(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
06 February 2025 (06.02.2025)

WIPO | PCT

(10) International Publication Number
WO 2025/030185 A1

(51) International Patent Classification:
B64D 47/08 (2006.01) *B64U 101/32* (2023.01)
B64U 20/87 (2023.01)

(21) International Application Number: PCT/ZA2024/050035

(22) International Filing Date: 12 July 2024 (12.07.2024)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
2310792.3 13 July 2023 (13.07.2023) GB
2310793.1 13 July 2023 (13.07.2023) GB

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(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, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CV, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, MG, MK, MN, MU, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH,

(54) Title: SCANNER MODULE AND METHOD

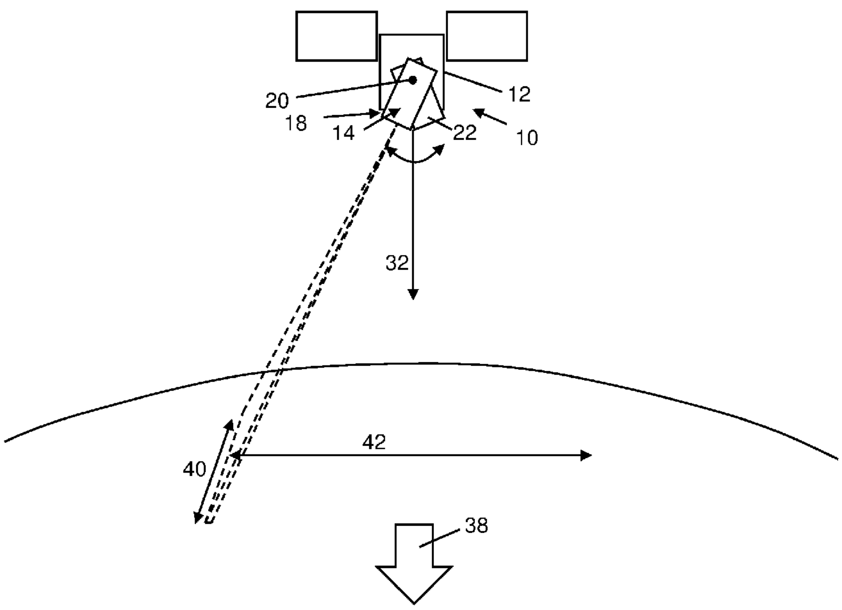

FIGURE 1

(57) Abstract: There is provided a scanner module (10) for an airborne or spaceborne platform (12), the scanner module (10) includes a camera body (14) pivotally coupled about a pivot axis (20) to the platform (12). An actuator is arranged to be powered by a power source onboard the platform (12) and capable of applying torque to the camera body (14) to pivot it about the pivot axis. A counterweight (22) is pivotally coupled about the pivot axis (20) to the camera body (14) pivotable independently of the camera body (14) in relation to the platform. The actuator may include a first portion (24) that is connected to the camera body (14) and a second portion (26) that is connected to the counterweight (22). If the camera body (14) is operatively pivoted e.g., by the actuator, the counterweight (22) may automatically react by pivoting in an opposite direction to counteract a substantial portion of angular momentum of the camera body (14) during the pivotal movement thereof.

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TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, CV, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SC, SD, SL, ST, 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, MC, ME, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*
— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*
— *in black and white; the international application as filed contained color or greyscale and is available for download from PATENTSCOPE*

SCANNER MODULE AND METHOD

CROSS-REFERENCES TO RELATED APPLICATIONS

This application claims priority from United Kingdom patent application numbers 2310793.1 and 2310792.3 both filed on 13 July 2023, both of which are incorporated by reference herein.

FIELD

The present disclosure relates to the field of space optics, and more particularly to airborne or satellite remote sensing performed with a scanning optical imaging sensor.

BACKGROUND

Mechanical scanning of Earth's surface by remote sensing satellites were the norm just a few decades ago, but progressively dropped out of favour in the visual and near infrared regions with the advent of charge-coupled device (CCD) linear arrays. The failure of the Landsat-7 scanning mechanism in 2003 further weakened the case argued by proponents of mechanical scanning.

Shortly afterwards, the NewSpace revolution was born into the era of large imaging arrays. This has brought about reductions in form factor, mass, and cost of spaceborne imaging systems. Pushbroom-related imaging techniques have become the workhorse for optical remote sensing by small satellites such as the CubeSat class.

These techniques use the forward motion of the satellite in low or medium Earth orbit to scan the surface with a linear array of detectors directed in a cross-track direction of satellite motion, much like a document scanner scans a document. Different detectors may accomplish pushbroom-type imaging i.e., linear arrays, matrix (2D) detectors or time delay integration (TDI) detectors. The primary drawback of these techniques is the limited swath they afford. The swath width is constrained to the field of view of the optical system i.e., the optics and the length of the imaging detector in the cross-track direction determines swath width. With these pushbroom-type systems, the swath width is a constant width across the direction of travel of the satellite and it is "pushed" along the earth's surface as the satellite travels. This has the drawback that it only covers a narrow strip of ground with each orbit of the satellite.

Many known satellite-based scanners scan a mirror. Whiskbroom-type scanners or paddle-wheel scan mirrors consume substantial volume. Continuously rotating satellites or telescopes are also inefficient since no more than about 1/4 of their scan period is usefully directed at Earth's surface, since the entire satellite or telescope rotates during its orbit. Furthermore, rotation of the entire satellite is undesirable in terms of mission optimisation, solar power generation, data transmission, etc. The use of a scan mirror occupies considerable volume which causes inefficiencies, especially due to launch weight considerations, and certain of these systems are also overly complex.

The preceding discussion of the background is intended only to facilitate an understanding of the present disclosure. It should be appreciated that the discussion is not an acknowledgment or admission that any of the material referred to was part of the common general knowledge in the art as at the priority date of the application.

SUMMARY

In accordance with an aspect of the present disclosure there is provided a scanner module for an airborne or spaceborne platform, the scanner module comprising:

a camera body which houses a camera and is shaped to be pivotally coupled about a pivot axis to the platform;

an actuator that is arranged to be powered by a power source onboard the platform and capable of applying torque to the camera body so as to pivot the camera body about the pivot axis; and

a counterweight which is pivotally coupled about the pivot axis to the camera body so as to be pivotable independently of the camera body in relation to the platform, the arrangement being such that if the camera body is operatively pivoted, the counterweight automatically reacts by pivoting in an opposite direction to the camera body so as to counteract a substantial portion of angular momentum of the camera body during its pivotal movement.

The actuator may include a first portion that is connected to the camera body and a second portion that is connected to the counterweight.

The actuator may be arranged to operatively pivot the camera body in relation to the counterweight.

The actuator may be an electric motor.

The first portion of the actuator may be a rotor of the electric motor. The second portion of the actuator may be a stator of the electric motor.

The camera body may be arranged to have its field of view generally pointed in a nadir direction of the airborne or spaceborne platform while the camera body is in a neutral orientation during flight (or during movement through the air or space) of the airborne or spaceborne platform.

The camera body may be pivotable by the actuator from the neutral orientation to oppositely angled orientations relative to the nadir direction.

The camera body may be pivotable from +45° to -45° relative to the nadir direction. However, other pivot angles of the camera body may also be possible. For example, the camera body may be pivotable from about +50°to about -50°, or from about +30° to about -30°, or from about +10° to about -10°, or from about +60° to about -60°, or from about +65° to about -65°, or from about +70° to about -70°, or from up to about +90° to about -90°, or more than 90° in either direction.

The actuator may be arranged to pivot the camera body by way of oscillation.

The actuator may be arranged to actively drive an oscillation of the camera body according to a desired speed profile.

The actuator may be arranged to drive the camera body as a resonant oscillator.

The camera body may be arranged to have its pivot axis generally aligned with a direction of flight of the airborne or spaceborne platform. The camera body may be arranged to be pivoted so as to cause the camera to perform scanning across the direction of flight.

The camera body may be arranged to trace a zig-zagged pattern on the ground or surface. The zig-zagged pattern may extend transverse to the direction of flight.

The field of view of the camera may define a swath extent of the camera onto the ground or surface. The swath extent may extend generally in line with the direction of flight of the of the airborne or spaceborne platform. Pivotal movement of the camera body may cause the swath extent of the camera to move across the direction of flight.

The camera body may be coupled to the airborne or spaceborne platform by way of a first bearing.

The counterweight may be coupled to the camera body by way of a second bearing.

One or more of the first and second portions of the actuator may be coupled to the airborne or spaceborne platform by way one or more bearings.

The counterweight may be connected to the airborne or spaceborne platform by way of a first biasing device.

The camera body may be connected to the airborne or spaceborne platform by way of a second biasing device.

The second biasing device may be arranged to urge the camera body to point toward a nadir direction of the airborne or spaceborne platform during flight thereof. The actuator may be arranged to pivot the camera body against the bias of the second biasing device when moving it away from the nadir direction.

The camera body may be connected to the counterweight by way of a third biasing device.

In accordance to another aspect of the present disclosure there is provided a method of scanning by a scanner module onboard an airborne or spaceborne platform, the method comprising:

providing a camera body which houses a camera and is shaped to be pivotally coupled about a pivot axis to the platform;

causing an actuator to be powered by a power source onboard the platform and applying torque to the camera body so as to pivot the camera body about the pivot axis;

providing a counterweight which is pivotally coupled about the pivot axis to the camera body so as to be pivotable independently of the camera body in relation to the platform; and

operatively pivoting the camera body such that the counterweight automatically pivots in an opposite direction to the camera body so as to counteract a substantial portion of angular momentum of the camera body during its pivotal movement.

The step of providing the counterweight may include having a first portion of the actuator connected to the camera body and a second portion of the actuator may be connected to the counterweight.

The step of operatively pivoting the camera body may be performed by the first portion of the actuator.

The counterweight and/or the second portion of the actuator may automatically pivot in an opposite direction to the camera body, e.g., during pivoting of the camera body.

Embodiments of the technology will now be described, by way of example only, with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

Figure 1 is a diagrammatic view of a scanner module onboard a spaceborne platform illustrating its path of flight relative to the ground or surface;

Figure 2 is a diagrammatic representation of a zig-zag pattern traced by the scanner module on the ground or surface;

Figures 3-5 are three-dimensional views of an exemplary embodiment of a scanner module on an exemplary airborne or spaceborne platform, showing a camera body and counterweight that are pivotable relative to one another;

Figure 6 is a diagrammatic sectional view of the scanner module taken along line VI-VI' in Figure 5, showing internal components of the scanner module as well as first and second biasing devices of the scanner module;

Figure 7 is an exemplary graph of camera body rotational acceleration (proportional to torque), as well as speed and position of the camera body over time when driven by way of oscillation by an electric motor;

Figure 8 is a diagrammatic sectional view of an alternative embodiment of the scanner module similar to Figure 6, showing a third biasing device that may connect the camera body to the counterweight; and

Figure 9 is a high-level flow diagram of an exemplary method of scanning by a scanner module onboard an airborne or spaceborne platform;

Figure 10 is another exemplary embodiment using a mirror to redirect the camera's field of view towards the ground or surface; and

Figures 11-12 show further detail of the exemplary embodiment of Figure 10.

