



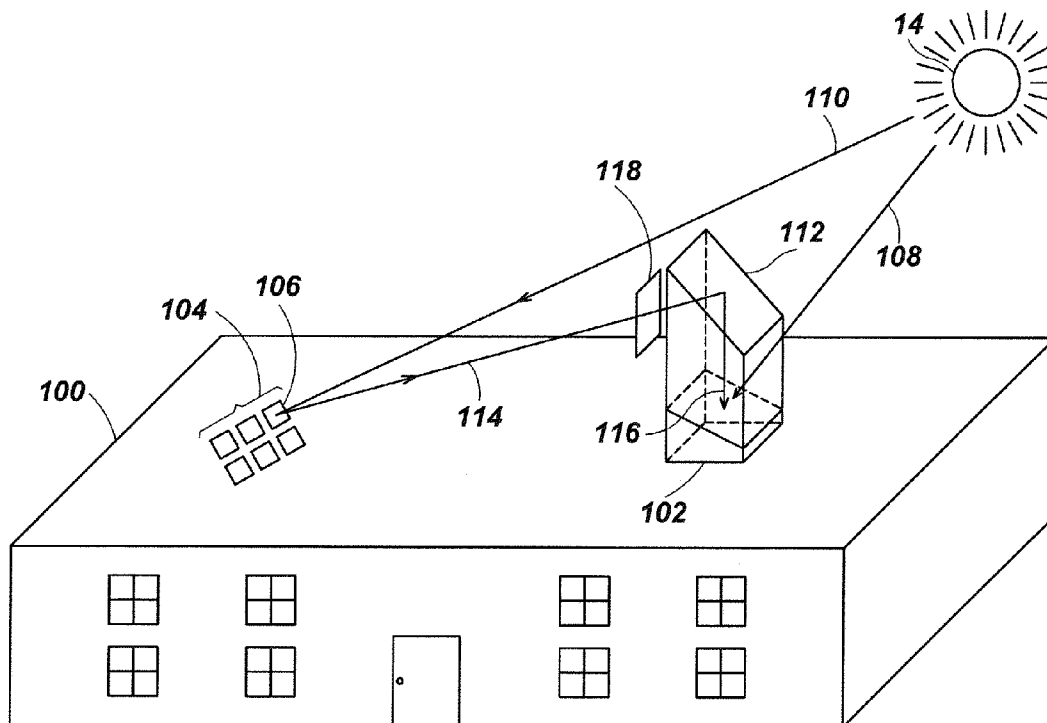
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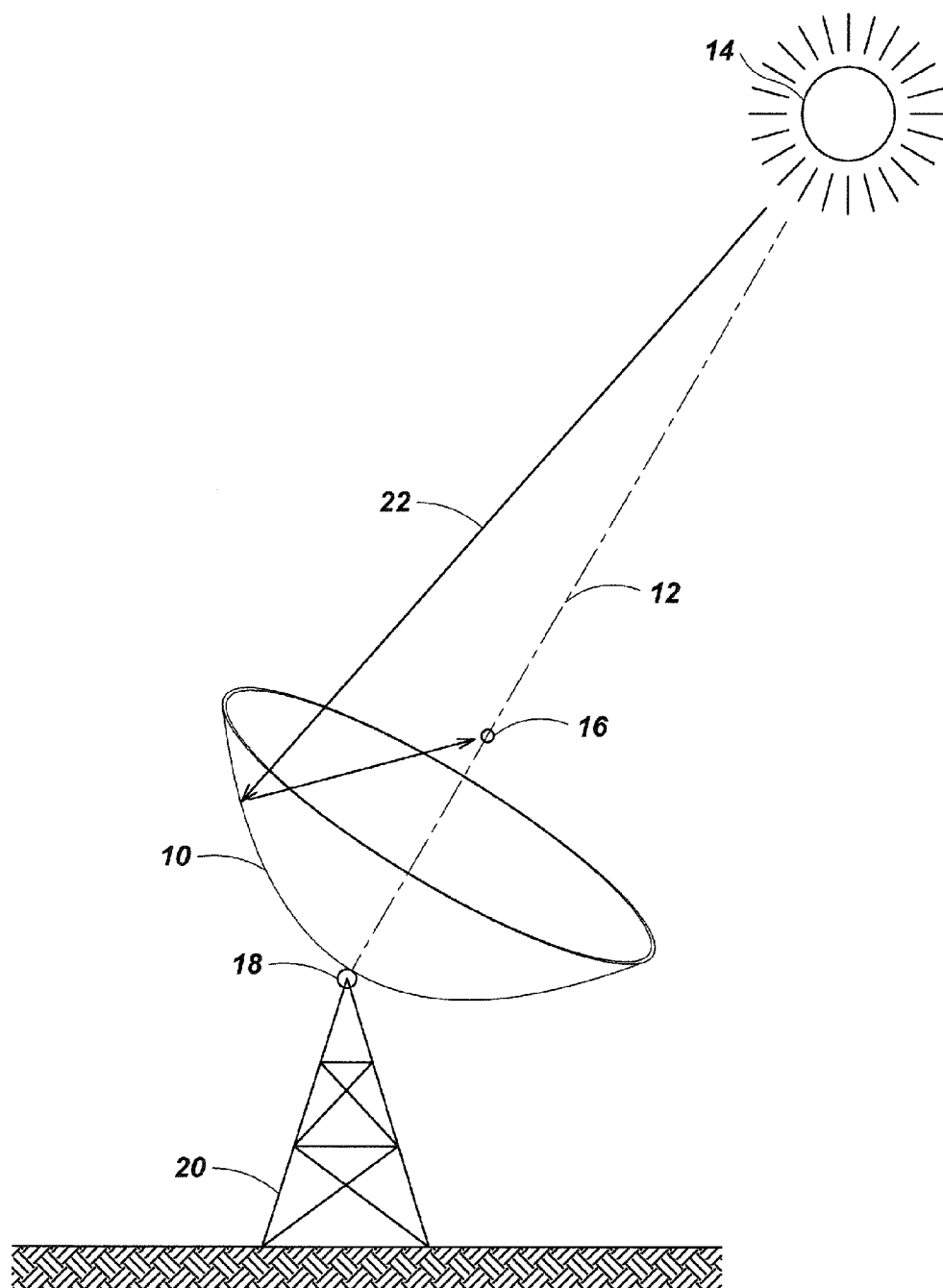
(19) **United States**(12) **Patent Application Publication**
Olsson(10) **Pub. No.: US 2011/0030672 A1**(43) **Pub. Date: Feb. 10, 2011**(54) **SOLAR COLLECTION APPARATUS AND
METHODS USING ACCELEROMETERS AND
MAGNETICS SENSORS**(76) Inventor: **Mark S. Olsson**, La Lolla, CA (US)

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CORONADO, CA 92118 (US)(21) Appl. No.: **12/901,289**(22) Filed: **Oct. 8, 2010****Related U.S. Application Data**(63) Continuation-in-part of application No. 11/763,267,
filed on Jun. 14, 2007, now abandoned.(60) Provisional application No. 60/807,456, filed on Jul.
14, 2006.**Publication Classification**(51) **Int. Cl.****F24J 2/40** (2006.01)**F24J 2/38** (2006.01)(52) **U.S. Cl. 126/574; 126/605; 126/601**(57) **ABSTRACT**

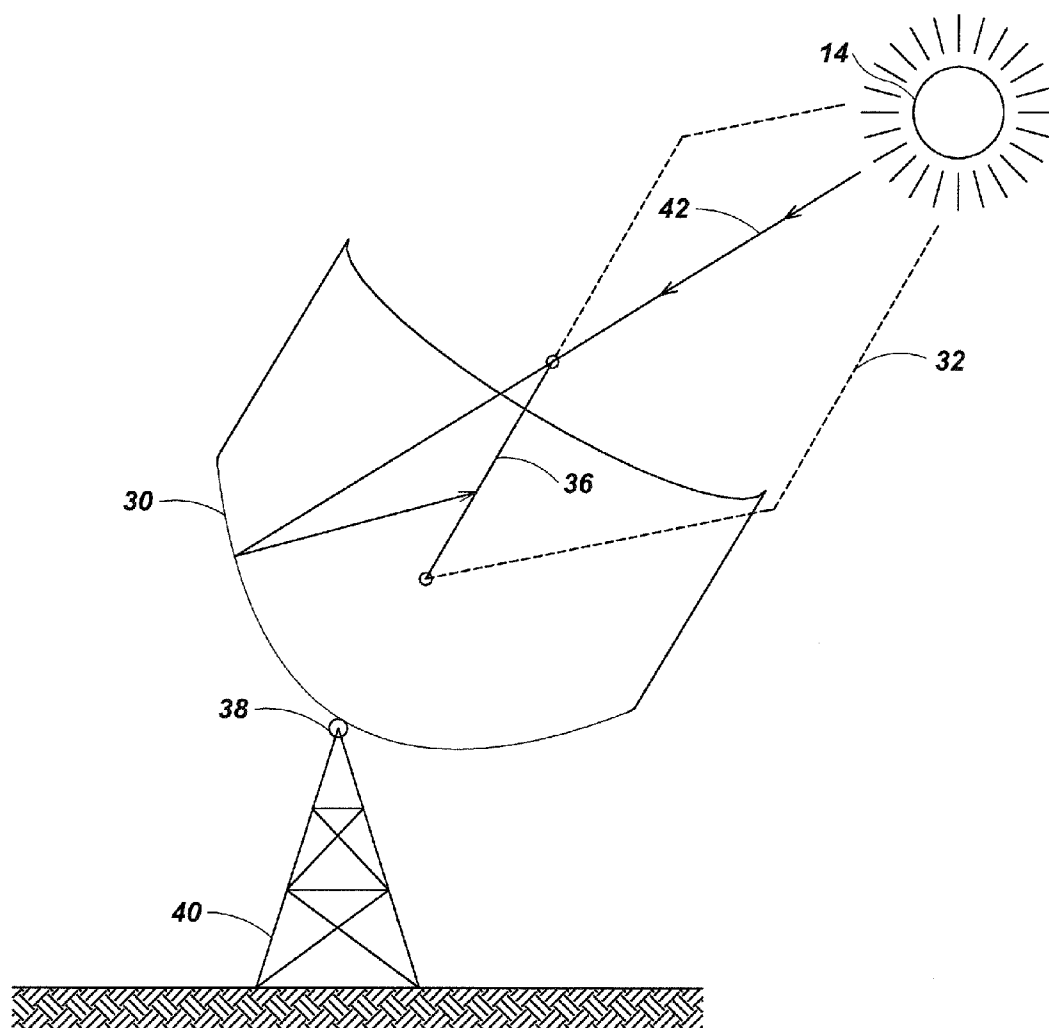
A mirror or other reflecting surface is used for collecting and reflecting incident solar radiation. The mirror is supported for independent motion about a pair of axes. An accelerometer generates signals representative of an amount and direction of motion of the mirror about each of the axes. Motors or other drive mechanisms independently drive the mirror about each of the axes. A tracking device provides information about the current position of the Sun. A control is connected to the accelerometer, the motors and the tracking device for maintaining a predetermined optimum orientation of the mirror as the Sun moves across the sky. Position sensors that sense the position of the mirror relative to the earth's magnetic field may also be employed.





