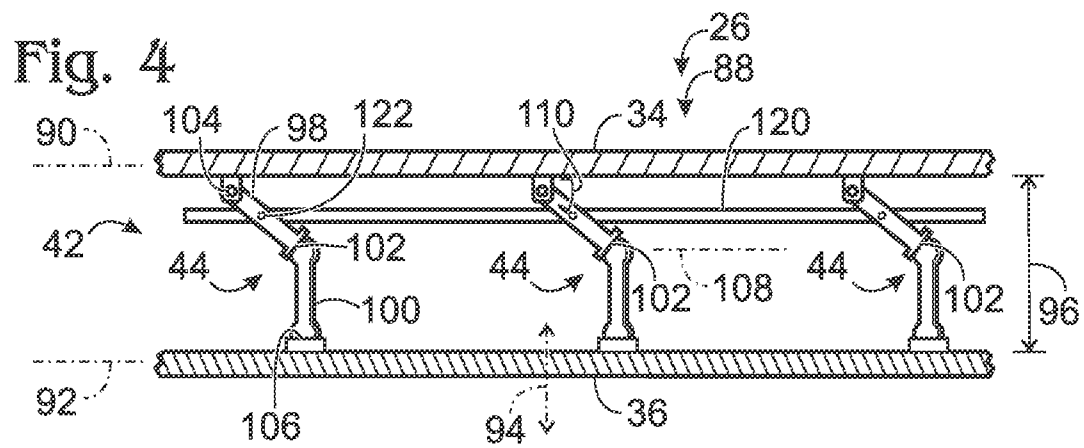


Fig. 2







4/15

Fig. 7

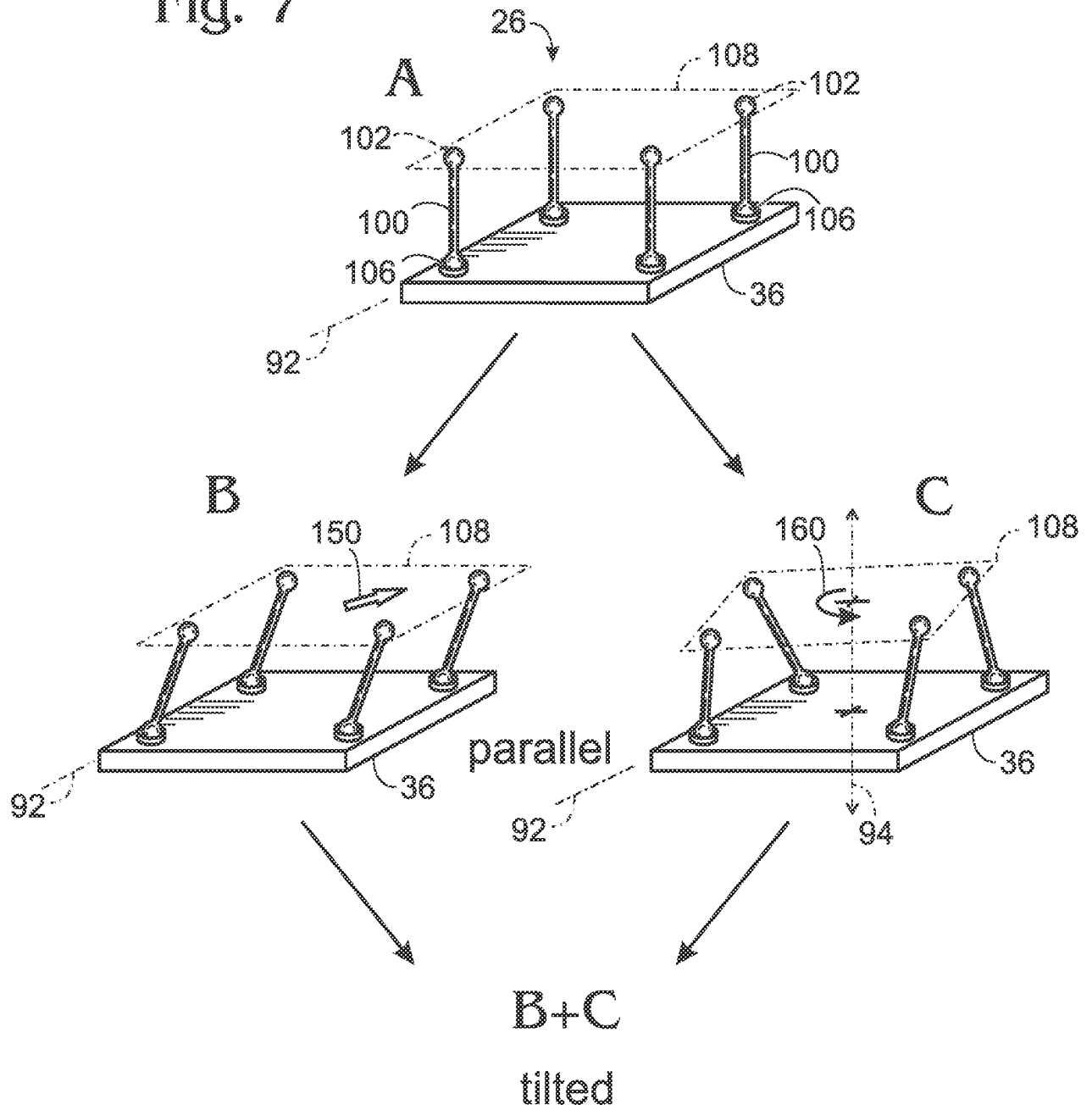
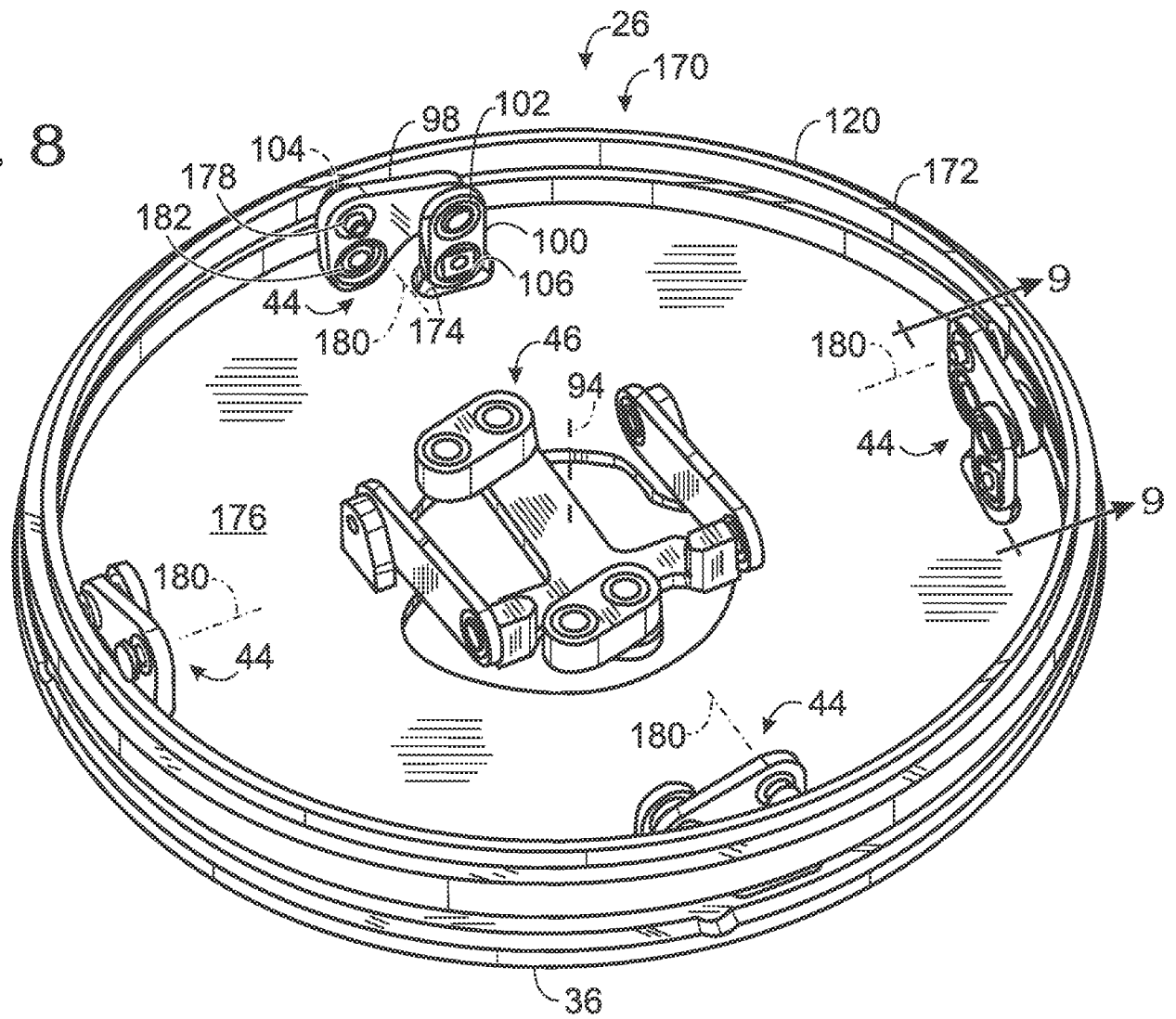