DETAILED DESCRIPTION WITH REFERENCE TO THE DRAWINGS

The present disclosure relates to an oscillating single-axis scanning optical imaging telescope which may be coupled to a host satellite platform or to a host airborne platform in a reactionless or near-reactionless manner. This may minimize interference with satellite or host platform stability during flight, orbit, or other movement thereof. The scanning optical imaging telescope may also be termed a scanner module, an imager, or a scanner system.

The present disclosure may implement a compact scanner module or system which may be capable of achieving oscillatory scanning with minimal interference to the host platform. The host platform may typically be a small satellite or a CubeSat class of miniaturized satellite, although larger platforms may also benefit from reduced disturbance that may be provided by aspects of the present disclosure. The present disclosure may implement scanning or imaging of a telescope (typically a small telescope) by a camera or imager in a reactionless manner or in a near-reactionless manner, instead of scanning with a scan mirror. By eliminating the mirror, packaging for launch may be possible within a very compact form factor, which may be critical on satellites and CubeSats, but it may also be advantageous in other applications.

The scanner module may have an image capturing device or camera associated therewith. The camera may also be referred to as a scanner. An optic may also be provided by the scanner module, and the camera may for example capture images through the optic. The optic may for example be a telescope. The camera and/or telescope may have a field of view associated therewith, and this field of view may typically be directed at the earth. The field of view may have a predefined size, and its size may depend on an altitude of the platform or craft carrying the scanner module. The field of view may also define a scanning region on the ground or surface, which may define an extent of a swath or swath width. The scanner module and the host craft or platform may be generally nadir pointing; or pointing downward below it toward the earth or other celestial body such as a planet, a sun, a moon, an asteroid, etc.

The scanner module or scanning system may include an associated counter-mass which may also be termed a counterweight. A motor or other actuator may drive the camera or imaging portion (also termed the imager or imaging payload), for example to oscillate it or to pivot or roll it relative to the host craft or platform. The counter-mass may react once this roll of the imaging payload happens, and this may substantially neutralise reaction torque or other reaction force(s) to be conveyed to the host satellite or other craft carrying the scanner module thereon. The present disclosure may be implemented to facilitate visible and near infrared (VNIR) imaging or scanning, or facilitate imaging other regions of the optical spectrum.

A first exemplary embodiment of the present disclosure is illustrated in Figures 1 to 7 and a second exemplary embodiment is illustrated in Figure 8. Figure 9 shows an exemplary method that may be implemented by aspects of the present disclosure. Figures 10 to 12 show another exemplary embodiment of the technology according to aspects of the present disclosure.

In the exemplary embodiment of the present disclosure shown in Figure 1, a scanner module (10) is provided onboard a spaceborne platform (12) such as a satellite. It will be appreciated that the scanner module may also be provided onboard other flying platforms, or airborne platforms such as unmanned aerial vehicles (UAV's), drones, aeroplanes, etc.

Turning to Figures 3-5, in the present embodiment, the scanner module (10) includes a camera body (14). The camera body (14) may for example house a camera (16) and a telescope (18) or other optic therein. The camera body (14) may be shaped so as to be pivotally coupled about a pivot axis (20) to the airborne or spaceborne platform (12), as can be seen in more detail in the sectional view of Figure 6. The camera body (14) may, for example, have a mounting structure (15) which is capable of being fitted to the airborne or spaceborne platform (12). The mounting structure may for example be a shaft or tube that extends from a major portion of the camera body in which the telescope and camera may be located. In embodiments of the present disclosure the mounting structure (15) may also be termed a rotor tube, for example when the actuator is an electric motor. The mounting structure may, for example, be hollow and it may define a cavity (17) therein. The cavity (17) may be used for a flexible connection, wiring, slip-ring(s) or the like. This may, e.g., facilitate a connection, mechanically and/or thermally and/or electrically between the camera body (14) (e.g., with its camera and telescope) and the host airborne or spaceborne platform (12).

The scanner module (10) further includes an actuator that is arranged to be powered by a power source (not shown) onboard the airborne or spaceborne platform (12). In the present embodiment the actuator may be in the form of an electric motor, which may also be termed a torque motor. The motor may also be termed a torquer, and many types of torquers or motors may be implemented by the present disclosure, such as a limited angle torque actuator (LATA). In the present embodiment, the actuator is capable of applying torque to the camera body (14) so as to pivot the camera body about the pivot axis (20) as demonstrated in Figures 3-5.

In the present embodiment, the scanner module (10) may further include a counterweight (22) which is pivotally coupled about the pivot axis (20) to the camera body (14) so as to be pivotable independently of the camera body (14) in relation to the airborne or spaceborne platform (12).

Referring to Figure 5, the camera body (14) may be arranged to have its field of view generally pointed in a nadir direction (32) of the airborne or spaceborne platform (12) while the camera body is in a neutral orientation (34) during flight of the airborne or spaceborne platform (12). The neutral orientation (14) may be generally aligned with a major axis (36) of the airborne or spaceborne platform which is shown in Figure 3. However, it will be appreciated that the neutral orientation (14) of the field of view of the camera need not be aligned with a nadir direction.

An exemplary direction of flight (38) (also termed a direction of travel) of the airborne or spaceborne platform (12) is shown in Figures 1-6. In the present embodiment, the camera body may be arranged to have its pivot axis (20) generally aligned with the direction of flight (38) of the airborne or spaceborne platform (12). The camera body (14) may be arranged to be pivoted or rolled (e.g., by the actuator) so as to cause the camera to perform scanning across the direction of flight (38) or transverse to it. For the sake of understanding, it will be appreciated that the direction of flight (38) of the airborne or spaceborne platform is “out of the page” when looking at Figure 1, and the pivot axis (20) also extends “out of the page”, the pivot axis being diagrammatically represented by the dot in Figure 1. The pivot axis may hence be substantially aligned with the direction of movement/flight (38) of the airborne or spaceborne platform.

Referring to the sectional view of Figure 6, in the present embodiment, the camera body (14) may be pivotable by the actuator, presently in the form of an electric motor. A diagrammatic exemplary motor is shown, to scale, in Figure 6, with the arrow tip of reference numeral (24) pointing at the rotor; and the stator generally at the arrow tip of reference numeral (54). The actuator, in this instance the motor, may have a first portion (24) thereof connected to the camera body (14). In other words, the mounting structure (15) of the camera body may be fitted to internal components of the scanner module, and these components may be connected, preferably rigidly, to the camera body (14). For the sake of explanation, the components of the scanner module that form part of (or that are connected to) the first portion (24) of the actuator are hatched by a wavy pattern in Figure 6. These components may collectively be termed the first portion (24) of the actuator, or they may be termed a rotor (24) portion, in the case of the actuator being an electric motor.

In the present embodiment, the actuator may further include a second portion (26) that may be connected to the counterweight (22). The second portion of the actuator may also be termed a stator portion, in the case of the actuator being an electric motor. For the sake of explanation, the components of the scanner module that may form part of (or that may be connected to) the second portion (26) of the actuator are hatched by a dotted pattern in Figure 6, so as to distinguish them from the first portion (or rotor portion) (24) of the actuator. Stated differently, the rotor portion of the actuator is shown by the wavy pattern, and the stator portion of the actuator is shown by the dotted pattern in Figure 6, merely for the sake of understanding the present disclosure.

The arrangement of the scanner module is in the present embodiment such that if the camera body (14) may be operatively pivoted by the actuator, e.g., in a clockwise direction as shown in Figure 3, the counterweight (22) may automatically react by pivoting in an opposite direction to the camera body (14). This may be implemented due to the counterweight optionally being connected to the stator portion of the motor, and the camera body optionally being connected to the rotor portion of the motor. The counterweight may be arranged so as to counteract a substantial portion of angular momentum of the camera body (14) during the pivotal movement of the camera. This may substantially inhibit reactive torque or reaction forces to be transferred or conveyed from the actuator to the airborne or spaceborne platform (12). It will be appreciated that the rotor portion of the actuator may instead be attached to the counterweight (22) and the stator to the camera body (14), as the camera body is actuated relative to the counterweight and both move in opposite directions. Further exemplary components of the scanner module will be described in more detail below.

The first portion (24) of the actuator may hence act as a rotor of the electric motor, and the second portion (26) of the actuator may act as a stator of the electric motor. These first and second portions of the actuator may counteract one another. E.g., when a torque is applied by the actuator to pivot the camera body in a first direction, the first portion (24) (e.g., the stator) may also be pivoted. Newton’s third law dictates that for every action (force) in nature there is an equal and opposite reaction. In other words, the counterweight (22) and the second portion (26) of the actuator may be configured to have a reactive torque that is equal or near-equal to that of the first portion, so as to substantially cancel or neutralise the angular momentum of the first portion (24) of the actuator when it is pivoted. If the moments of inertia of the first and second portions of the actuator are not matched, the rotational speed of the two may differ, but momentum may still be substantially neutralised by the embodiments of the present disclosure. E.g., momentum transferred to the platform (12) may be substantially reduced or neutralised.

Still referring to Figure 6, in the present embodiment, the camera body (14) is coupled to the airborne or spaceborne platform (12) by way of a first bearing (28). An inner portion of this first bearing may be fitted to the mounting structure (15) of the camera body, so as to be rotatable or pivotable in unison therewith in use. This first bearing (28) may enable the actuator to be substantially freely rotatable in relation to the airborne or spaceborne platform (12). The inner portion of the first bearing (28) is also marked by the wavy pattern so as to illustrate that it may form part of the first portion (24) of the actuator (also termed the rotor portion in the case of the actuator being an electric motor).

The counterweight (22) may, in the present embodiment, be coupled to the camera body (14) by way of a second bearing (30). An outer portion of the second bearing (30) may form part of the second portion of the actuator (e.g., the stator portion), and it is also marked by the dotted pattern in Figure 6 to illustrate this.

The present disclosure extends to a scanner module that has one or more of the first and second portions (24, 26) of the actuator coupled to the airborne or spaceborne platform (12) by way of one or more bearings. Presently, first and second bearings (28, 30) are implemented as explained above, however other arrangements, different numbers or different locations of bearings may be possible.

The camera body may house the camera (16) therein. The camera may be arranged to scan or capture images through a telescope (18), and the telescope may for example be directed toward the earth, e.g., for taking images of the earth for further processing. The camera and telescope may be termed the “payload”. The rotor portion (24) (and therefore payload/telescope) may in exemplary embodiments be driven by a torque motor.

The motor’s stator (26) may be mounted rigidly to the counterweight (22) or countermass. Under torque, the counterweight may accelerate and rotate freely in a reactive manner relative to the rotor portion (24). In the present embodiment, the motor may be driven according to a predetermined speed profile, for example, such that a near-constant angular speed is maintained over a substantial portion of an oscillatory arc of the camera body (14). The present disclosure extends to a technique wherein the actuator may be arranged to actively drive an oscillation of the camera body according to a desired speed profile. The actuator may alternatively, or in addition, be arranged to drive the camera body as a resonant oscillator.