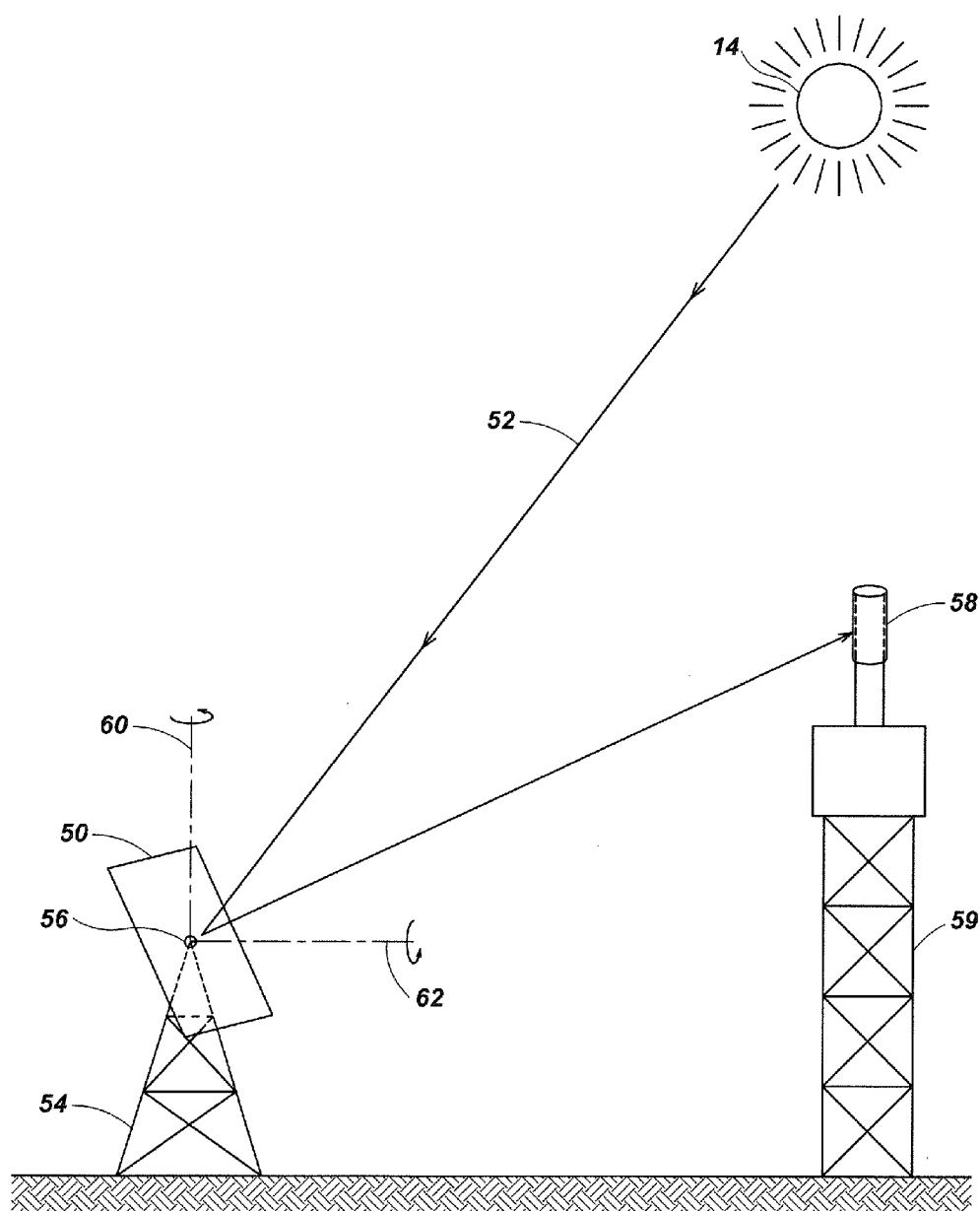
(Prior Art)

FIG. 1



(Prior Art)

FIG. 2



(Prior Art)