Fig. 8



6/15

Fig. 9

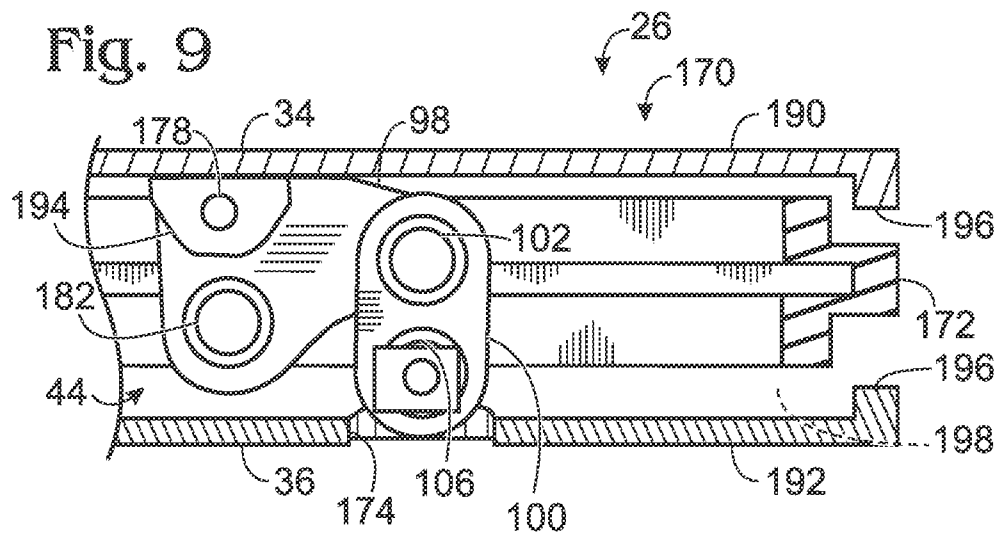


Fig. 10

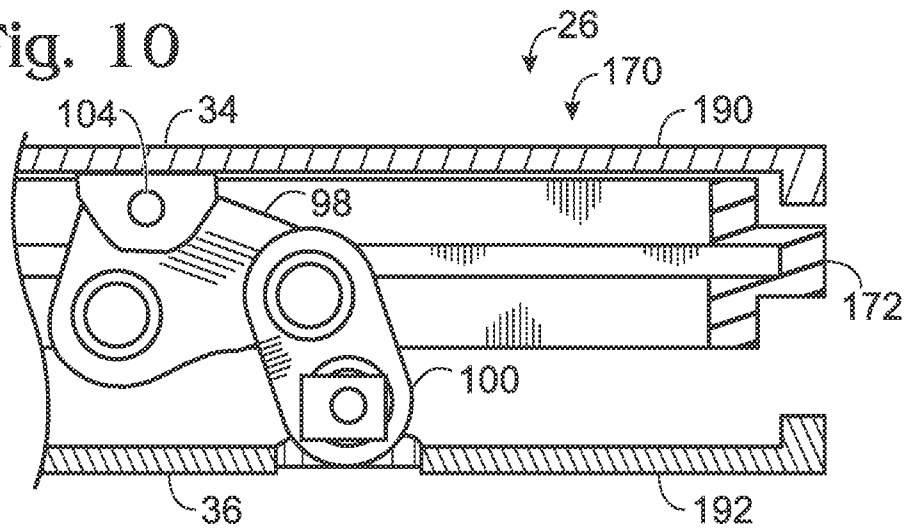
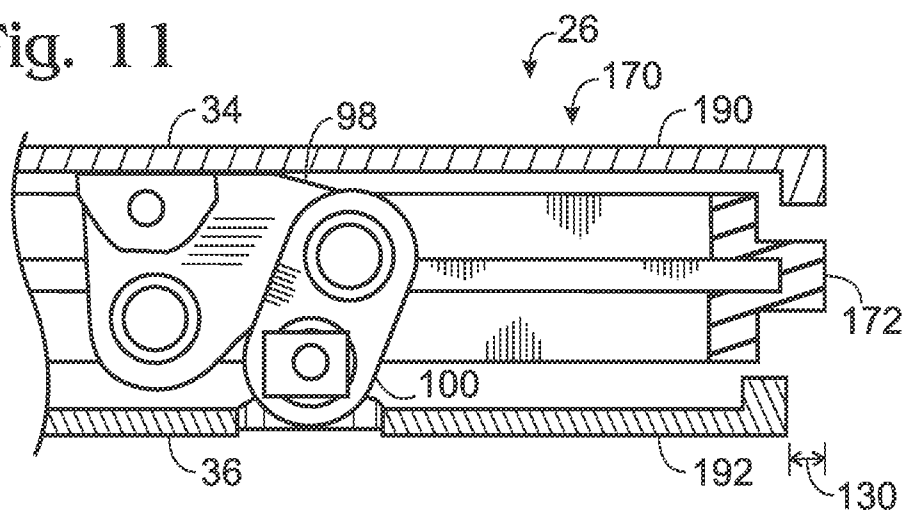