The rotor (24) of the motor may be rigidly attached to the scanning payload (telescope) (e.g., via the mounting structure (15)). The motor’s stator (26) may be rigidly attached to the counterweight (22). The rotor and stator (24, 26) may be coupled through the ball-bearing (30). The counterweight (22), in turn, may be coupled to the airborne or spaceborne platform (12) through two sets of ball bearings (i.e., through the first bearing (28) and through the second bearing (30)). The motor’s reactive torque may therefore be transferred to the counterweight rather than to the host airborne or spaceborne platform (12). It will be appreciated that in embodiments of the present disclosure the airborne or spaceborne platform may be a satellite.

Referring again to Figures 3-5, in the present embodiment, the camera body may be pivotable by the actuator from the neutral orientation (34) to oppositely angled orientations relative to the nadir direction (32). In other words, the camera body may be pivotable by the actuator from a first orientation shown in Figure 3, to a second orientation shown in Figure 4, through the neutral orientation (34) of Figure 5. The neutral orientation may also be referred to as a resting orientation, or neutral state of the camera body. The actuator may operatively be arranged to pivot the camera body (14) by way of oscillation, e.g., between the first orientation of Figure 3 and the second orientation of Figure 4, and e.g., starting from the neutral orientation in Figure 5.

In the exemplary embodiment, the camera body may be pivotable from +45° to -45° relative to the nadir direction. In other words, the camera body (14) may be pivotable by a first pivot angle (α) relative to the neutral orientation (34) (or relative to nadir (32)); and the camera body may be pivotable by a second pivot angle (β) relative to the neutral orientation (34) (or relative to nadir (32)). These first and second pivot angles (α, β) may also be measured from the major axis (36) of the airborne or spaceborne platform (12). These first and second pivot angles (α, β) may be +45° and -45° respectively. However, other pivot angles of the camera body may also be possible. For example, the first and second pivot angles may be about +50° and -50°, or about +30° and -30°, or about +10° and -10°, or about +60° and -60°, or about +65° and -65°, or about +70° and -70°, or up to about +90° and -90°, or more. Alternatively, the first and second pivot angles (α, β) need not be equal, for example when targeting a specific off-nadir region or to avoid sunglint.

Referring again to Figure 1, the camera's field of view may define a swath (40) extent. The swath extent (40) may also be termed a scanning region. When, e.g., pivoted by the actuator, the camera may perform a cross-track scanning motion (42) which causes this swath (42) or scanning region to move from left to right in Figure 1. This may provide the advantage of covering a wide area by the scanning motion (42). This may be particularly advantageous for time delay integration (TDI) imaging which may be implemented by the scanner module (10). The swath extent may extend generally in line with the direction of flight (38) of the airborne or spaceborne platform (12).

Pivotal movement of the camera body (14) may cause the swath (40) of the camera to move across the direction of flight (38) during operation of the scanning module (10). The swath of the camera may also be termed the swath width, but for the sake of understanding the swath may be termed a swath extent, so as not to be confused with the width of the scanning motion (42) relative to the flight direction (38). In other words, a swath width of the scanner module (10) may be defined not by the field of view of the camera, but rather by the pivotal movement of the camera body, e.g., by the actuator, which may cause a large region of the earth, ground, or surface to be scanned by the scanning motion (42). This may also be termed a cross-track scanning motion (42), where the “track” may be defined by a ground-level path aligned with a flight path of the airborne or spaceborne platform.

The camera body (14) may be arranged to trace a zig-zagged pattern (44) on the ground or surface. An example of this is diagrammatically illustrated in Figure 2. The zig-zagged pattern may extend transverse to the direction of flight (38) of the airborne or spaceborne platform. An area between the two lines labelled “1” may represent the camera or scanner module’s swath scanned from left to right. An area between the two lines labelled “2” may represent the camera or scanner module’s swath scanned back from right to left. An area between the two lines labelled “3” may represent the camera or scanner module’s swath scanned from left to right again. As before, the directional arrow (38) represents forward flight direction of the airborne or spaceborne platform, presently a satellite. It should further be noted that when the first and/or second pivot angles (α, β) are arranged to be relatively large (e.g., about 30°, or about 45°, or about 50°, or about 60°, or more than 60°), the swath extent may increase noticeably from nadir towards maximum scan angles.

Referring again to Figure 1, the scanning telescope (18) may be oriented with its swath (40) extending in an along-track direction (38) of the satellite (12), instead of the conventional orientation where swath would have extended in the cross-track direction, e.g., for conventional pushbroom imaging. In case of implementing a linear imaging array in the present embodiment (10), a detector array may be generally aligned with a satellite velocity vector.

Scanning may be accomplished by partial rotation (roll) of the camera body (14) (which may also be termed an imaging payload) about the satellite’s velocity vector (X-axis) which may be aligned with the direction of flight (38). The camera may for example rotate (roll) from -45° to +45° about the nadir point in the cross-track direction. Scanning may therefore be achieved in the cross-track direction, which may trace the zig-zagged line-scanned pattern (44) on the ground (see Figure 2). Scan speed and off-nadir roll angle(s) may be matched to a satellite forward velocity to ensure continuous coverage (i.e., to inhibit gaps in coverage) for as long as the scanning imager is activated. In the present embodiment, the camera may be rotated or pivoted relative to the host satellite platform, which in turn may remain nominally nadir pointing (see Figure 1). In other words, the satellite body does not need to roll to achieve the scanning action of the camera. The present embodiment may implement a driven oscillator which may allow a predetermined ground speed profile (or surface speed profile) during operation of the scanner module.

Referring again to Figure 6, the counterweight (22) may in the present embodiment be connected to the airborne or spaceborne platform (12) by way of a first biasing device (46). The first biasing device may be in the form of a first torsion spring which connects the counterweight (22) (e.g., forming part of the second portion (26) of the actuator) to the airborne or spaceborne platform (12), e.g., by way of a first connecting structure (48). In other words, the first torsion spring (46) may be arranged to bias the stator portion (26) or second portion of the actuator relative to the airborne or spaceborne platform (12). It should be noted that the connection between the first torsion spring (46) and the counterweight (22) is not shown in Figure 6, but it will be appreciated that it may, for example, connect to a structural element (54) that forms part of the counterweight (22) (or that is attached thereto).

The camera body (14) may be connected to the airborne or spaceborne platform (12) by way of a second biasing device (50). The second biasing device may be in the form of a second torsion spring which connects the camera body (14) (e.g., forming part of the first portion (24) of the actuator) to the airborne or spaceborne platform (12), e.g., by way of a second connecting structure (52). In other words, the second torsion spring (50) may be arranged to bias the rotor portion (24) (also termed the first portion of the actuator) relative to the airborne or spaceborne platform (12). It should be noted that the connection between the second torsion spring (50) and the camera body (14) is not shown in Figure 6, but it will be appreciated that it may, for example, connect to the mounting structure (15) or rotor tube of the camera body (14).

The second biasing device (50) may be arranged to urge the camera body (14) to point toward the nadir direction (32) of the airborne or spaceborne platform (12) during flight thereof. The actuator may be arranged to pivot the camera body (14) against the bias of the second biasing device (50) when moving it away from the nadir direction (i.e., when pivoting it away from the neutral orientation (34) in Figure 5).

The present embodiment may implement a torque motor driving an oscillation of the camera body (and by implication the counterweight) at constant speed through a large part of an arc of movement of the camera body.

Referring to Figure 7, there is illustrated an example plot or graph of rotational acceleration (proportional to torque) of the camera body (which may also be termed a “payload”), as well as speed and position of the payload over time, for a driven oscillator. In other words, the actuator may be driven to pivot the rotor and stator portions as an oscillator.

In the exemplary graph in Figure 7, the angular position of the payload relative to the nadir direction (32) is indicated by an angle (θ), measured in radians. The angular speed is denoted by (ω) and measured in rad/s, and angular acceleration by ($\acute{\omega}$) measured in rad/s^2. Torque applied by the actuator may be approximately proportional to angular acceleration experienced by the payload. In this example, limited or no torque is applied at T = 0s, and the angular speed of the payload is constant. During the period of constant angular velocity (ω), sufficient torque may be applied to maintain a constant angular velocity. This torque is generally small compared to the torque required for reversal of direction. Application of torque by the actuator, from 0.33s to 0.66s, reverses the direction of the payload at the extreme of oscillation (which may, e.g., be at maximum value of the first pivot angle (α)) and inverts angular velocity (ω) (changes from positive at 0.33s to negative at 0.66s). Angular position (θ) starts decreasing and returns to 0 rad at nadir position (32) at T = 1s. It continues at constant angular velocity (ω) towards the other extreme of oscillation (which may, e.g., be at maximum value of the second pivot angle (β)) before application of torque by the actuator in the opposite direction once again slows down and inverts the angular velocity in the region of T = 1.5s.

In Figure 8 is shown another exemplary embodiment of a scanner module (100) according to aspects of the present disclosure. In the present embodiment (100), similar reference numerals may be used to designate similar components to those of the embodiment (10) described above with reference to Figures 1 to 7. It will be appreciated that the present embodiment may include one or more features of the other embodiments of the present disclosure and vice versa.

Many features of this embodiment (100) may be similar to those of the embodiment (10) described above. For the sake of brevity, a description of all the components of the scanner module of the present embodiment (100) will not be repeated here. Suffice to say that the similar components (camera body, bearings, first and second portions of the actuator, (also termed the rotor and stator portions), counterweight and airborne or spaceborne platform) of the present embodiment may function in a similar way to those described with reference to Figures 1 to 7.

However, in the present embodiment of the scanner module (100), a camera body (114) and/or its mounting structure (115) may be connected to a counterweight (122) by way of a third biasing device (156). The third biasing device (156) may be in the form of a third torsion spring which connects the camera body (114) (e.g., forming part of the first portion (24) or rotor of the actuator) to the counterweight (122), e.g., by way of a third connecting structure (158). In other words, the third torsion spring (156) may be arranged to bias the rotor portion (124) (also termed the first portion of the actuator) relative to the stator portion (122, 126) (also termed the second portion of the actuator). It should be noted that the connection between the third torsion spring (156) and the camera body (114) is not shown in Figure 6, but it will be appreciated that it may, for example, connect to the mounting structure (115) or rotor tube of the camera body (114).

First and second biasing devices (146, 150) may also be provided, respectively connecting the stator portion (126) and the rotor portion (124) to the airborne or spaceborne platform (112) in a similar way as described above with reference to Figure 6. In the present exemplary embodiment (100), the first spring (146) (or biasing device) is between the stator (122, 126) and the platform (112), the second spring (150) (or biasing device) is between the rotor (124) and the platform (112), and the third spring (156) (or biasing device) is between the rotor (124) and the stator (126).