FIG. 3

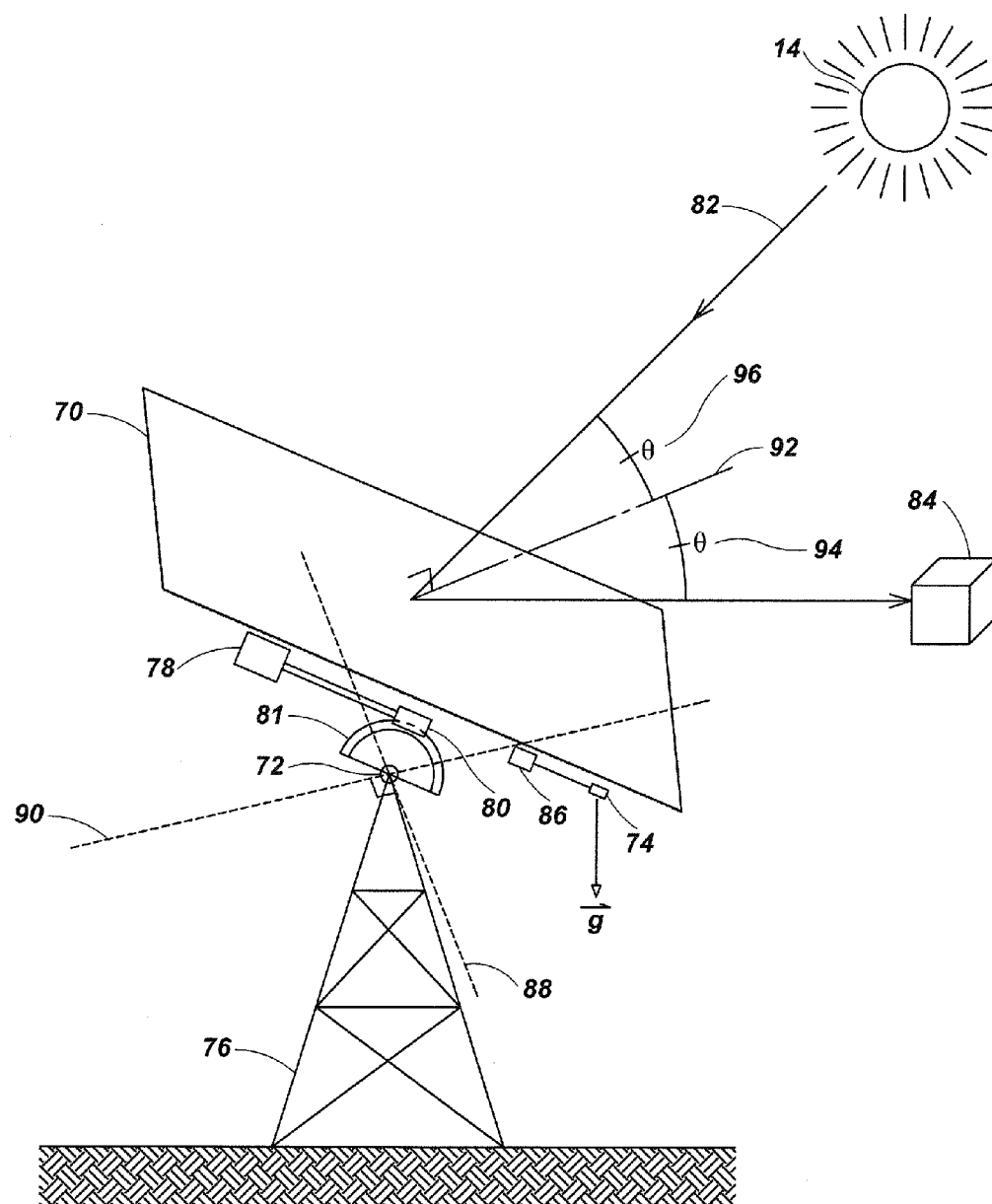


FIG. 4

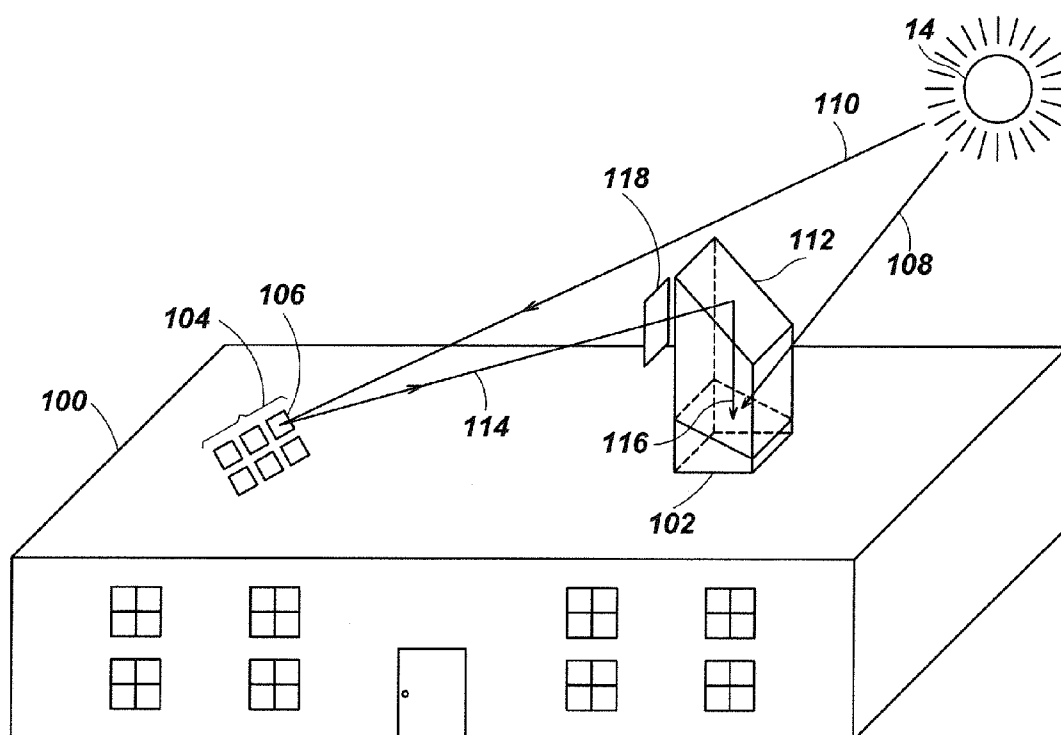


FIG. 5

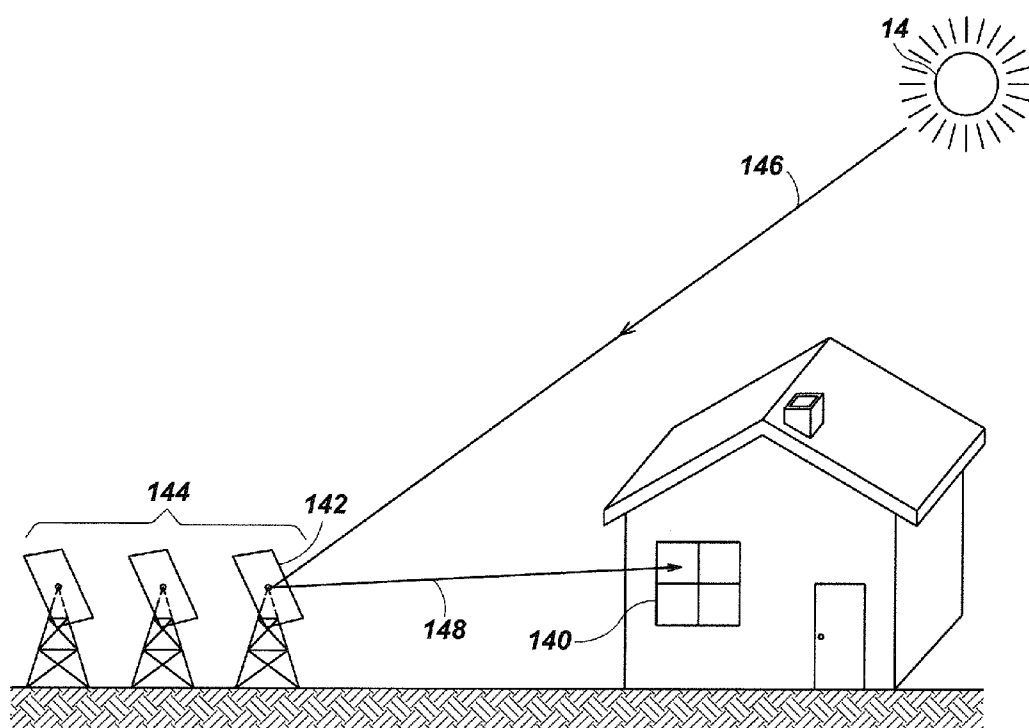


FIG. 6

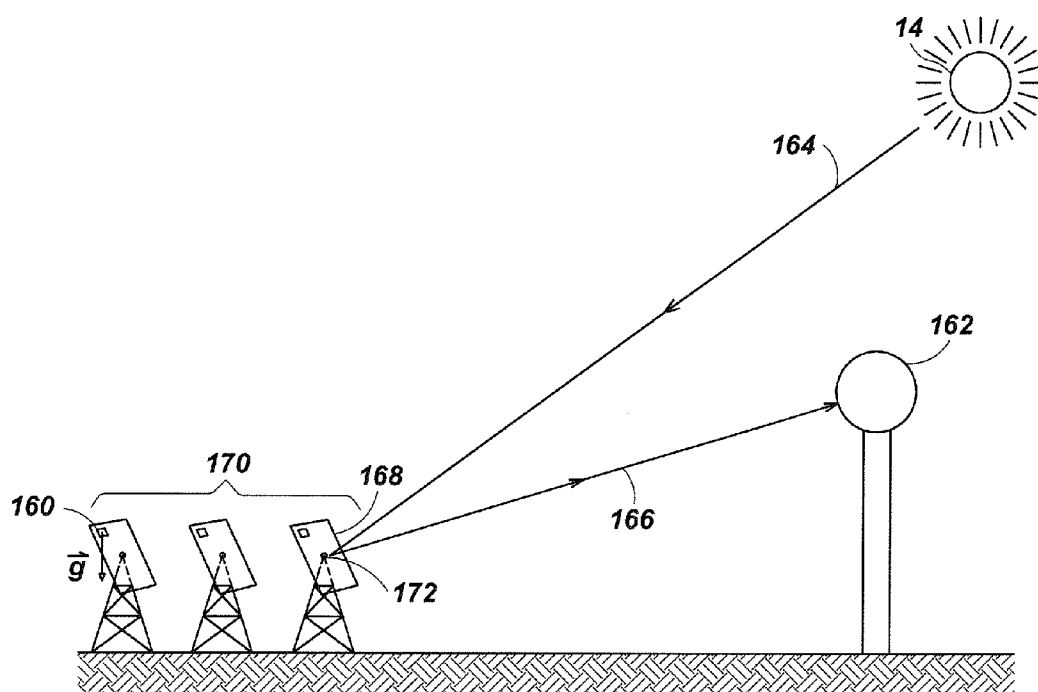


FIG. 7

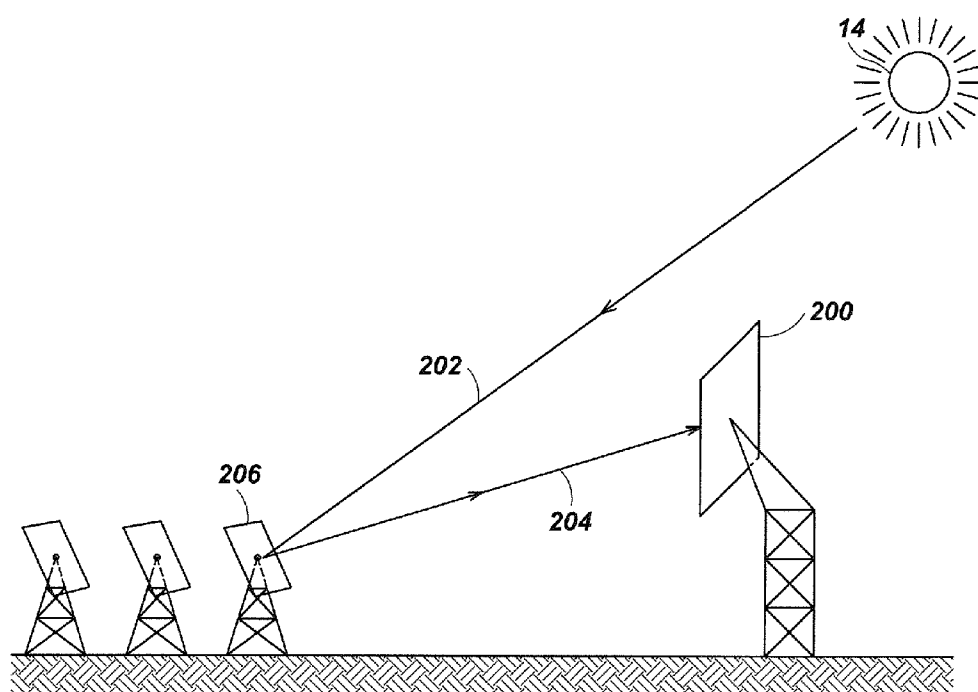
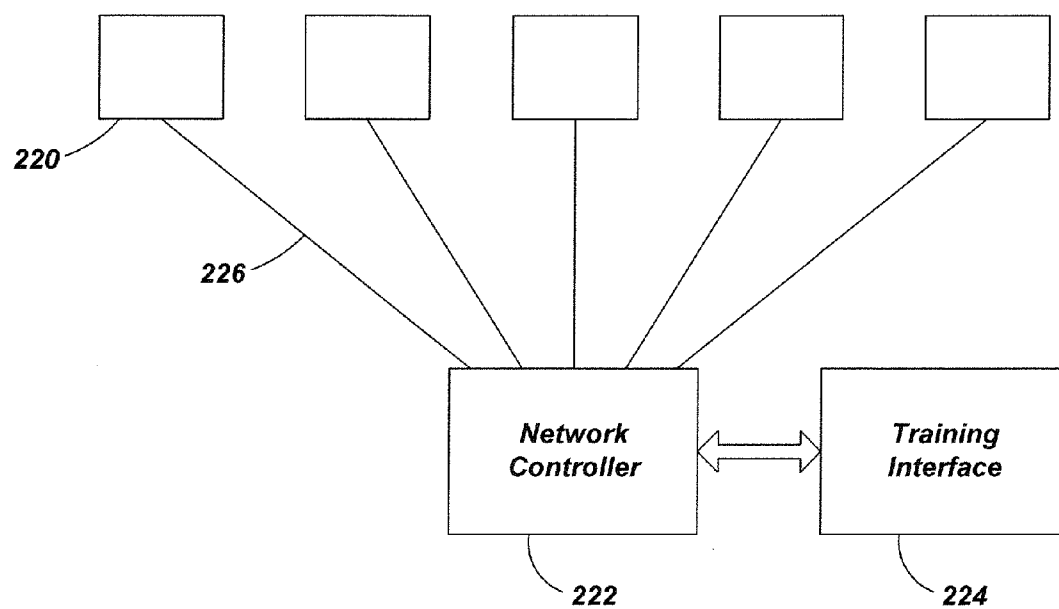