Fig. 11



7/15

Fig. 12

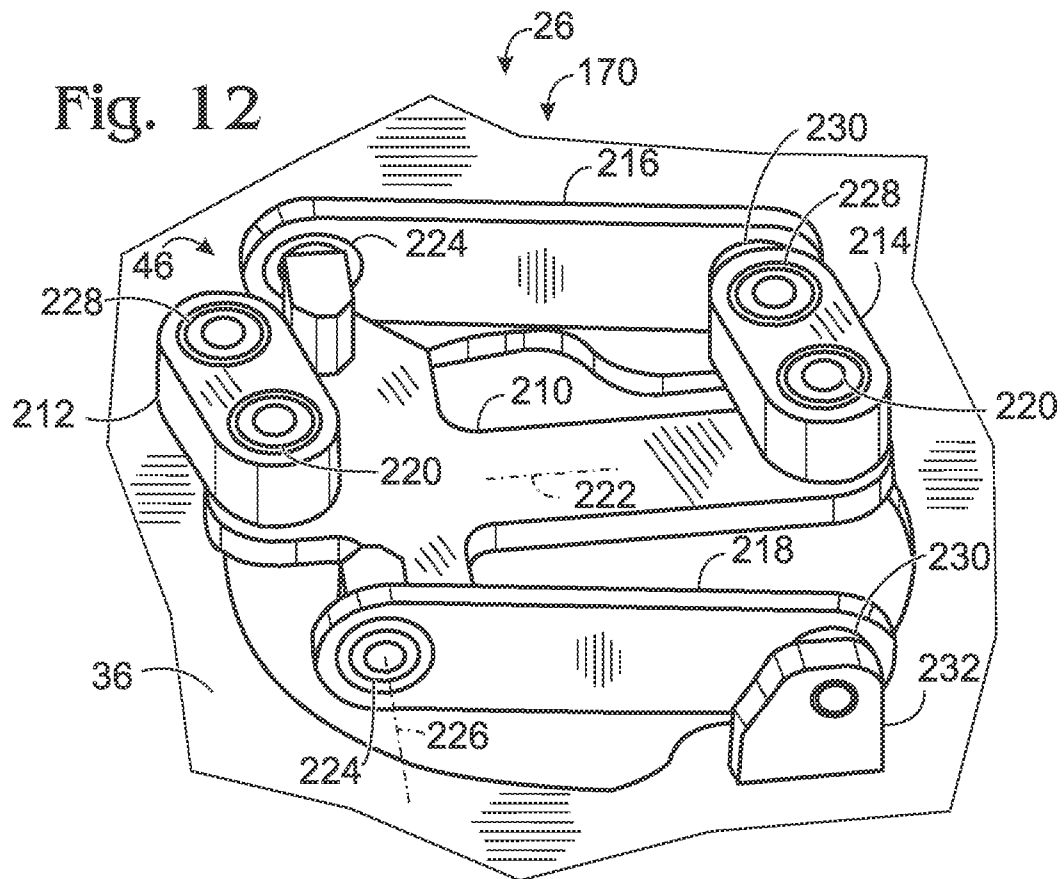
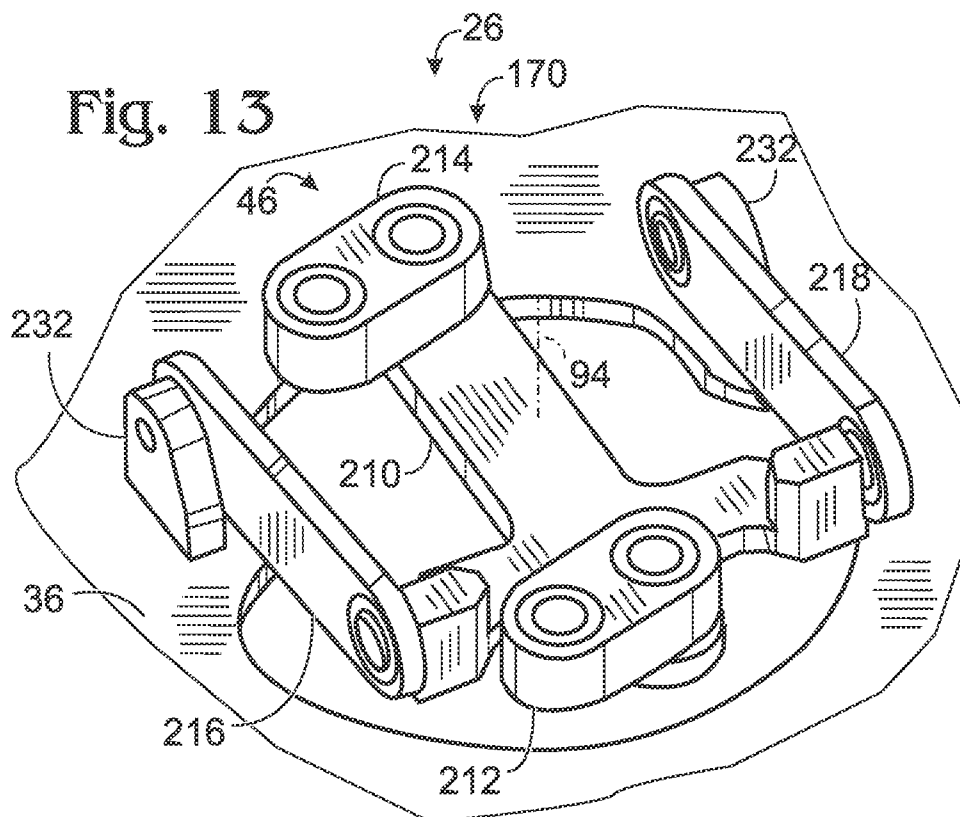


Fig. 13



8/15

Fig. 14

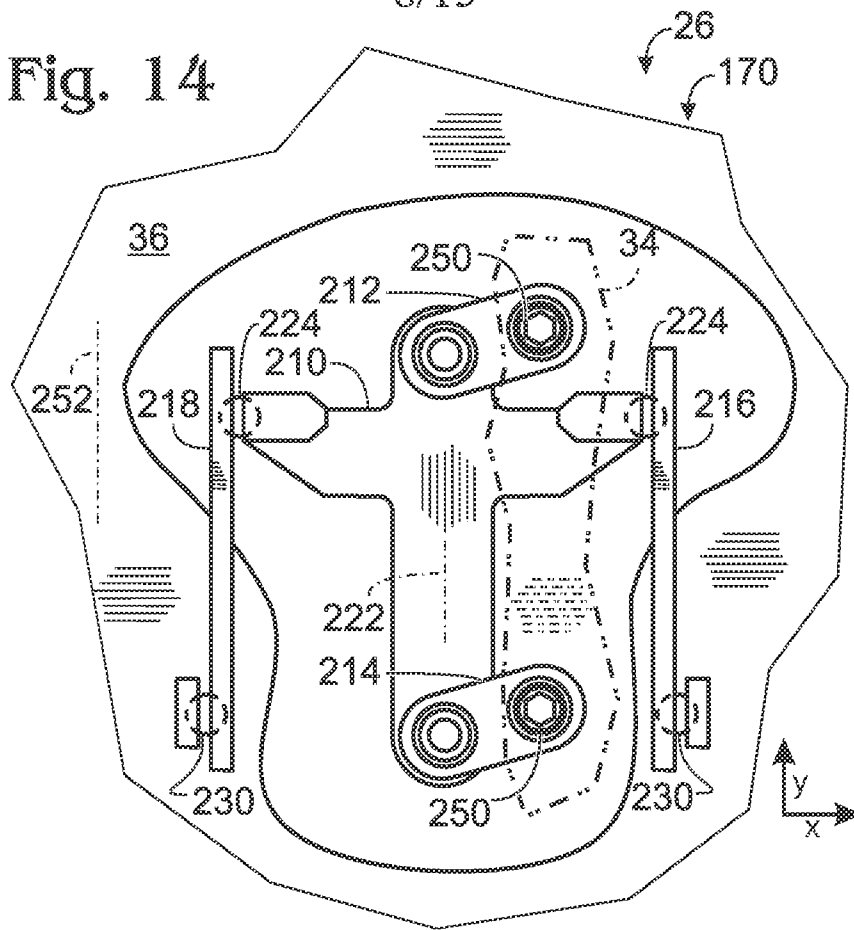
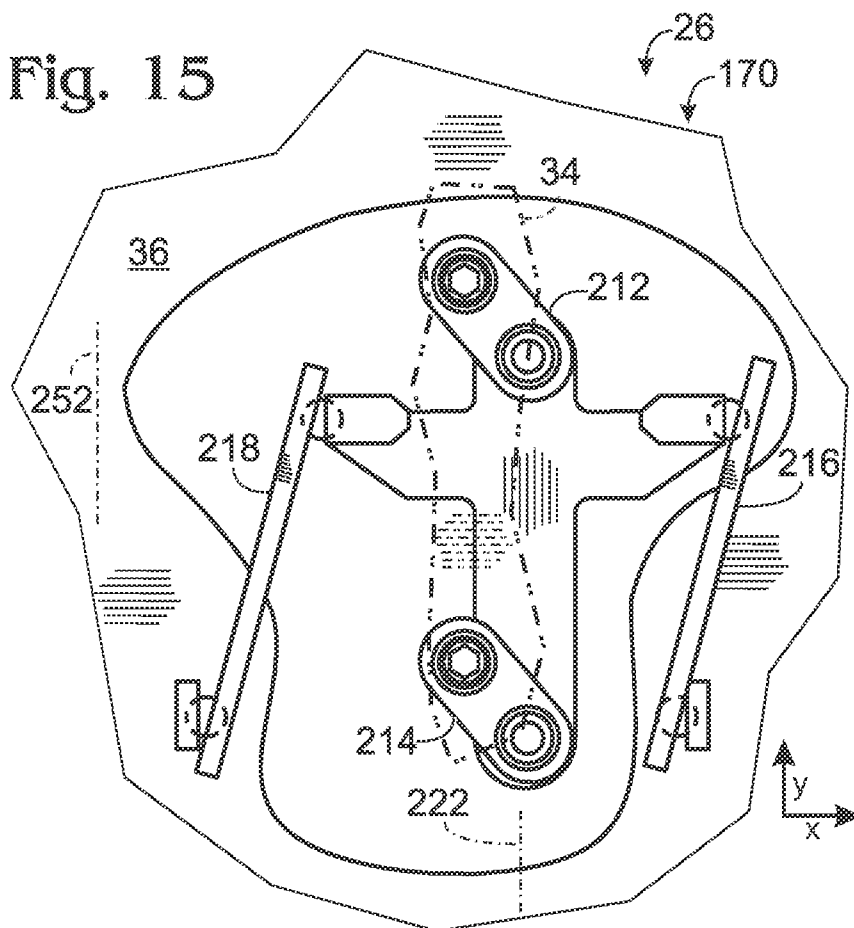