The third torsional spring (156) may be implemented in the present embodiment. The torque motor may apply only a light torque (in other words, a torque which need only be sufficient to overcome losses (e.g., frictional losses) in the system), so as to maintain a resonance of the scanner module (100), i.e., the rotor portion (124). A lightly driven resonant oscillation of the rotor relative to the counterweight (122) may be implemented. The rotor (124) may be coupled to the counterweight (122) by the third torsional spring (156). In the present embodiment (100), angular velocity may not be maintained as constant, but may decrease as an off-axis scan angle increases. The off-axis scan angle may be similar to the first and second pivot angles (α, β) described above with reference to Figures 3 and 4, and it may, for example, be defined as an angle of the camera body (100) relative to a major axis of the platform (112), or relative to nadir.

This present embodiment may require less power, since it may rely on resonance at a natural frequency and it may only need to be driven lightly by the actuator as described above (e.g., to overcome relatively minor frictional losses, etc.). Resonant oscillation may be performed by way of the third torsional spring (156), and/or by virtue of the motor or actuator driving it. The other torsional springs (146, 150) may also have natural frequencies associated with each of them, as with the corresponding first and second springs (46, 50) of the other embodiment of Figures 1 to 7. The first, second and/or third biasing devices may affect the natural frequency (or frequencies) of one or more components of the scanner module (10, 100) when driven by the actuator.

Further advantages of the present disclosure may include an increased dwell time of the scanner module at off-nadir angles, where ground sampling distance (GSD) may be worse than at nadir. An increased dwell time of the scanner module (100) may improve a signal to noise ratio. This may also improve image quality, which may compensate for poorer GSD. The reduced off-nadir ground speed may also, for example, aid yaw steering of the satellite. This may be the case for Fig. 6 (e.g., using a driven oscillator) and for Fig. 8 (e.g., using a resonant oscillator). In case of

Fig. 6 the motor speed could also be reduced off-nadir. In the resonant case too, the speed may be managed or controlled, e.g. using flexural pivots as bearings and springs, or using non-linear springs.

A reactive torque of the third torsional spring (156) which may accelerate the rotor (124) may be conveyed to the counterweight (122) rather than directly to the host satellite platform (112). Once oscillation is established, the actuator may function merely to lightly drive or pulse the rotor (124) so as to resonate relative to the counterweight (122) by overcoming the system's or the scanner module's (100) torque losses. Torque losses may include friction of the bearings, or other relatively minor torque losses. The actuator may therefore be a relatively simple electromechanical mechanism capable of lightly driving or pulsing the rotor (124). The first and second springs (146, 150) may also be termed centring springs. The present embodiment (100) may implement a resonant oscillator. In other words, a lightly driven resonance at natural frequency may be used as opposed to a driven oscillator, e.g., such as a driven oscillator implemented according to aspects of Figures 1 to 7. In exemplary embodiments, the third spring's function may be energy storage (typically a larger, stronger spring than the generally 'lightweight' centring springs).

The bearings and springs may be replaced by pivot bearings or flexural pivots, which may be configured to perform the combined function of conventional bearings and centring and energy storage required for reversal of direction.

In other respects the present embodiment (100) may be similar or identical to the embodiment of Figures 1 to 7. A few commonalities between the two are briefly described below. The rotor (24, 124) and counterweight (22, 122) may be oscillated, 180° out of phase with one another. Both the rotor and counterweight may oscillate relative to the host airborne or spaceborne platform (12, 112) and the earth or celestial body below, and a nominal zero position may be defined as the airborne or spaceborne platform's (12, 112) nadir point (e.g., 32 in Figure 1).

A small reactive torque may be transferred to the host airborne or spaceborne platform (12, 112) due to bearing friction, the centring springs (46, 50, 146, 150, 156 as the case may be) and/or wire wraps, slip rings, or the like. This disturbance torque should amount to only a fraction of the reactive torque and it may be referred to as the system's torque losses. In the case of the present embodiment (100) (which may be implemented as a resonant oscillator) the reactive torque may be brought about by the torsional spring more so than by the motor which may only lightly pulse the resonance.

The shape of the counterweight may be chosen conveniently to minimize overall volume of the scanner module, or so as to facilitate balancing, etc. The counterweight may preferably be centred along a Z-axis (which may correspond to the nadir direction) of the airborne or spaceborne platform. The first torsional spring (46, 146) (e.g., similar to a clock spring) may lightly couple the counterweight (22, 122) to the airborne or spaceborne platform (12, 112). In a similar manner, the rotor (24, 124) (and therefore the telescope) may also be lightly coupled to the host satellite platform via the second torsional spring (50, 150), e.g., so as to maintain neutral nadir pointing thereof (e.g., in a resting state, the camera body may be nadir pointing).

In the embodiments of the present disclosure, a rotary encoder (58, 158) may be provided. The rotary encoder (58, 158) may, e.g., be provided onboard the airborne or spaceborne platform (12, 112). The rotary encoder (58, 158) may be arranged to monitor a position and an angular speed of the payload (e.g., the camera body and/or telescope) relative to the platform (12, 112). Encoder data may be used to enable geolocation and synchronisation of TDI clocking.

It should be appreciated that several variations may be implemented in realising a system operating on the same or similar principles. A wire wrap harness either within the cavity or external to the pivot shaft may, for instance, be used to centre each of the rotor and the counterweight relative to the host platform, instead of using torsional springs. In other words, wire wrap harnesses may be used, and they may act as torsional springs in order to maintain centring the rotor and stator. Still other means of centring the rotor (camera body) and the counterweight may be envisaged.

The third torsional spring may be replaced by other means of energy storage to maintain resonance, such as one or more coiled compression springs, flexural pivots, etc.

The rotor tube (15) may have a cavity therein, or it may be solid. It may for example be a solid shaft without a cavity. It may have a much smaller diameter than the rotor tube with a cavity.

Connections such as cables and thermal conductors may pass as wire wraps and / or flexible connections outside of the pivot shaft.

The countermass (22) and stator (26) may take any convenient form or function. The countermass (22) need not be rectangular shaped as per Figures 1, 3, 4, and 5. It may, for example, take the shape of a disc. The countermass may be flat as per Figures 1, 3, 4, and 5 or it may be shaped in three dimensions. It may for example encapsulate or partially surround or enclose the camera (16), for example in Figure 11. It may surround or partially enclose the rotor tube (15). It may surround or partially enclose the camera (16) and / or the rotor tube (15). The countermass (22) may occupy or partially occupy the cavity (17) within the rotor tube (15).

The countermass (22) may serve other functions. Other purposes may include radiation shielding, thermal management, mechanical structure, mounting, support and enclosure, etc. The countermass may house equipment or electronics or mechanics relating to the camera or relating to other functions of the host platform. The countermass may be a second camera unit. The second camera may rotate or oscillate counter to the first camera (16, 18). A second camera may serve various purposes such as redundancy, or increasing the number of spectral bands, or improving the signal to noise ratio, or improving the spatial resolution by super resolution techniques or providing additional information for moving target detection and characterisation.

In any of the embodiments of the present disclosure, the bearings may take various forms such as ball bearings, or roller bearings, or plain bearings, or PTFE bearings, or magnetic bearings, or pivot bearings, or flexural pivots or any other convenient form. The bearings may be located in various positions and in various quantities, for example in pairs rather than single bearings. Bearings may couple to an internal shaft or be provided externally or surrounding the camera body or the countermass.

The actuator (24, 26) may take any convenient form. It may for example be an electric actuator or any other form of actuator. It may be an electric motor, a limited angle torque motor, a rotary solenoid, piezo actuator, etc.

The actuator may be configured to apply torque throughout the full angular range, or only at specific points or for example by pulses. The actuator may be configured to apply torque predominantly at the reversal points (where angular acceleration $\acute{\omega}$ or ωdot deviates from zero in Figure 7) and apply minimal or zero torque during the active imaging region of the profile (where $\acute{\omega}$ is zero in Figure 7). The actuator may be configured to completely disengage from the load during active imaging (where $\acute{\omega}$ is zero in Figure 7) and coast freely. The actuator may be configured to apply torque differently or in different locations when initiating motion than during steady state motion.

Note that the camera (16) and telescope (18) may be collectively referred to as the camera. The camera and telescope may take various forms. As an example, see Figures 10 to 12, which shows another airborne or spaceborne platform (1012) and exemplary scanner module (1010). The camera (1016, 1116) may have an external mirror (1019, 1119) to redirect the optical axis (1023, 1123) and full field of view of the camera towards the ground or imaged surface (1021). The camera (1016) may include a telescope and the camera may have a pivot axis (1020). A boresight of the camera (1016) may also be termed an optical axis (1023) of the camera, which may be redirected by the mirror (1019). The mirror (1019, 1119) may be fixed to the camera and telescope to rotate along with them. A camera (1016, 1116) with external mirror (1019, 1119) may reduce the inertia around an axis of rotation, albeit at expense of a larger camera unit, including the mirror.

As with other exemplary embodiments, a counterweight (1022) may be implemented. The counterweight may, e.g., be operative to pivot or rotate in an opposite direction to that of the camera (1016), as shown in Figures 10-11. The counterweight (1022) may be provided axially adjacent to the camera (e.g., Figure 11). Alternatively (or in addition), a counterweight (1122) may be provided radially adjacent to the camera (1116), e.g., coaxially therewith. As before, with the present examples of Figures 10-12, the arrangement may be such that if the camera body is operatively pivoted by the actuator, the counterweight (1022, 1122) may automatically react by pivoting in an opposite direction to the camera body so as to counteract a substantial portion of angular momentum of the camera body during its pivotal movement. Further features of the present embodiment may be similar to those of the other embodiments of the present disclosure. It will be appreciated that any one or more features of the present embodiments of Figures 10-12 may be used in conjunction with selected features from one or more of the other embodiments and vice versa.

Various other configurations may be envisaged where torque applied to the camera transfers the reactive torque to a countermass rather than the satellite body.

The airborne or spaceborne platform (12) may be a picosatellite, or a nanosatellite, or a cubesat or it may be a much larger platform such as a microsatellite, or a small satellite or a large satellite.

One or more scanner modules (10) may be mounted on one airborne or spaceborne platform (12).

The angular position, velocity and acceleration profiles in Figure 7 may take any desired shape.

In Figure 9 is shown an exemplary method (200) of scanning by a scanner module (10, 100) onboard an airborne or spaceborne platform (12, 112) that may be implemented by aspects of the present disclosure. The method may include providing (210) a camera body which houses a camera that is shaped to be pivotally coupled about a pivot axis to the airborne or spaceborne platform. The method may further include causing (212) an actuator to be powered by a power source onboard the airborne or spaceborne platform and applying torque to the camera body so as to pivot the camera body about the pivot axis. The method may yet further include providing (214) a counterweight which is pivotally coupled about the pivot axis to the camera body so as to be pivotable independently of the camera body in relation to the airborne or spaceborne platform. Optionally, a first portion of the actuator may be connected to the camera body and a second portion of the actuator may be connected to the counterweight. The method may still further include operatively pivoting (216) the camera body such that the counterweight (and, optionally the second portion of the actuator) automatically pivots in an opposite direction to the camera body so as to counteract a substantial portion of angular momentum of the camera body during the pivotal movement of the camera. Operatively pivoting the camera body may, e.g., be performed by the actuator. Alternatively, operatively pivoting the camera body may, e.g., be performed by the third torsional spring, with the actuator injecting energy to overcome losses and maintain resonance.