FIG. 8

**FIG. 9**

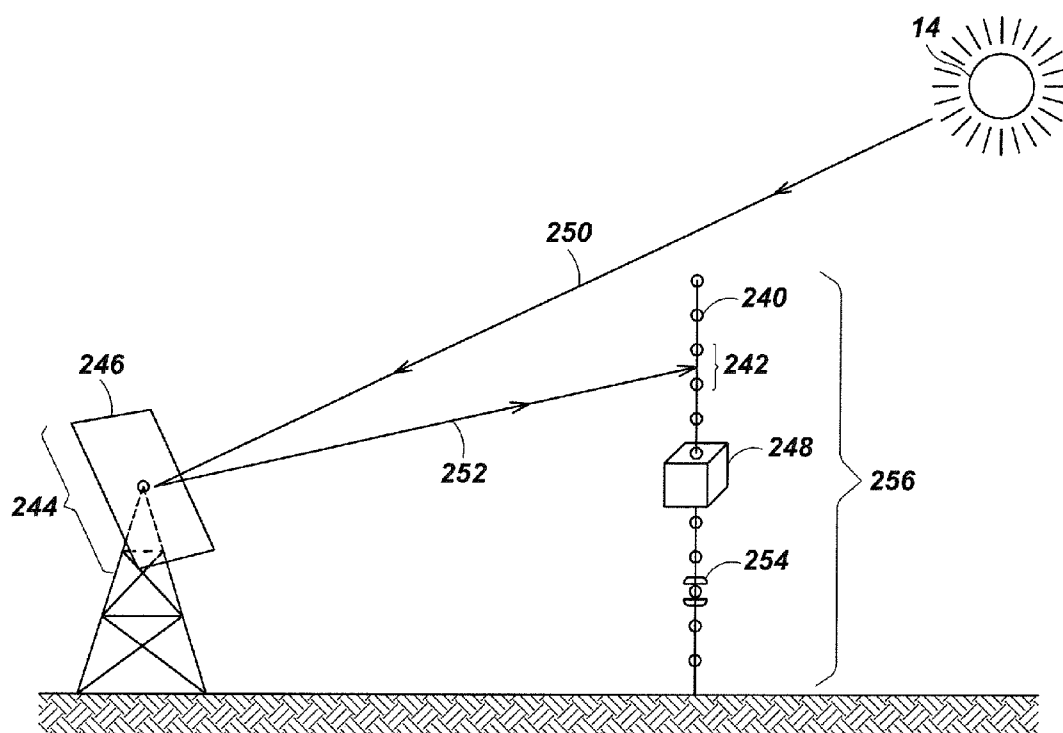


FIG. 10

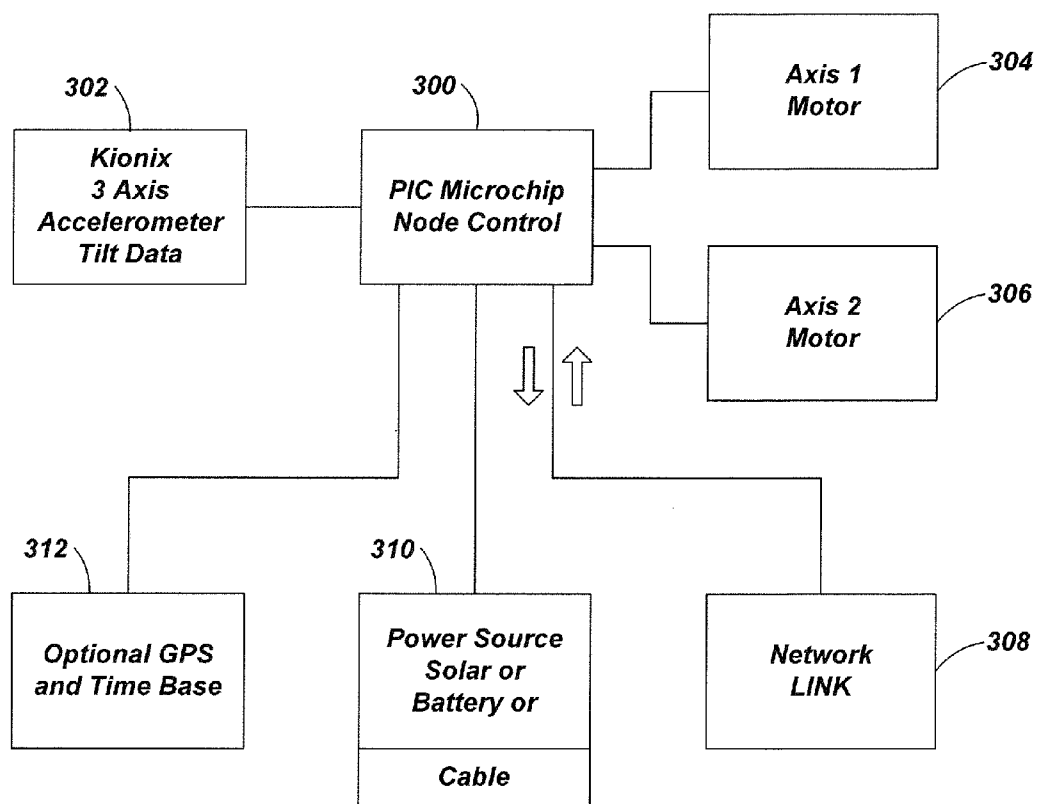


FIG. 11

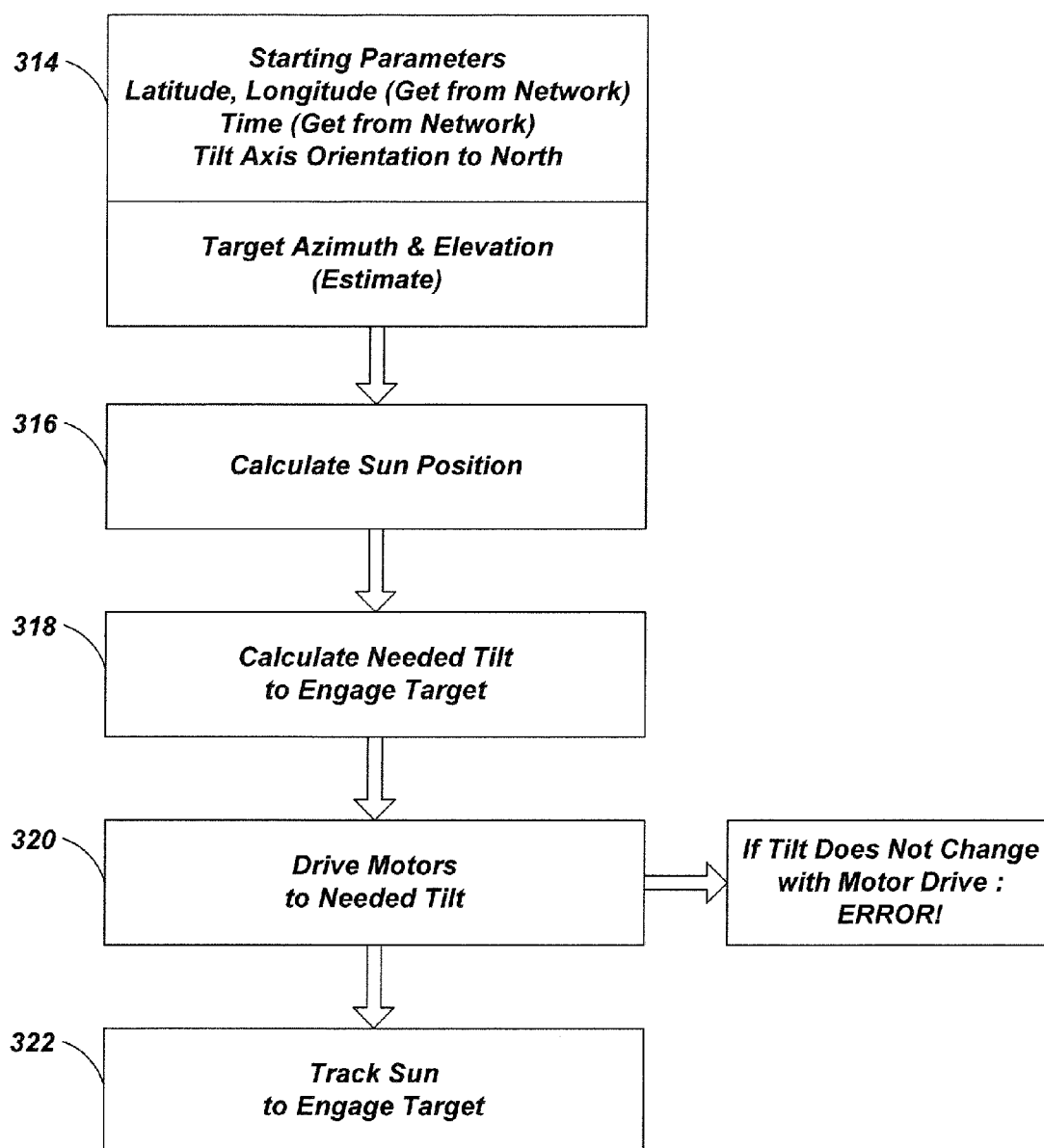
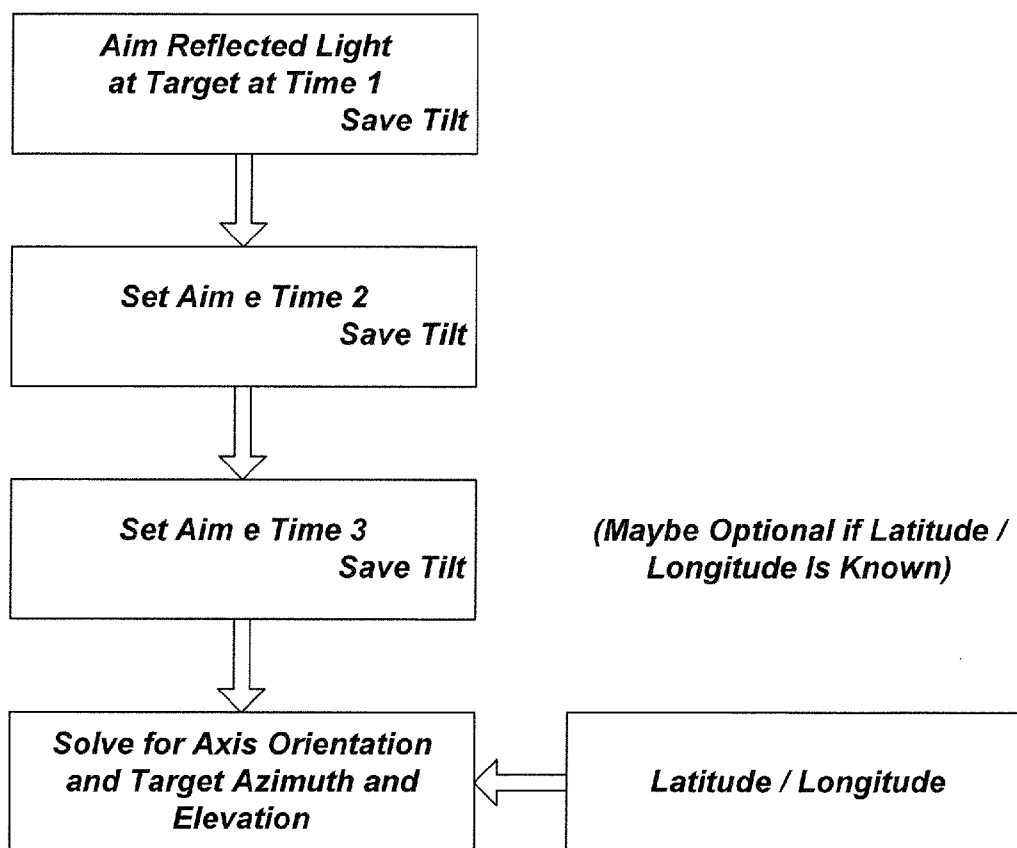