Fig. 15



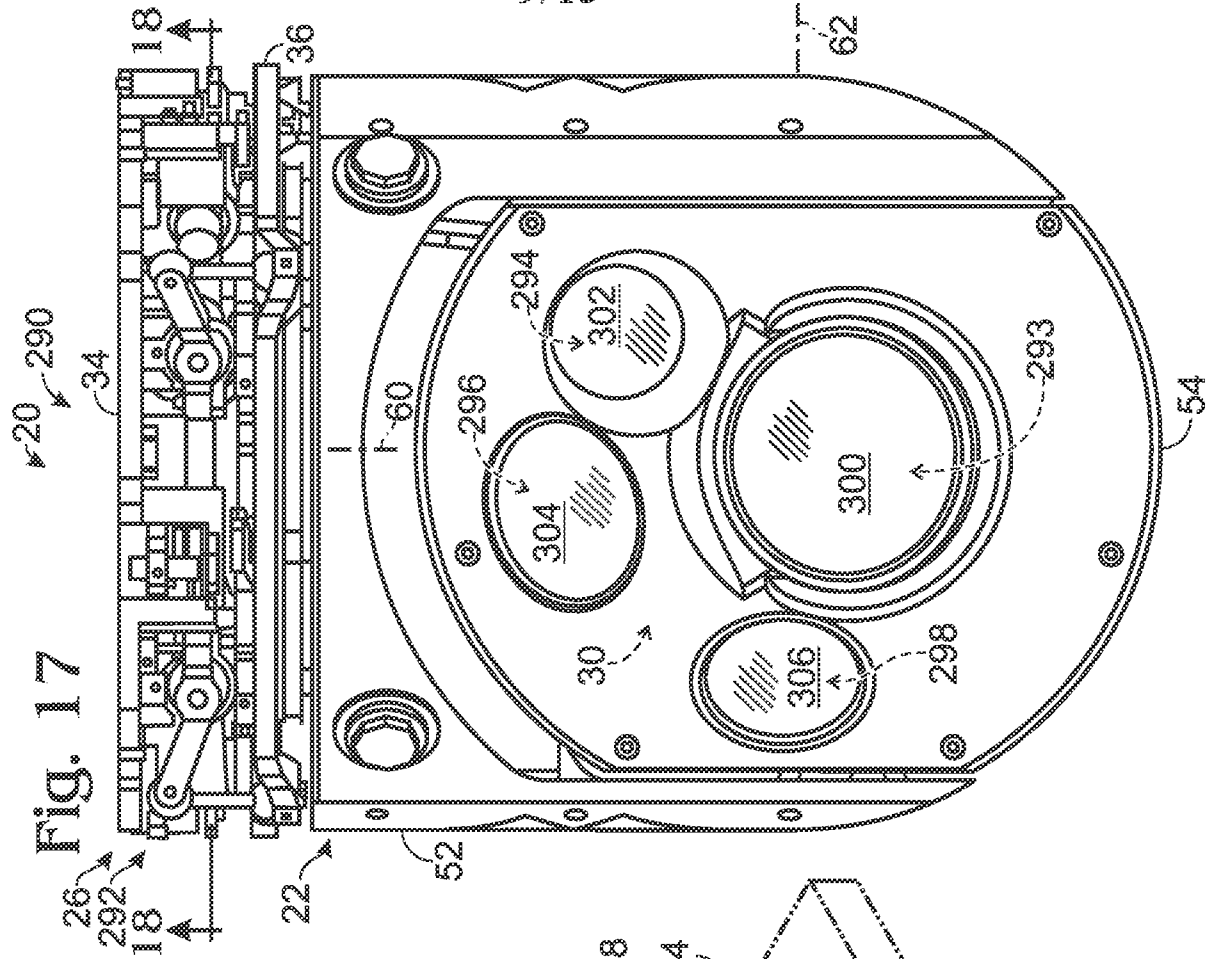
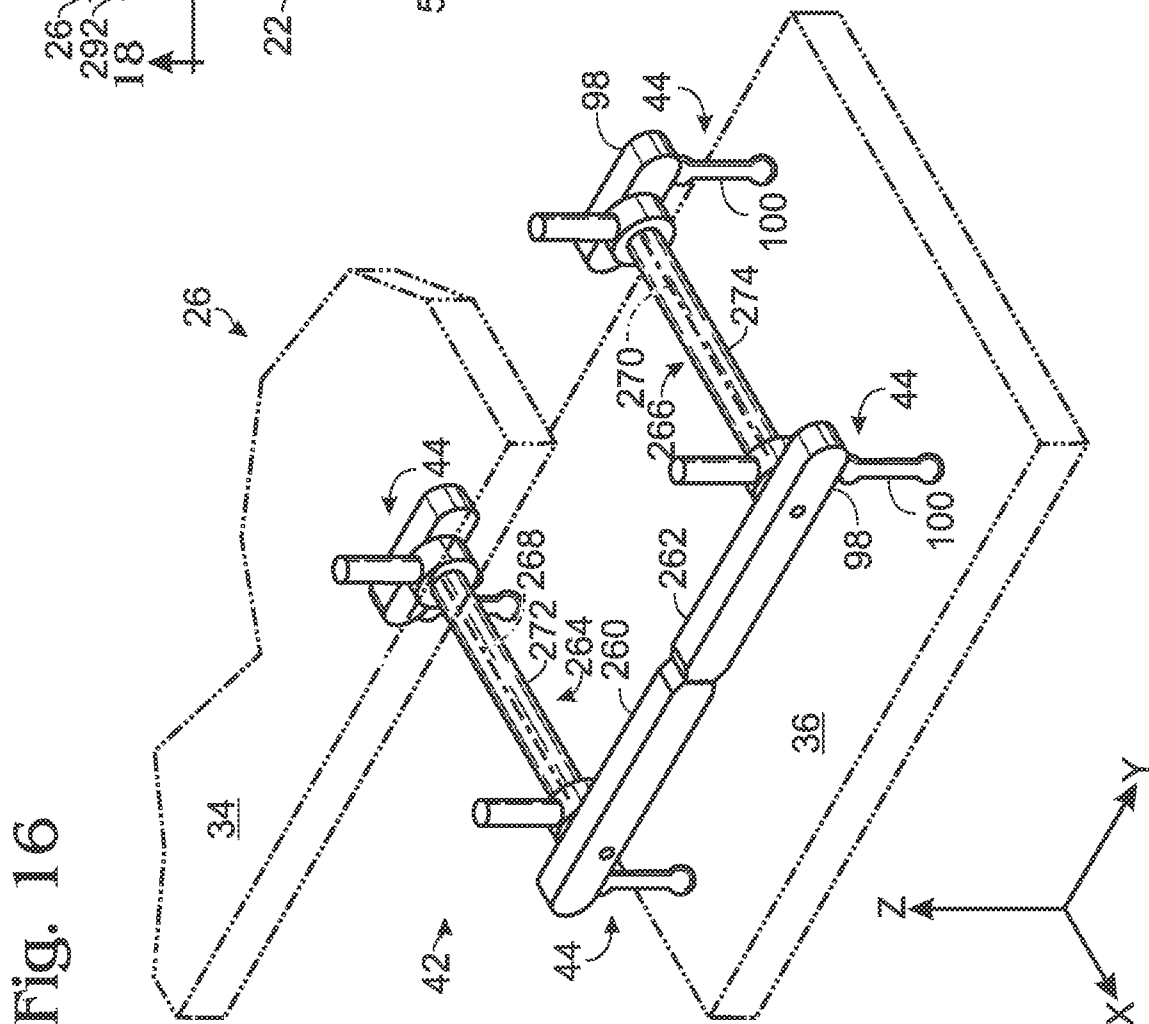