It will be appreciated that the present disclosure may improve coverage efficiency i.e. cost of imagery data per square kilometre of earth that is scanned. The present disclosure may also facilitate a wider swath width than would have been possible had a forward scanning optical field of view been used. In other words, the scanned region of the present disclosure may be much wider, due to the swath of the camera being generally aligned with the direction of flight of the airborne or spaceborne platform, and because the camera is pivoted across the direction of flight. Widening of the effective swath may provide advantages, and embodiments of the present disclosure may also provide a more compact scanner module which may provide a cost reduction especially in the context of space-based imaging.

It will further be appreciated that the entire camera body may be pivoted, including the telescope and image detector or camera located therein. This may be implemented at very high rotational speed relative to what has been possible with prior art devices or systems. The present disclosure may enable scanning at an angular velocity of about 90°/s, (e.g., as illustrated by Figure 7), or over 90°/s (e.g., about 180°/s), or at an angular velocity of over 45°/s, or over 60°/s, or over 70°/s. These angular velocities of scanning may enable scanning at faster speeds than known systems (about an order of magnitude faster, or ten times faster than known systems). Scanning may also be achieved in a near reactionless manner, so as to minimise disturbances to the host satellite platform. The counterweight, also termed a countermass may be passively rotated or pivoted in an opposite direction to the oscillating camera (e.g., out of phase with the camera oscillation). This may neutralise or substantially reduce reactive torque that may be transferred from the actuator to the host satellite platform.

The present disclosure may also enable a significantly wider area to be scanned than with pushbroom imaging. This is because the swath of the camera extends in line with the direction of flight and it sweeps across from left to right, thereby covering a large and wide area of ground or surface during a single orbit or flight path of the airborne or spaceborne platform. This may alleviate the drawbacks of known devices and systems, and it may enable more efficient scanning.

The present disclosure may provide a very compact scanning mechanism or scanner module that has minimal impact on the satellite platform. The scanner module may provide maximum dwell time on Earth's surface. An important consideration is packaging of the scanning mechanism and satellite platform according to the CubeSat standard. The compact nature and alignment of the camera body with the counterweight in its neutral orientation may facilitate packaging for launching it into orbit more efficiently. Weight may also be reduced by virtue of the scanner module having a single pivot axis. Efficiency in size and a reduction in component count may be achieved by attaching the camera and the counterweight (as well as the actuator, e.g., its rotor/stator) on a single pivot axis.

The single pivot axis may also facilitate wider scanning due to the cross-track movement of the swath of the camera. Additional dwell time (e.g., at off-nadir angles) may be desirable for example to improve object detection by multiple (at least two) scans of a region of interest on the ground or surface. The present disclosure may also enable scanning while the airborne or spaceborne platform continues in a substantially straight path, and roll of the host platform may not be needed. This may overcome drawbacks of known devices and systems. The present disclosure may enable a scanning action or scanning motion (42), and this scanning action may effectively achieve an imaging (linescanning) function.

The foregoing description has been presented for the purpose of illustration; it is not intended to be exhaustive or to limit the technology to the precise forms disclosed. Persons skilled in the relevant art can appreciate that many modifications and variations are possible in light of the above disclosure.

The language used in the specification has been principally selected for readability and instructional purposes, and it may not have been selected to delineate or circumscribe the inventive subject matter. It is therefore intended that the scope of the present disclosure be limited not by this detailed description, but rather by any claims that issue on an application based hereon. Accordingly, the present disclosure is intended to be illustrative, but not limiting, of the scope of any accompanying claims.

Finally, throughout the specification and any accompanying claims, unless the context requires otherwise, the word ‘comprise’ or variations such as ‘comprises’ or ‘comprising’ will be understood to imply the inclusion of a stated integer or group of integers but not the exclusion of any other integer or group of integers.

CLAIMS:

1. A scanner module for an airborne or spaceborne platform, the scanner module comprising:

a camera body which houses a camera and is shaped to be pivotally coupled about a pivot axis to the platform;

an actuator that is arranged to be powered by a power source onboard the platform and capable of applying torque to the camera body so as to pivot the camera body about the pivot axis; and

a counterweight which is pivotally coupled about the pivot axis to the camera body so as to be pivotable independently of the camera body in relation to the platform,

the arrangement being such that if the camera body is operatively pivoted, the counterweight automatically reacts by pivoting in an opposite direction to the camera body so as to counteract a substantial portion of angular momentum of the camera body during its pivotal movement.

2. The scanner module as claimed in claim 1, wherein the actuator includes a first portion that is connected to the camera body and a second portion that is connected to the counterweight.

3. The scanner module as claimed in claim 1 or claim 2, wherein the actuator is arranged to operatively pivot the camera body in relation to the counterweight.

4. The scanner module as claimed in claim 1, wherein the actuator is an electric motor.

5. The scanner module as claimed in claim 4, wherein a first portion of the actuator is a rotor of the electric motor, and wherein a second portion of the actuator is a stator of the electric motor.

6. The scanner module as claimed in any one of the preceding claims, wherein the camera body is arranged to have its field of view generally pointed in a nadir direction of the airborne or spaceborne platform while the camera body is in a neutral orientation during flight of the airborne or spaceborne platform.

7. The scanner module as claimed in claim 6, wherein the camera body is pivotable by the actuator from the neutral orientation to oppositely angled orientations relative to the nadir direction.

8. The scanner module as claimed in claim 7, wherein the camera body is pivotable from +45° to -45° relative to the nadir direction.

9. The scanner module as claimed in any one of the preceding claims, wherein the actuator is arranged to pivot the camera body by way of oscillation.

10. The scanner module as claimed in any one of the preceding claims, wherein the actuator is arranged to actively drive an oscillation of the camera body according to a desired speed profile.

11. The scanner module as claimed in any one of claims 1 to 9, wherein the actuator is arranged to drive the camera body as a resonant oscillator.

12. The scanner module as claimed in any one of the preceding claims, wherein the camera body is arranged to have its pivot axis generally aligned with a direction of flight of the airborne or spaceborne platform, and wherein the camera body is arranged to be pivoted so as to cause the camera to perform scanning across the direction of flight.

13. The scanner module as claimed in claim 12, wherein the camera body is arranged to trace a zig-zagged pattern on the ground or surface, the zig-zagged pattern extending transverse to the direction of flight.

14. The scanner module as claimed in claim 12 or claim 13, wherein the field of view of the camera defines a swath extent of the camera onto the ground or surface, the swath extent extending generally in line with the direction of flight of the airborne or spaceborne platform, and wherein pivotal movement of the camera body causes the swath extent of the camera to move across the direction of flight.

15. The scanner module as claimed in any one of the preceding claims, wherein the camera body is coupled to the airborne or spaceborne platform by way of a first bearing.

16. The scanner module as claimed in any one of the preceding claims, wherein the counterweight is coupled to the camera body by way of a second bearing.

17. The scanner module as claimed in any one of the preceding claims, wherein one or more of the first and second portions of the actuator are coupled to the airborne or spaceborne platform by way one or more bearings.

18. The scanner module as claimed in any one of the preceding claims, wherein the counterweight is connected to the airborne or spaceborne platform by way of a first biasing device.

19. The scanner module as claimed in any one of the preceding claims, wherein the camera body is connected to the airborne or spaceborne platform by way of a second biasing device.

20. The scanner module as claimed in claim 19, wherein the second biasing device is arranged to urge the camera body to point toward a nadir direction of the airborne or spaceborne platform during flight thereof, and wherein the actuator is arranged to pivot the camera body against the bias of the second biasing device when moving it away from the nadir direction.

21. The scanner module as claimed in any one of the preceding claims, wherein the camera body is connected to the counterweight by way of a third biasing device.

22. A method of scanning by a scanner module onboard an airborne or spaceborne platform, the method comprising:

providing a camera body which houses a camera and is shaped to be pivotally coupled about a pivot axis to the platform;

causing an actuator to be powered by a power source onboard the platform and applying torque to the camera body so as to pivot the camera body about the pivot axis;

providing a counterweight which is pivotally coupled about the pivot axis to the camera body so as to be pivotable independently of the camera body in relation to the platform; and

operatively pivoting the camera body such that the counterweight automatically pivots in an opposite direction to the camera body so as to counteract a substantial portion of angular momentum of the camera body during its pivotal movement.