FIG. 12

**FIG. 13**

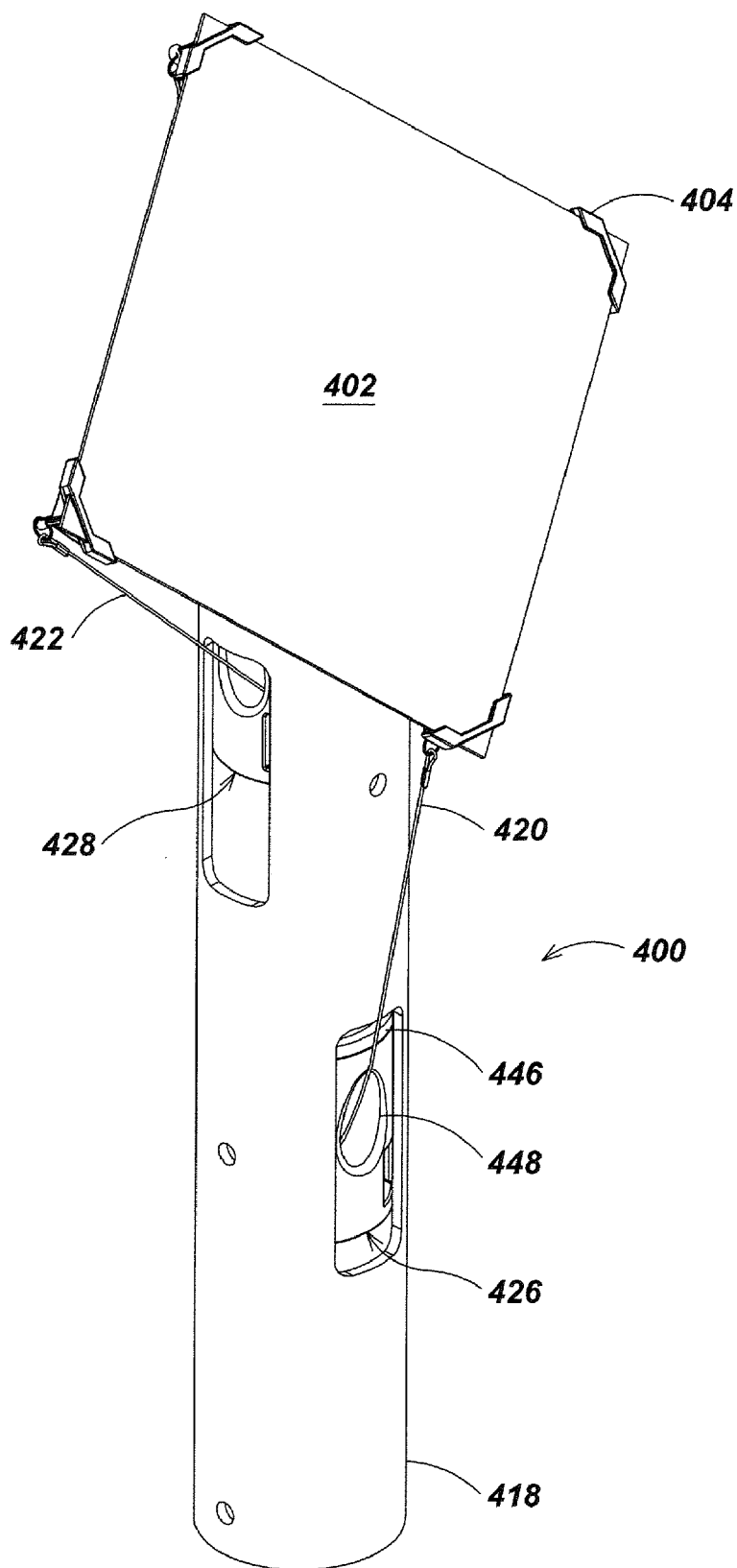


FIG. 14

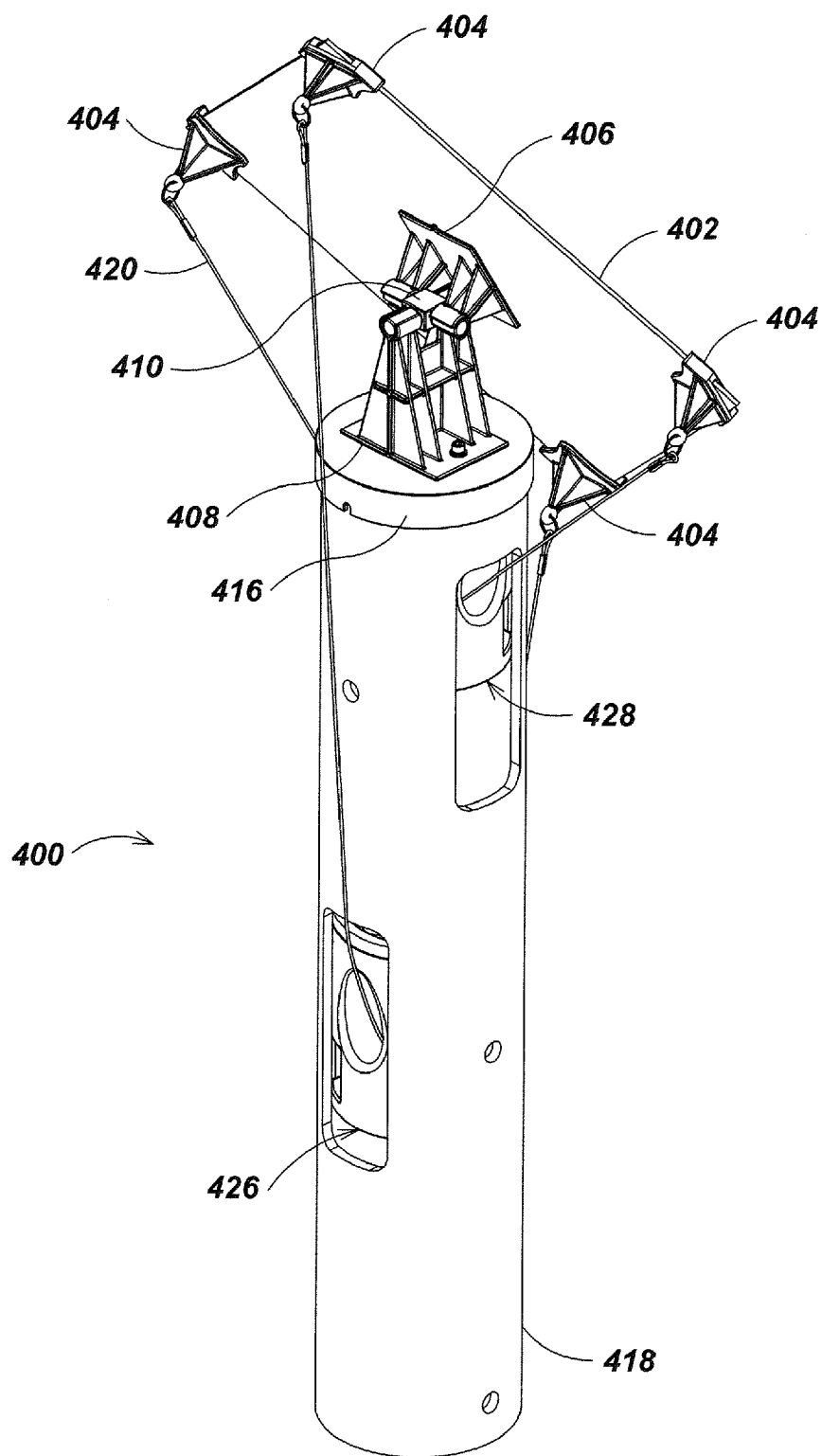


FIG. 15