Fig. 17



195

10/15

Fig. 18

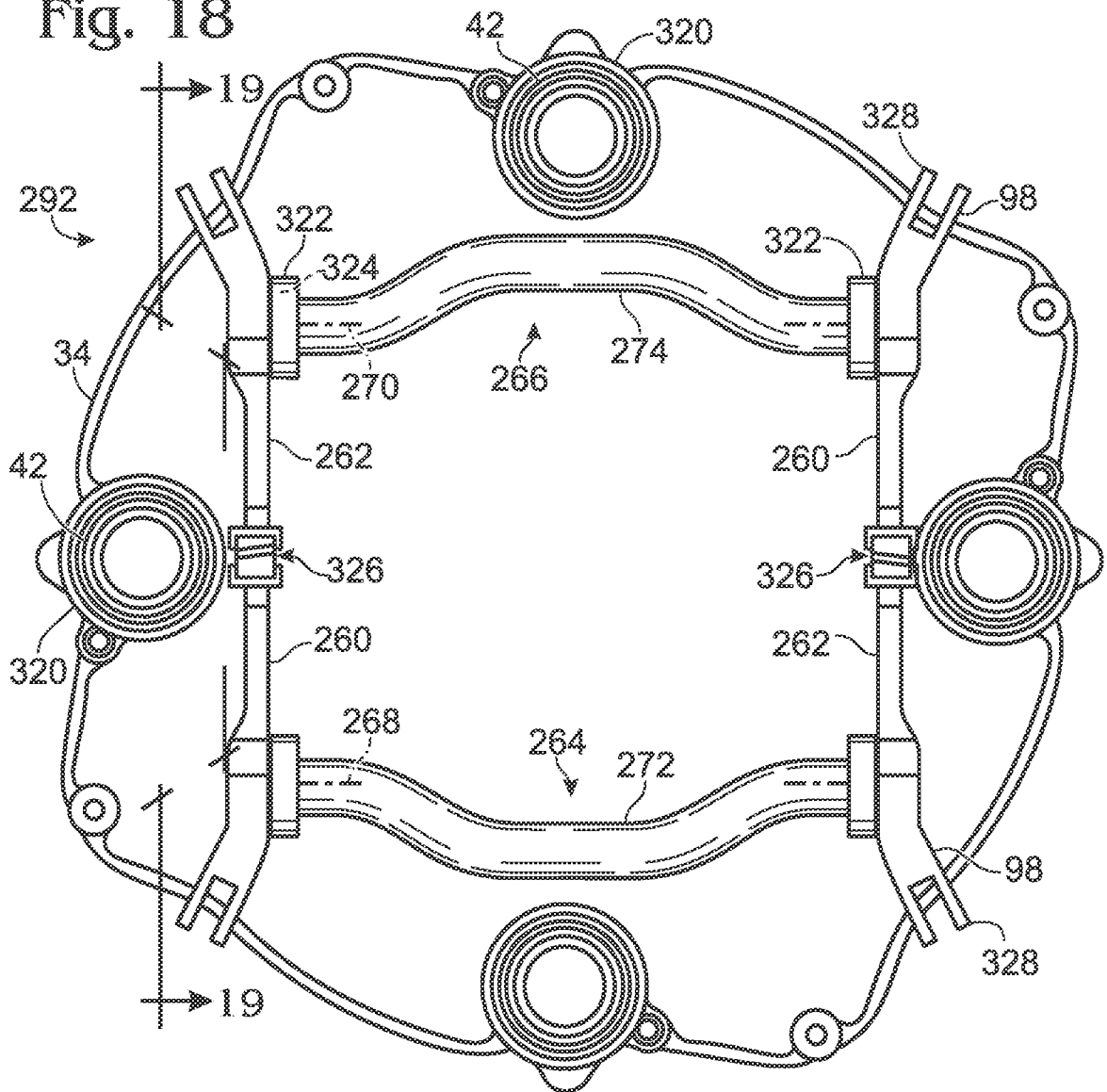
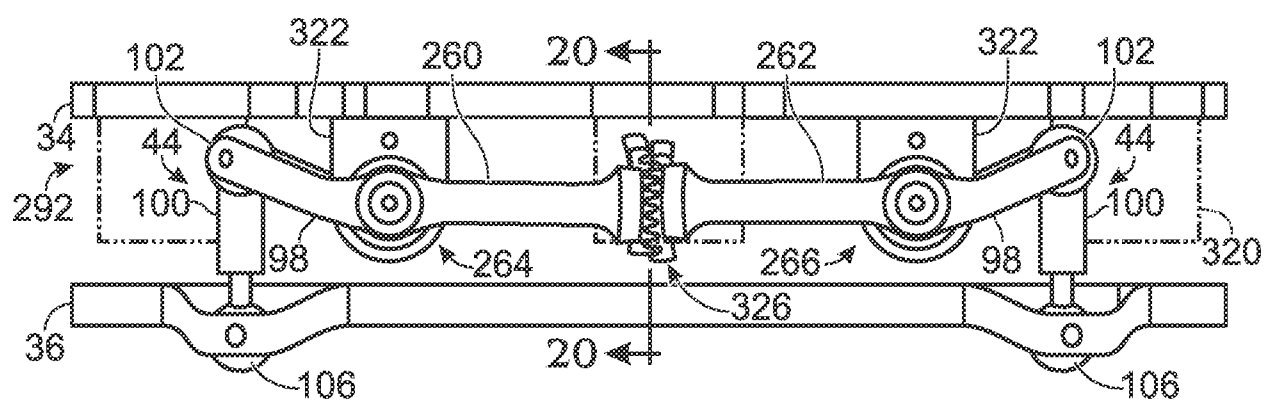