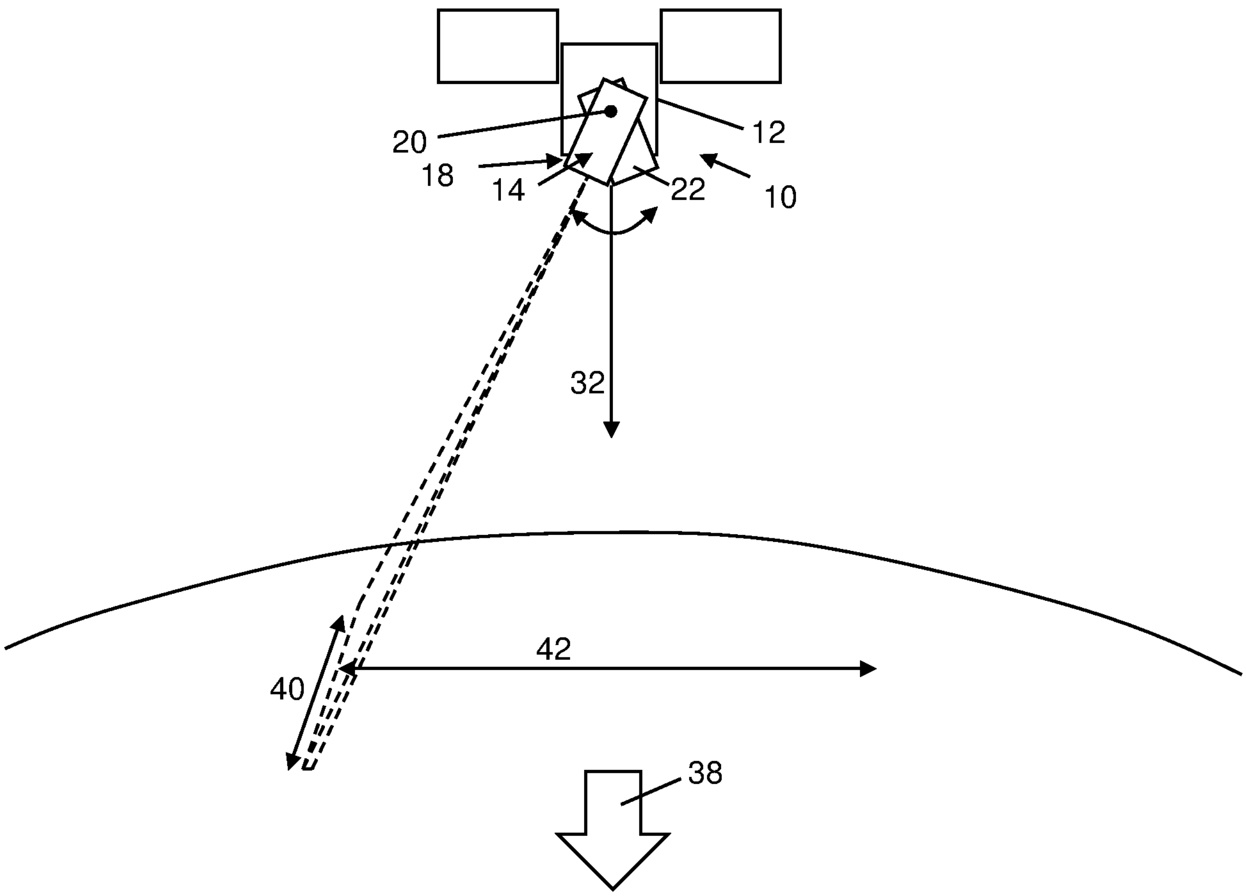


FIGURE 1

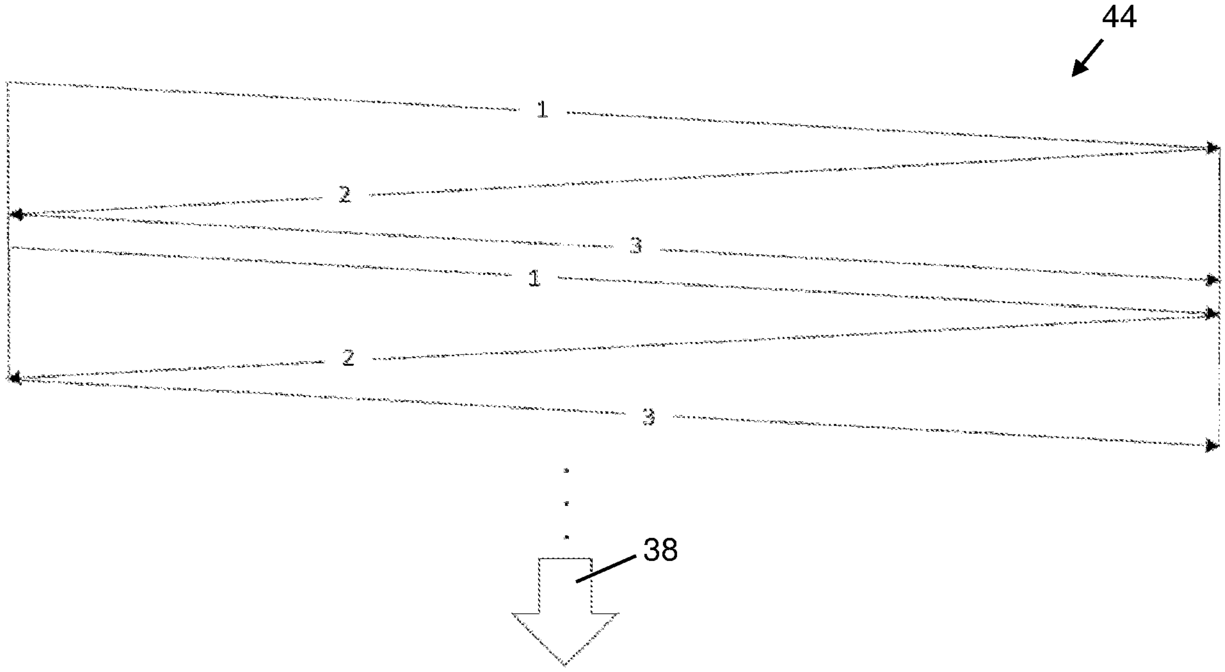


FIGURE 2

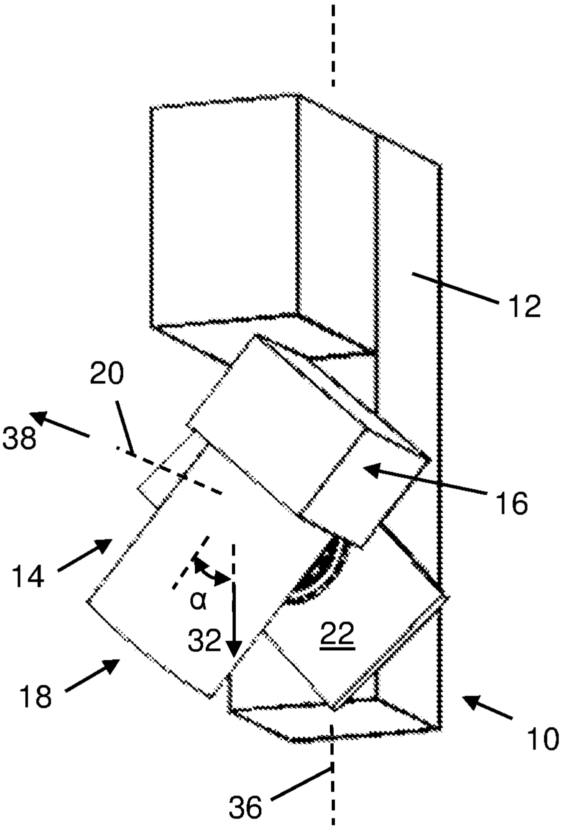


FIGURE 3

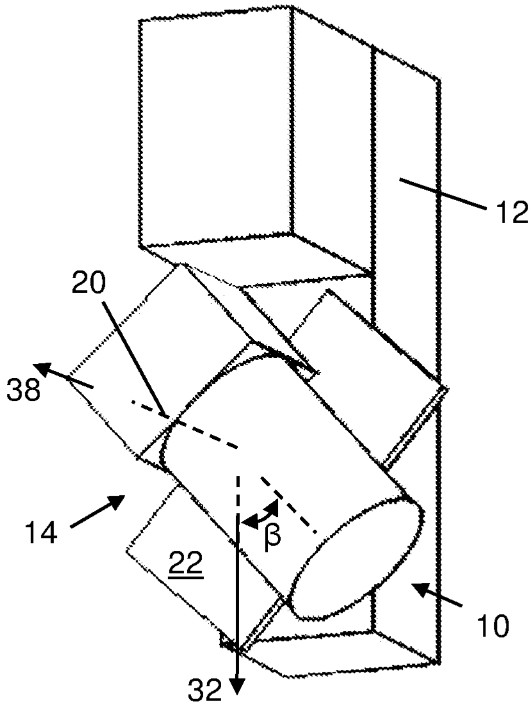


FIGURE 4

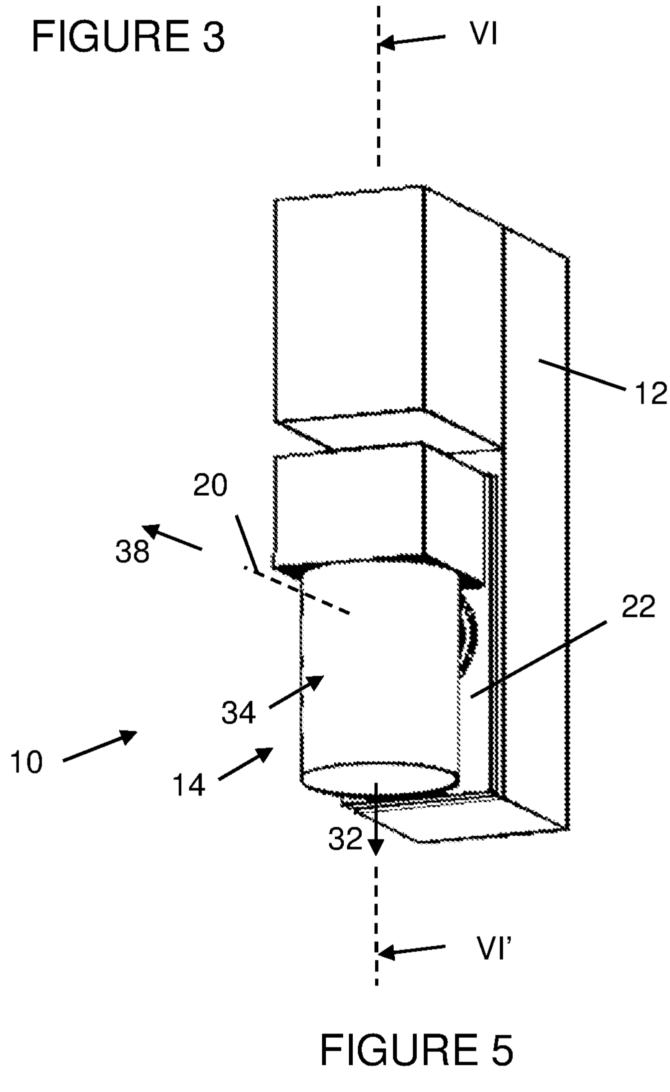
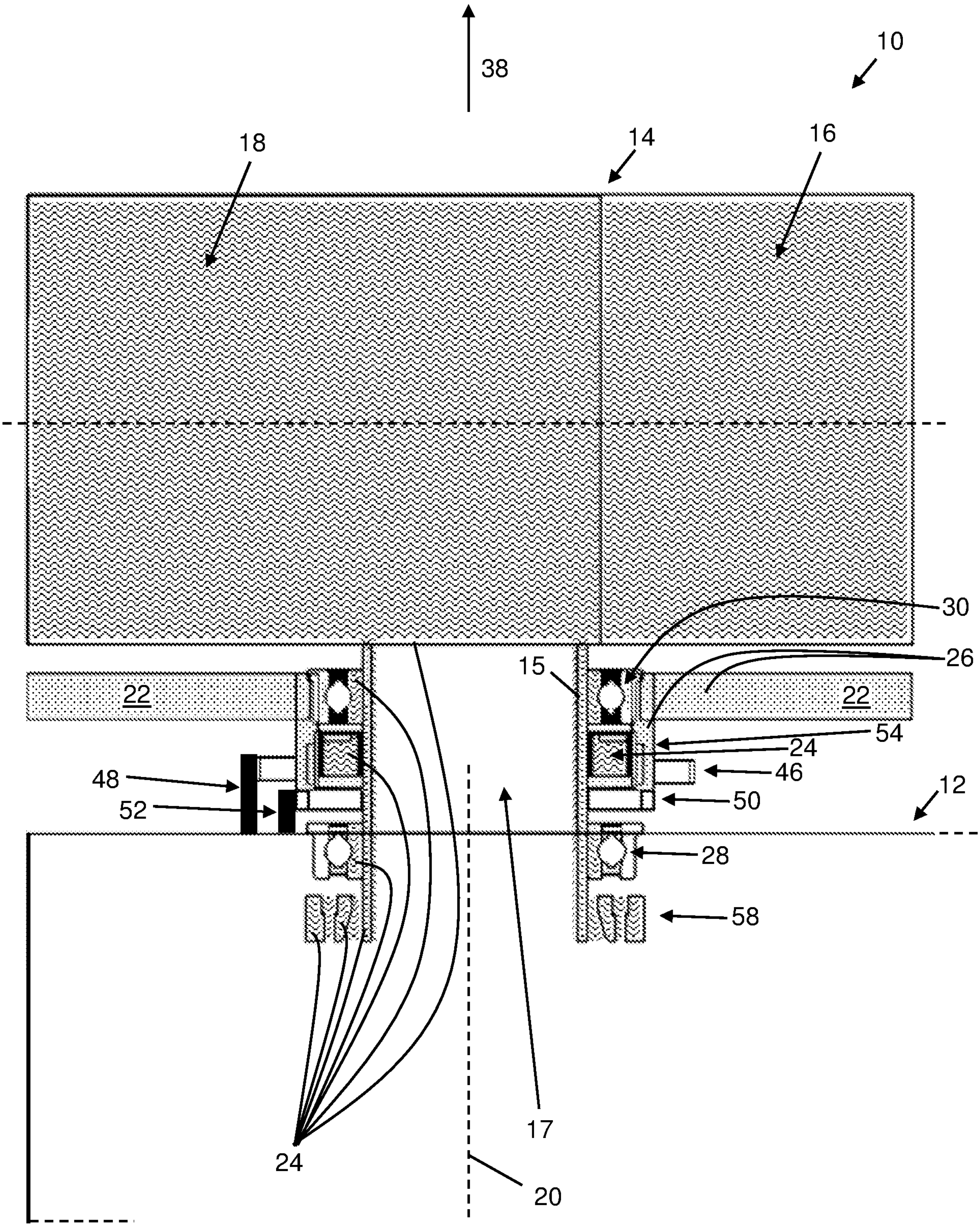