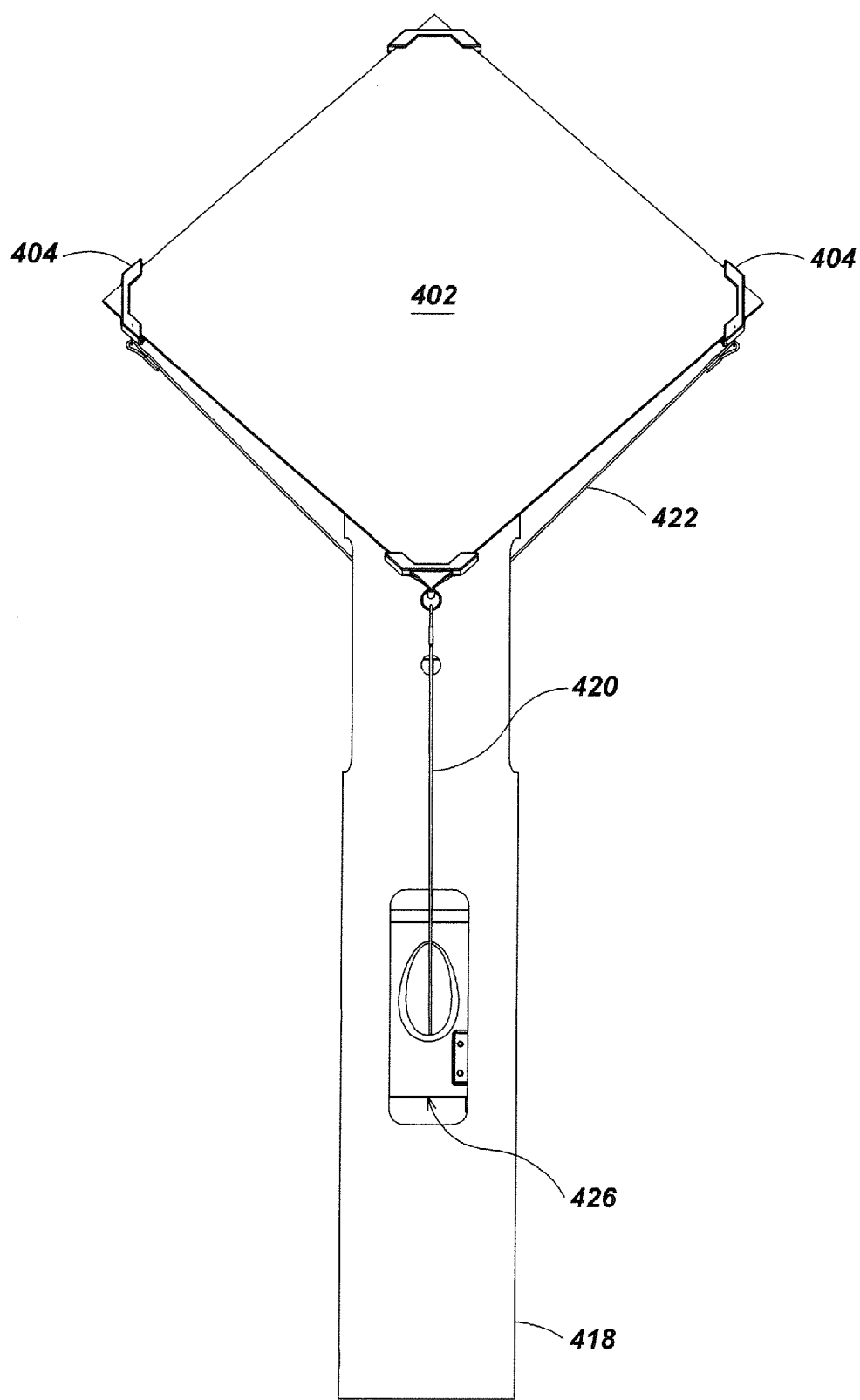


FIG. 16

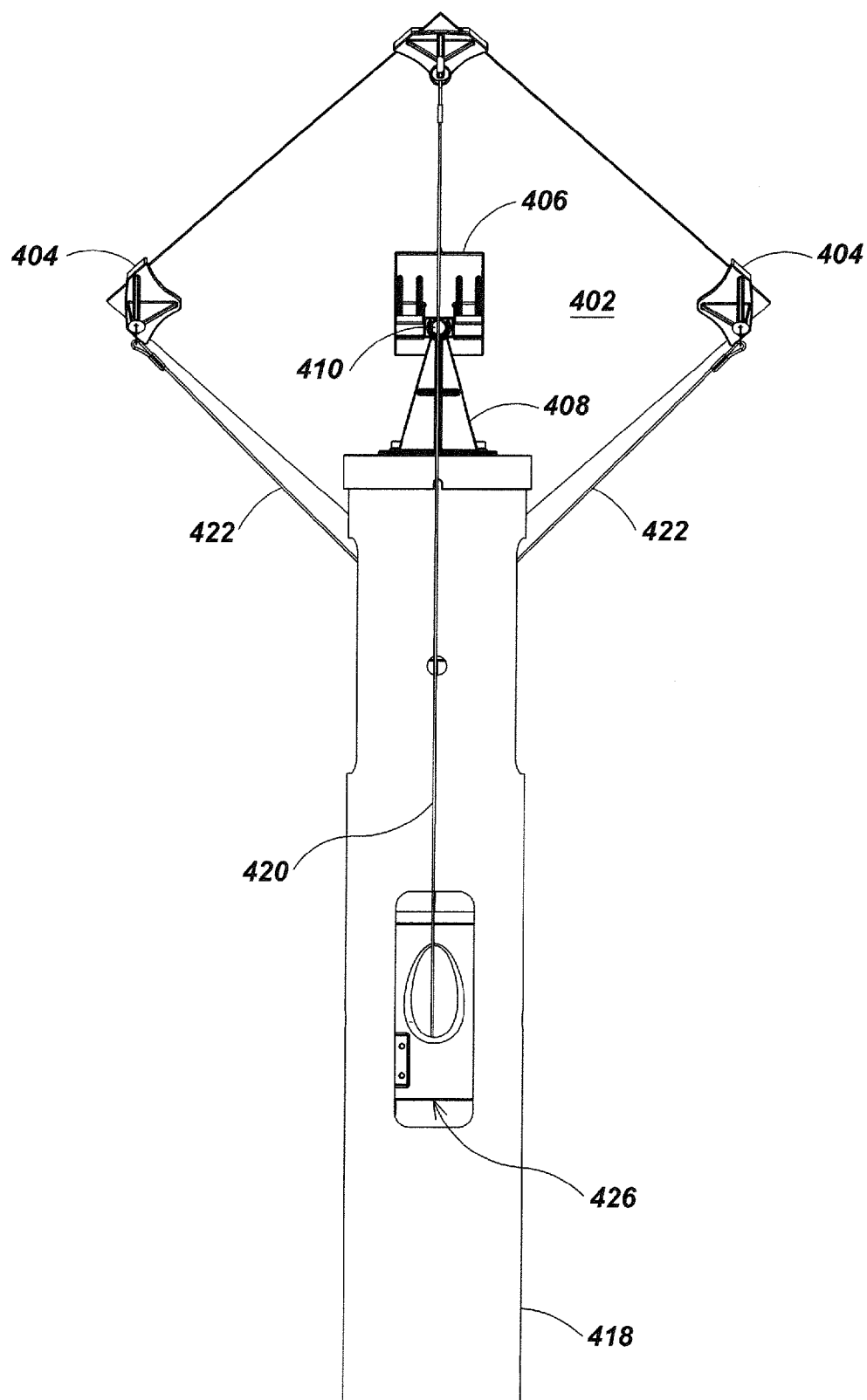


FIG. 17

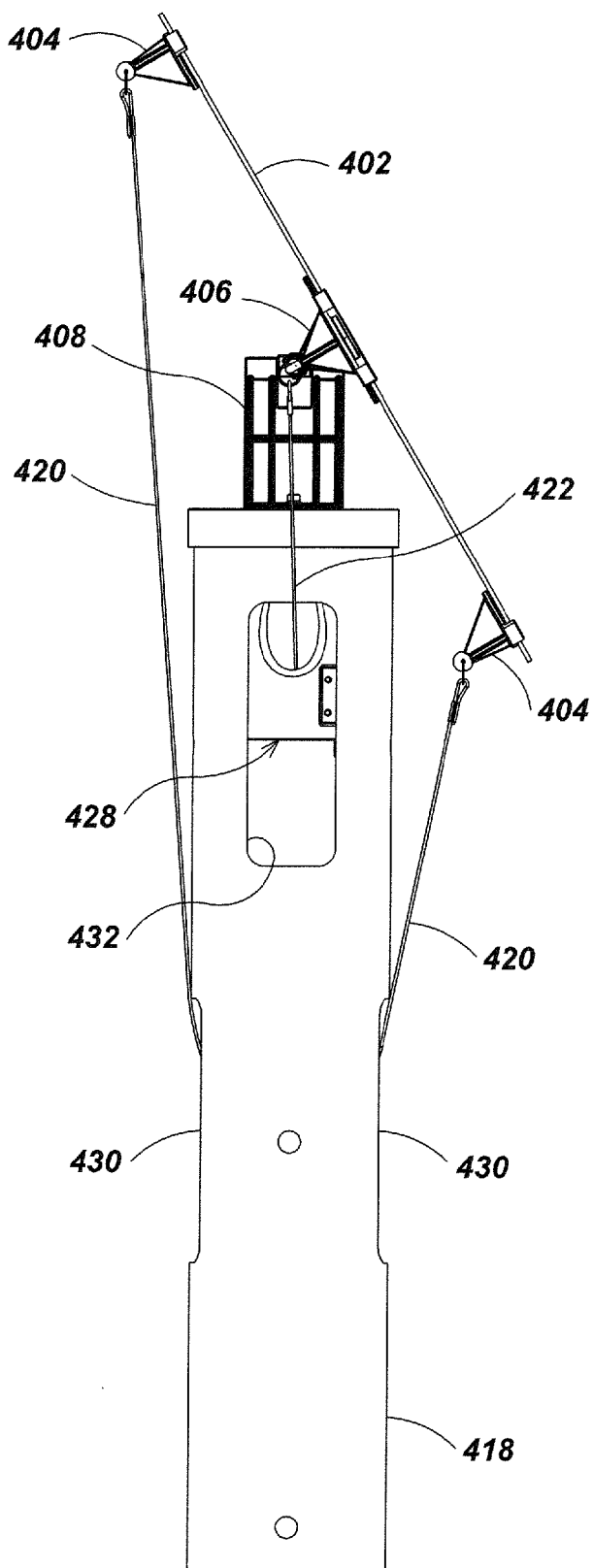