Fig. 19



11/15

Fig. 20

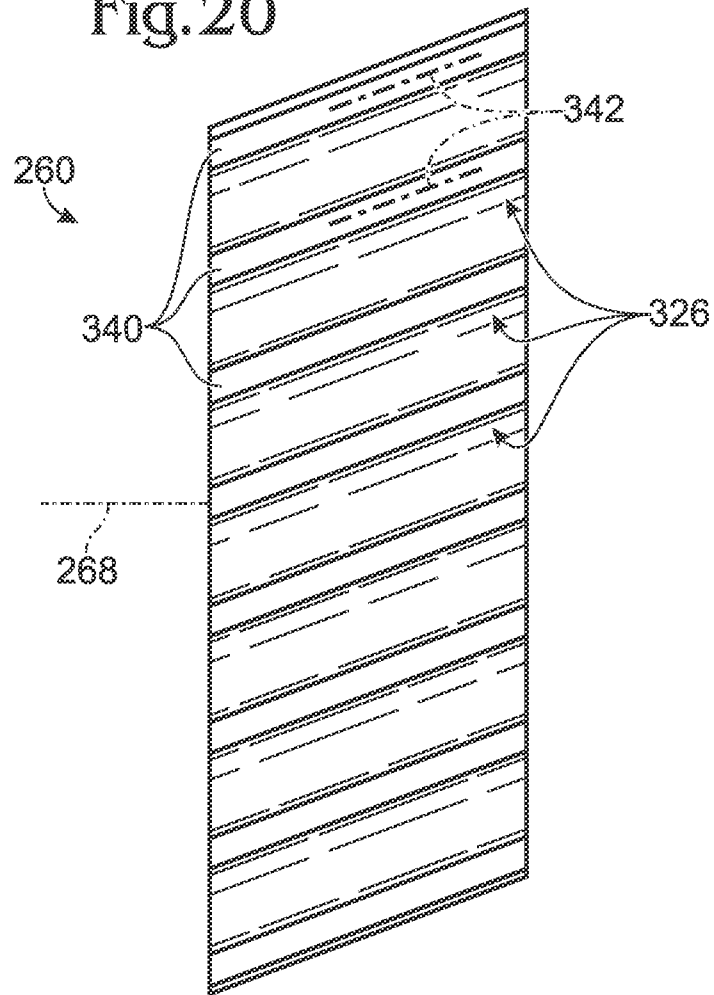
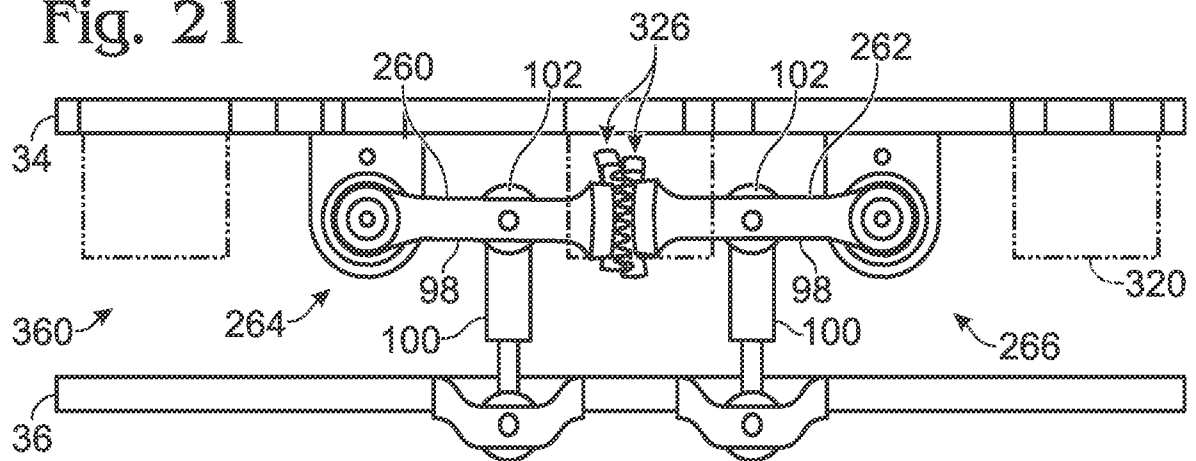