FIGURE 5



VI - VI'

FIGURE 6

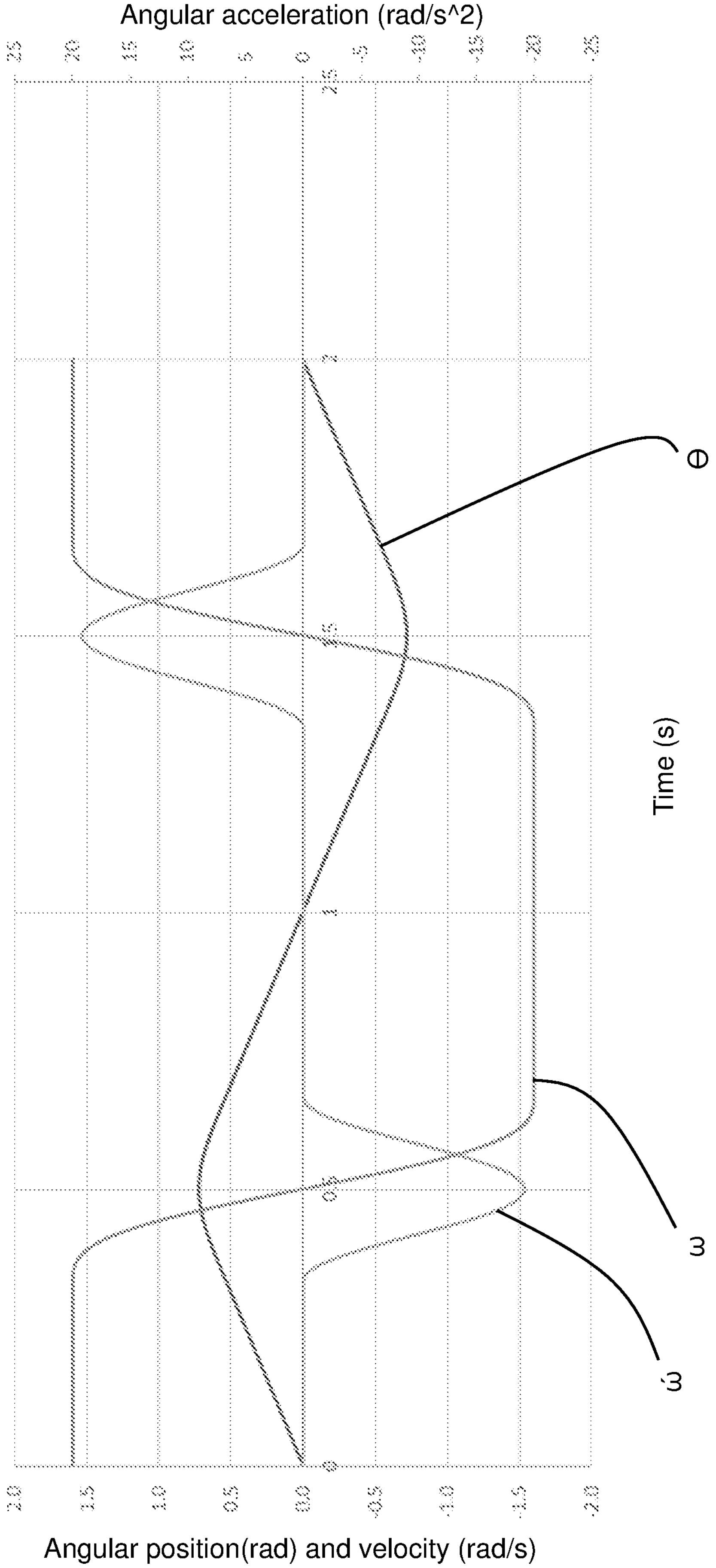

Angular acceleration (rad/s^2)
Angular position(rad) and velocity (rad/s)
Time (s)
θ
ω
ώ