FIG. 18

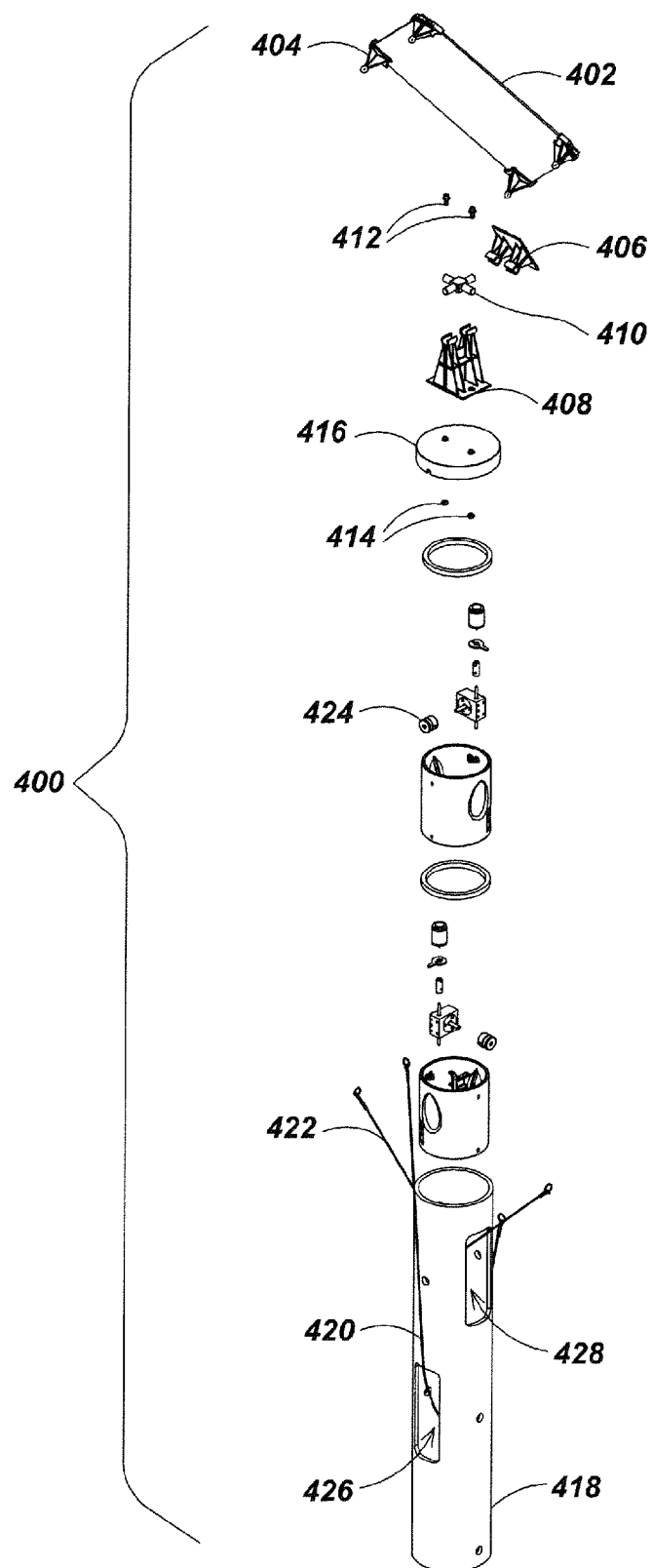


FIG. 19

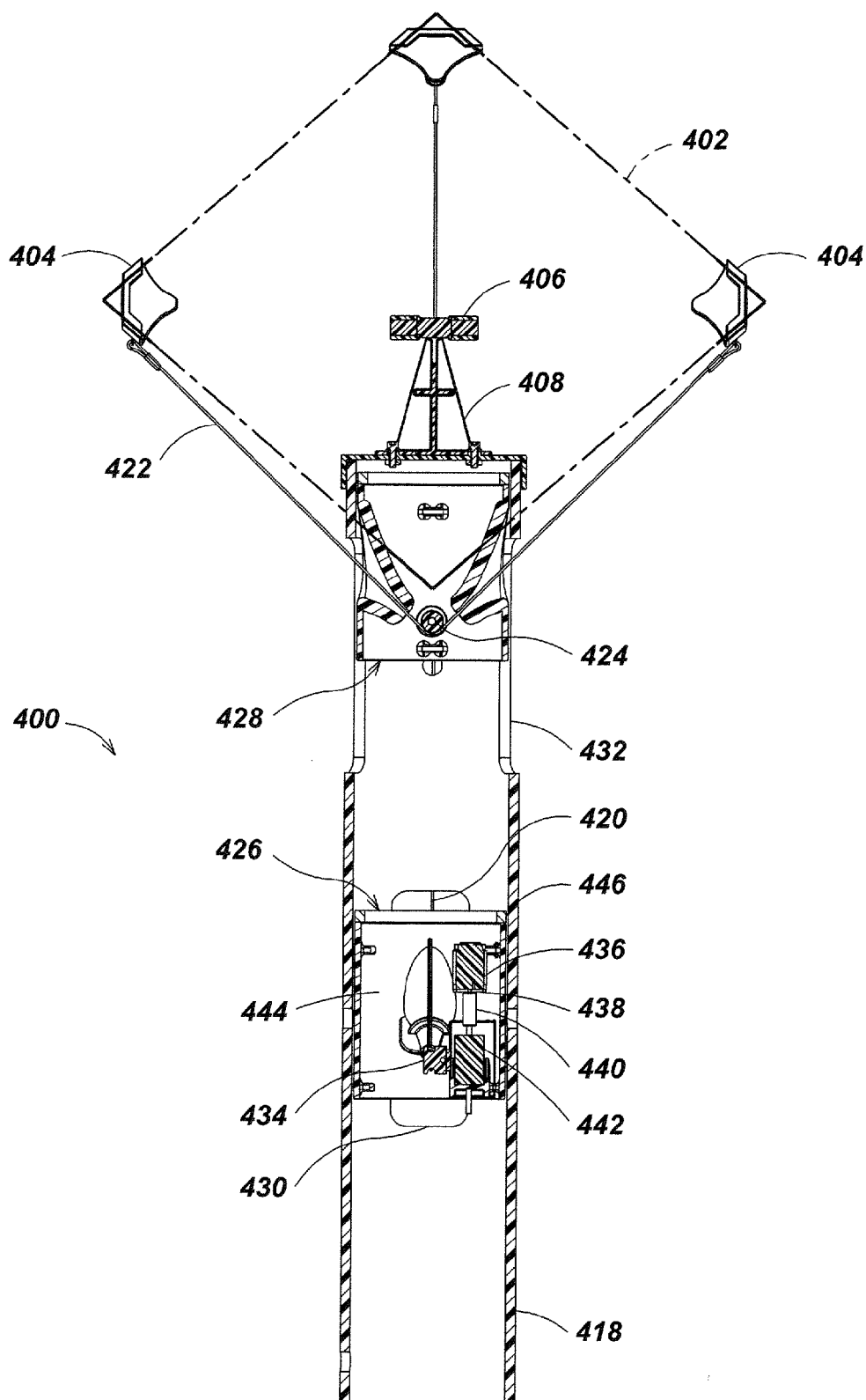


FIG. 20