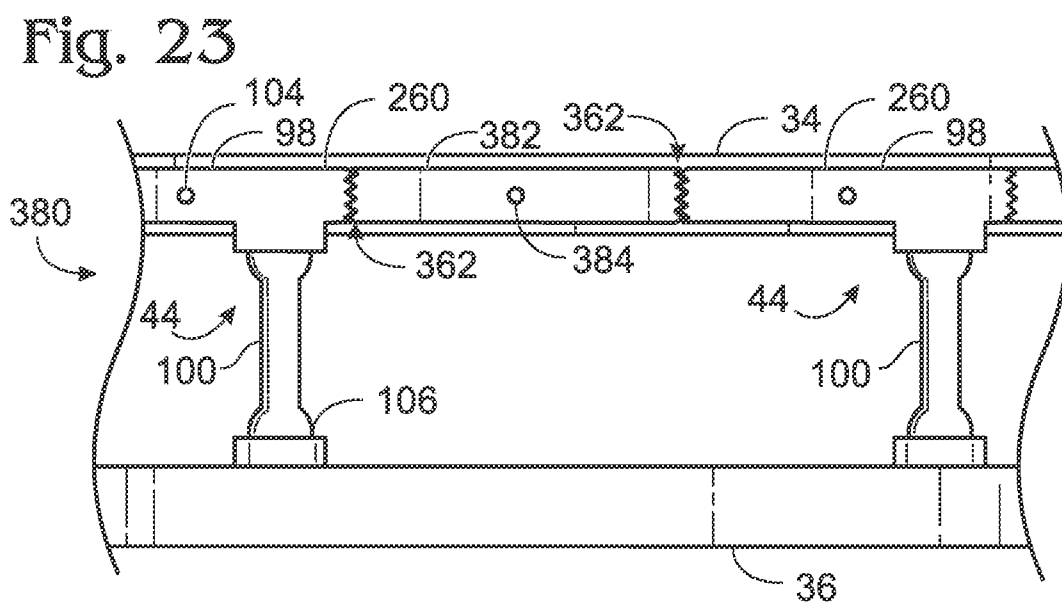
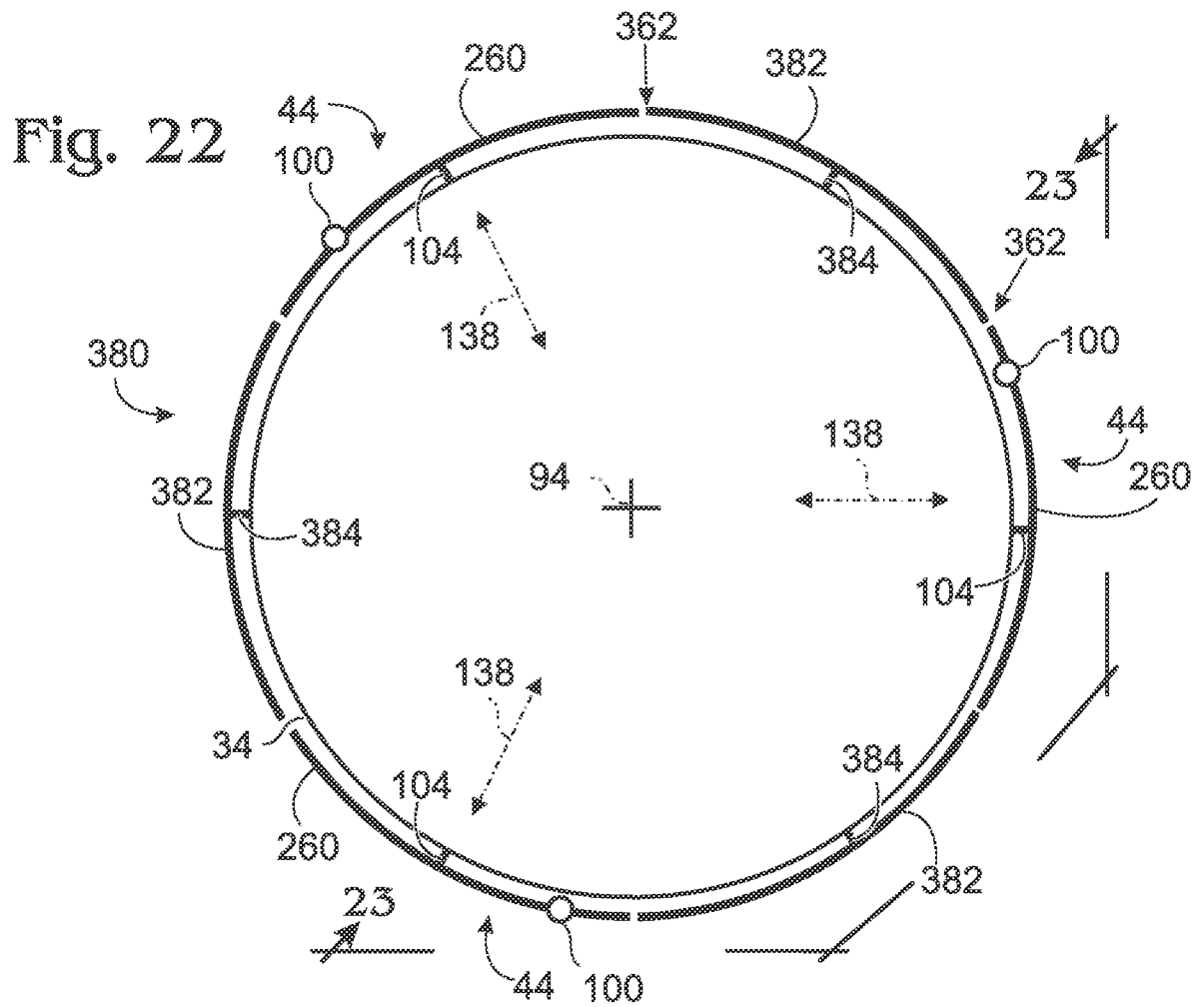
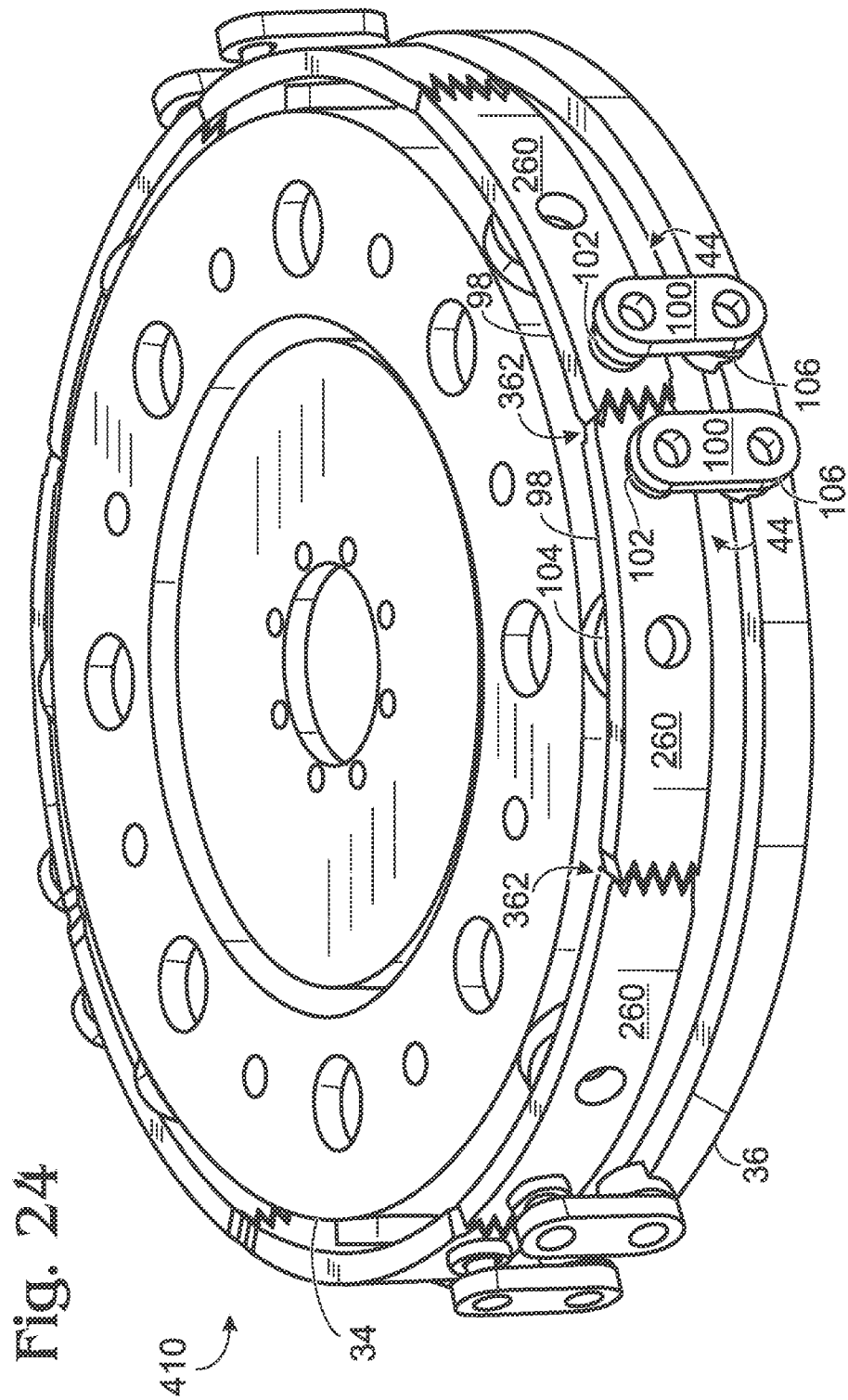