FIGURE 7

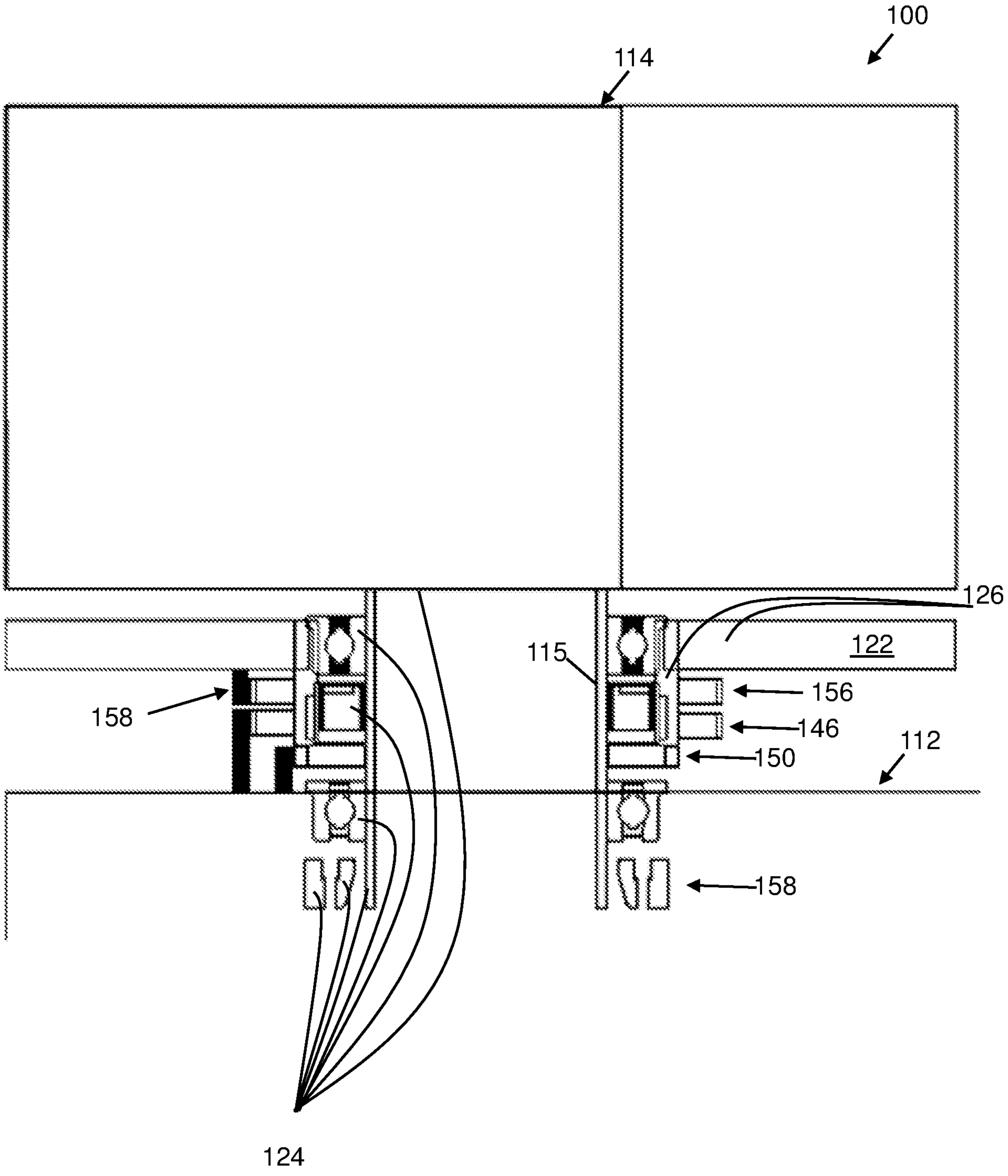


FIGURE 8

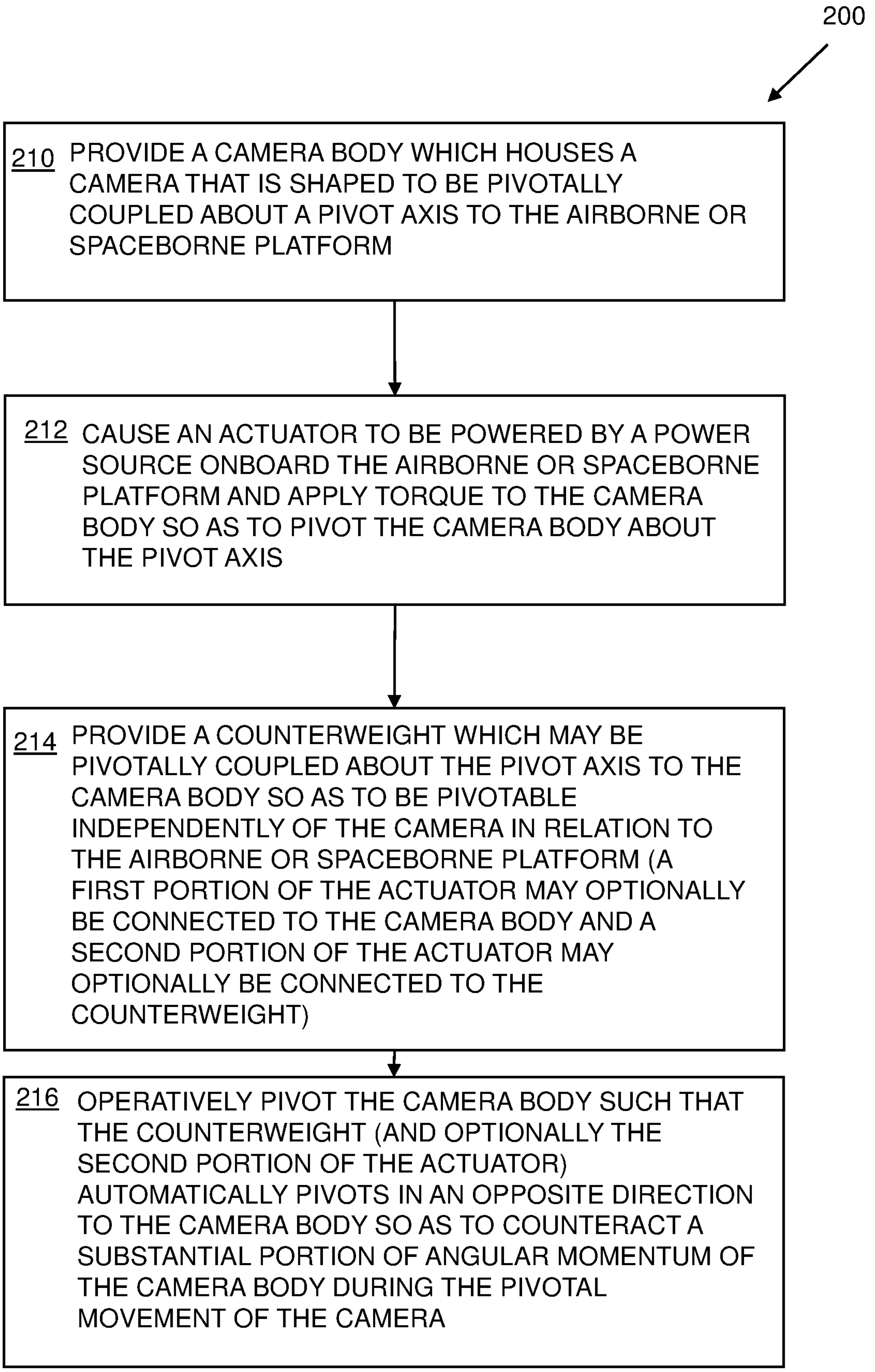

200
210 PROVIDE A CAMERA BODY WHICH HOUSES A CAMERA THAT IS SHAPED TO BE PIVOTALLY COUPLED ABOUT A PIVOT AXIS TO THE AIRBORNE OR SPACEBORNE PLATFORM
212 CAUSE AN ACTUATOR TO BE POWERED BY A POWER SOURCE ONBOARD THE AIRBORNE OR SPACEBORNE PLATFORM AND APPLY TORQUE TO THE CAMERA BODY SO AS TO PIVOT THE CAMERA BODY ABOUT THE PIVOT AXIS
214 PROVIDE A COUNTERWEIGHT WHICH MAY BE PIVOTALLY COUPLED ABOUT THE PIVOT AXIS TO THE CAMERA BODY SO AS TO BE PIVOTABLE INDEPENDENTLY OF THE CAMERA IN RELATION TO THE AIRBORNE OR SPACEBORNE PLATFORM (A FIRST PORTION OF THE ACTUATOR MAY OPTIONALLY BE CONNECTED TO THE CAMERA BODY AND A SECOND PORTION OF THE ACTUATOR MAY OPTIONALLY BE CONNECTED TO THE COUNTERWEIGHT)
216 OPERATIVELY PIVOT THE CAMERA BODY SUCH THAT THE COUNTERWEIGHT (AND OPTIONALLY THE SECOND PORTION OF THE ACTUATOR) AUTOMATICALLY PIVOTS IN AN OPPOSITE DIRECTION TO THE CAMERA BODY SO AS TO COUNTERACT A SUBSTANTIAL PORTION OF ANGULAR MOMENTUM OF THE CAMERA BODY DURING THE PIVOTAL MOVEMENT OF THE CAMERA

FIGURE 9

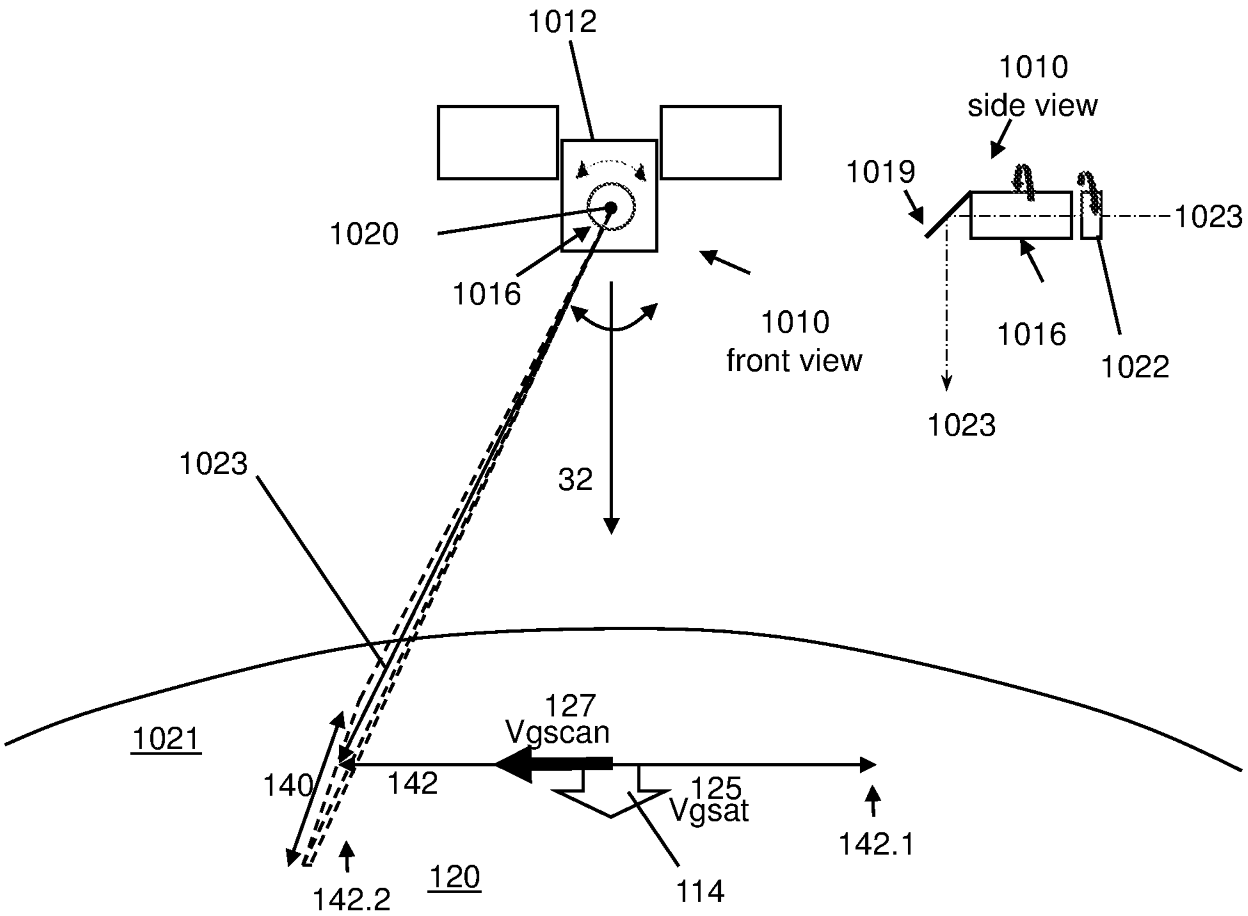

1012
1010
side view
1019
1023
1020
1016
1010
front view
1016
1022
1023
1023
32
127
Vgscan
1021
140
142
125
Vgsat
142.1
142.2
120
114

FIGURE 10

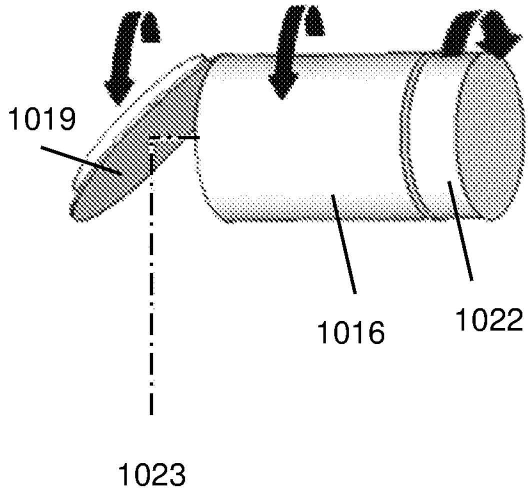


FIGURE 11

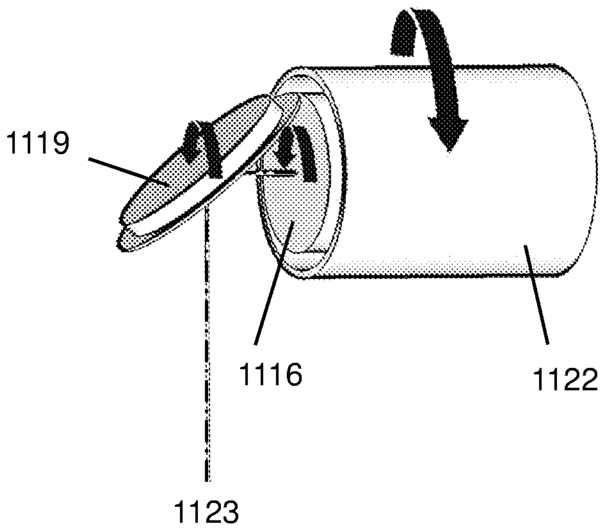


FIGURE 12

INTERNATIONAL SEARCH REPORT

International application No.
PCT/ZA 2024/050035

A. CLASSIFICATION OF SUBJECT MATTER
IPC: ***B64D 47/08*** (2006.01); ***B64U 20/87*** (2023.01); ***B64U 101/32*** (2023.01)

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)
B64D, B64U

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPODOC, WPIAP, TXPEnn, TXPGnn, TXPFnn

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2019084698 A1 (LEATHAM JAMES) 21 March 2019 (21.03.2019) paragraphs [0047], [0049] - [0052], [0061] - [0066]; figures 4 and 11	1
A	JP 2021020672 A (UNIV SHINSHU) 18 February 2021 (18.02.2021) paragraphs [0067], [0076]; figures 15 and 16	1
A	JP 2019127245 A (TECHNOS MIHARA CO LTD) 01 August 2019 (01.08.2019) paragraphs [0019] - [0024]; figures 1 and 2	1
A	US 2014263834 A1 (GOODMAN RONALD C) 18 September 2014 (18.09.2014) paragraphs [0027], [0028]; figure 2	1

Further documents are listed in the continuation of Box C. [X] See patent family annex.

* 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

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"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	Date of mailing of the international search report
22 November 2024 (22.11.2024)	27 November 2024 (27.11.2024)

Name and mailing address of the ISA/AT	Authorized officer
Austrian Patent Office Dresdner Straße 87, A-1200 Vienna Telephone No. +43 (1) 53424 342	Bukovnik Monika Telephone No. +43 1 534 24 548

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