Fig. 21



12/15





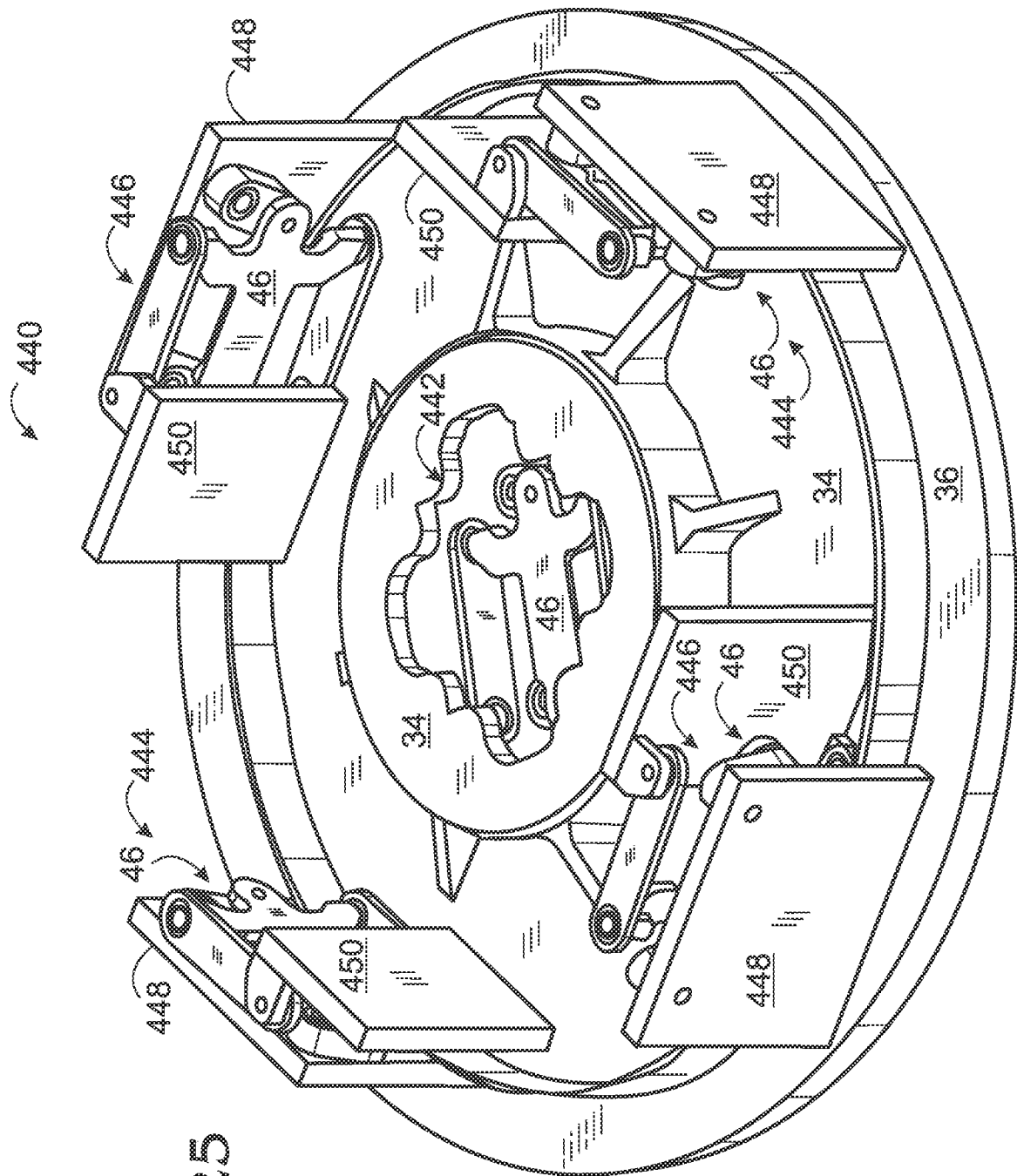
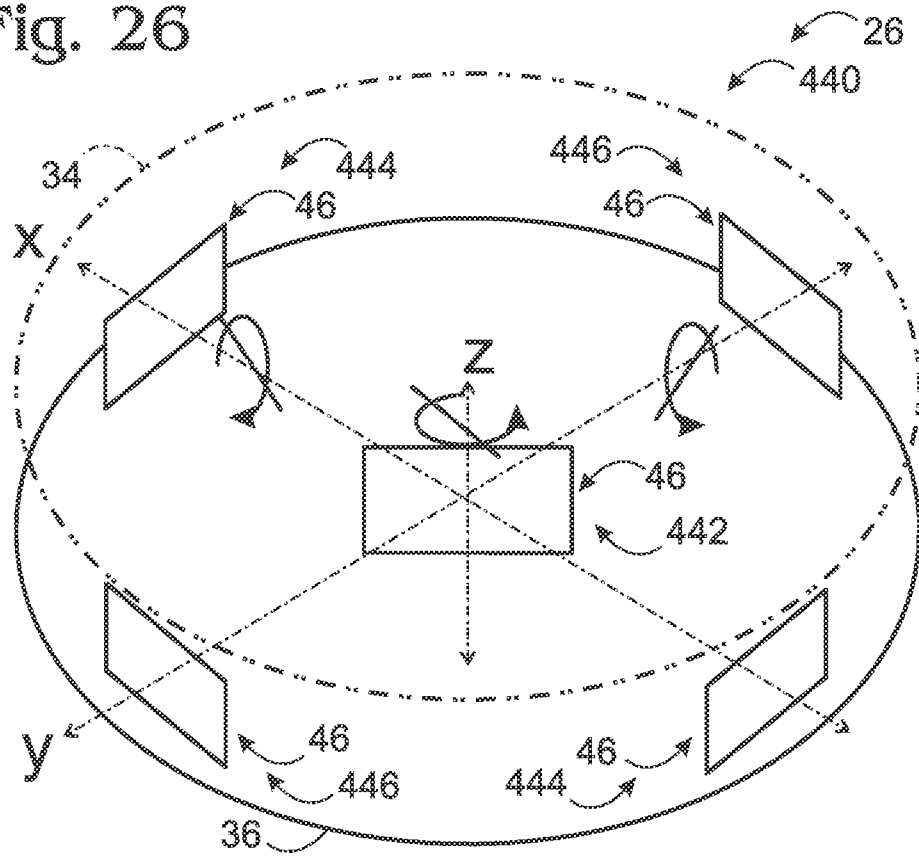


Fig. 25

Fig. 26



INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 12/41327

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - F16M 11/14, F16M 11/06 (2012.01)

USPC - 248/184.1

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

USPC: 248/184.1

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

USPC: 248/637, 646, 660, 176.1, 183.1, 184.1, 187.1, 550

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Pubwest (USPT,PGPB,EPAB,JPAB); GooglePatent; GoogleScholar; Thomson Innovation; Search Terms: gimbal frame plane pivot joint mount bridge intermediate parallel hinge

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ---- Y	US 6,154,317 A (SEGERSTROM et al.); 28 November 2000 (28.11.2000); Fig. 1, 2, and 4; col. 1, ln. 12-37, 65-67; col. 2, ln. 1-19, 38-67; col. 3, ln. 4-15.	49-52 ---- 1-48
Y	US 2003/0159535 A1 (GROVER et al.); 28 August 2003 (28.08.2003); Fig. 1 and 7; para. [0009], [0034]-[0036], [0038], [0043], [0049], and [0051].	1-48
Y	US 2002/0145077 A1 (SHULTZ); 10 October 2002 (10.10.2002); para. [0008], [0028], [0029], [0032].	27-30
Y	US 5,123,621 A (GATES); 23 June 1992 (23.06.1992); Fig. 2 and 3, claim 7; col. 3, ln. 15-30; col. 4, ln. 65-68; col. 5, ln. 1-12.	9-12, 15, 23-24
Y	US 3,335,989 A (BACHMAN et al.); 15 August 1967 (15.08.1967); Fig. 2 and 6; col. 1, ln. 54-68; col. 2, ln. 40-72; col. 3, ln. 10-30; col. 4, ln. 62-72; col. 5, ln. 1-5.	1-37, 43
Y	US 4,686,866 A (ROSHEIM); 18 August 1987 (18.08.1987); Fig. 1-3; col. 2, ln. 33-44; col. 3, ln. 37-52; col. 4, ln. 25-43.	17, 19, 21, 46
Y	US 6,512,509 B1 (MCVICAR); 28 January 2003 (28.01.2003); Fig. 10; col. 2, ln. 37-44; col. 9, ln. 17-32.	18

☐ Further documents are listed in the continuation of Box C.

* Special categories of cited documents:

“A” document defining the general state of the art which is not considered to be of particular relevance

“E” earlier application or patent but published on or after the international filing date

“L” document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

“O” document referring to an oral disclosure, use, exhibition or other means

“P” document published prior to the international filing date but later than the priority date claimed

“T” later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

“X” document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

“Y” document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

“&” document member of the same patent family

Date of the actual completion of the international search

24 July 2012 (24.07.2012)

Date of mailing of the international search report

10 AUG 2012

Name and mailing address of the ISA/US

Mail Stop PCT, Attn: ISA/US, Commissioner for Patents
P.O. Box 1450, Alexandria, Virginia 22313-1450

Facsimile No. 571-273-3201

Authorized officer:

Lee W. Young

PCT Helpdesk: 571-272-4300
PCT OSP: 571-272-7774