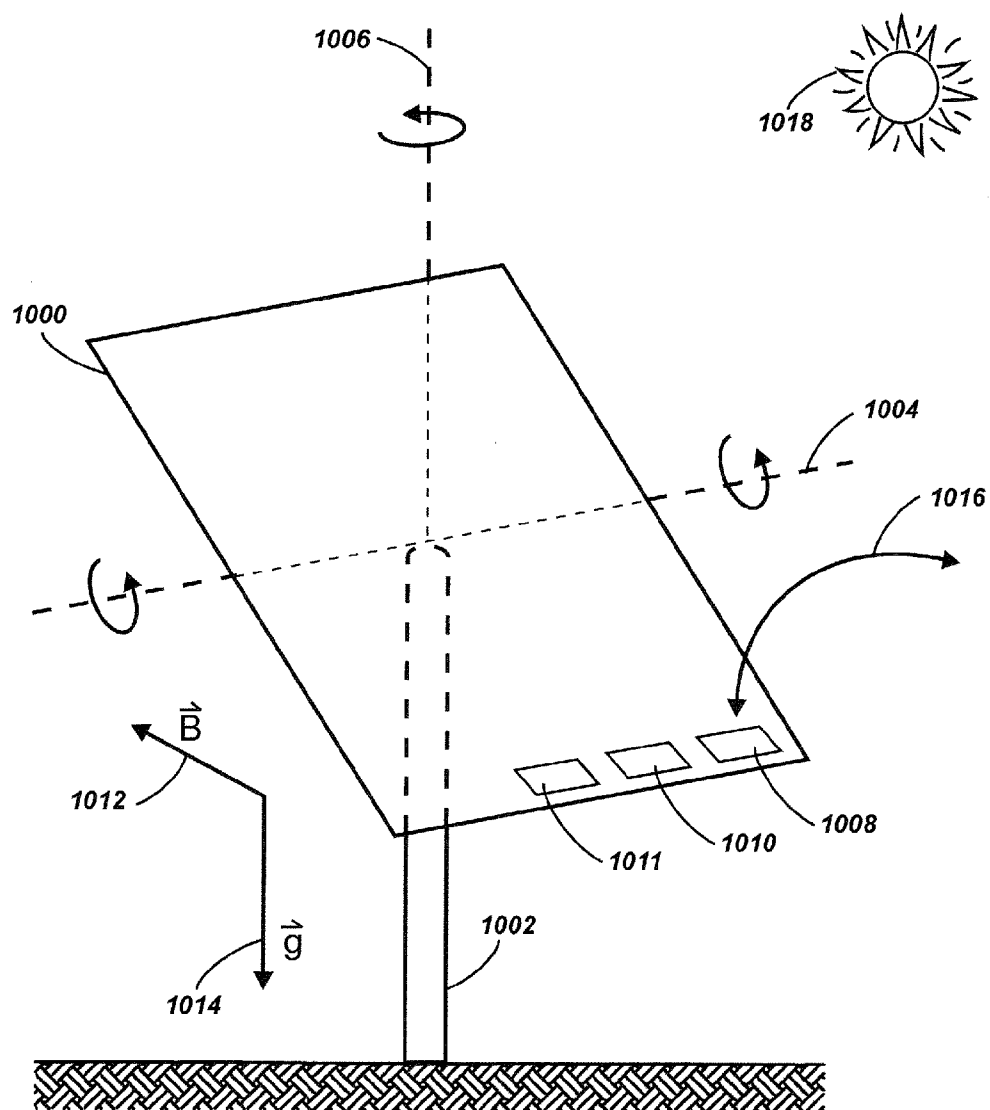


FIG. 21

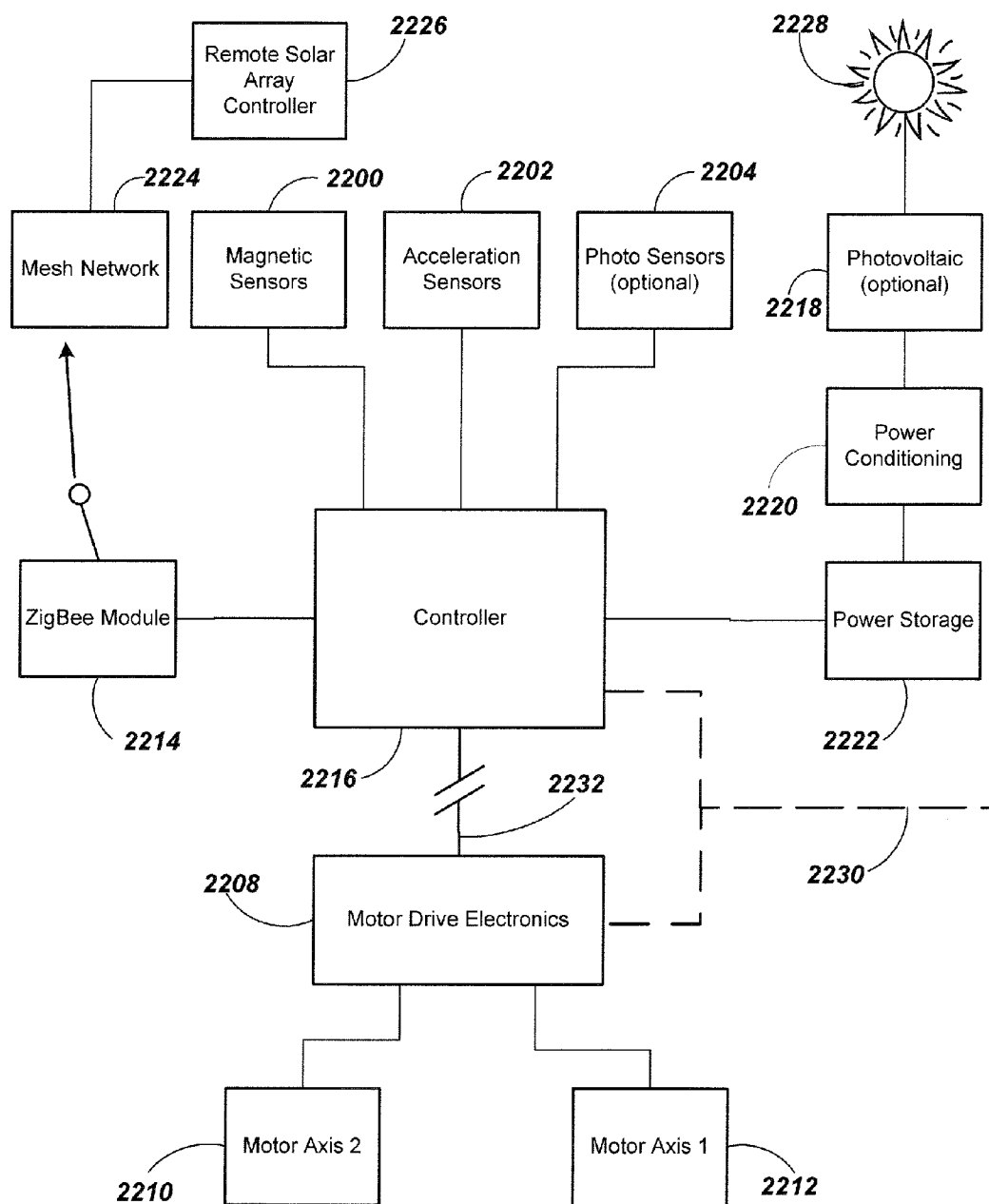


FIG 22

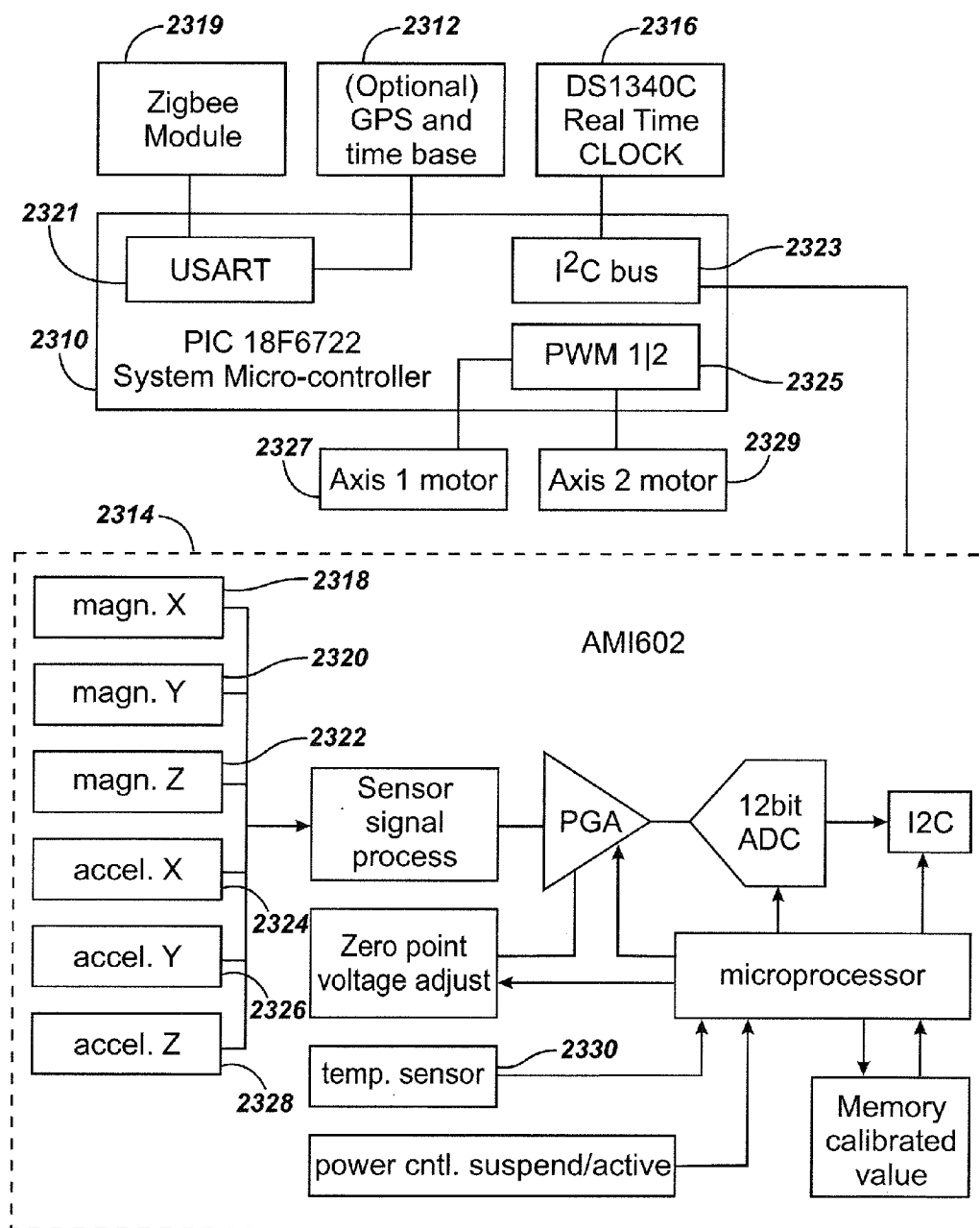


FIG. 23

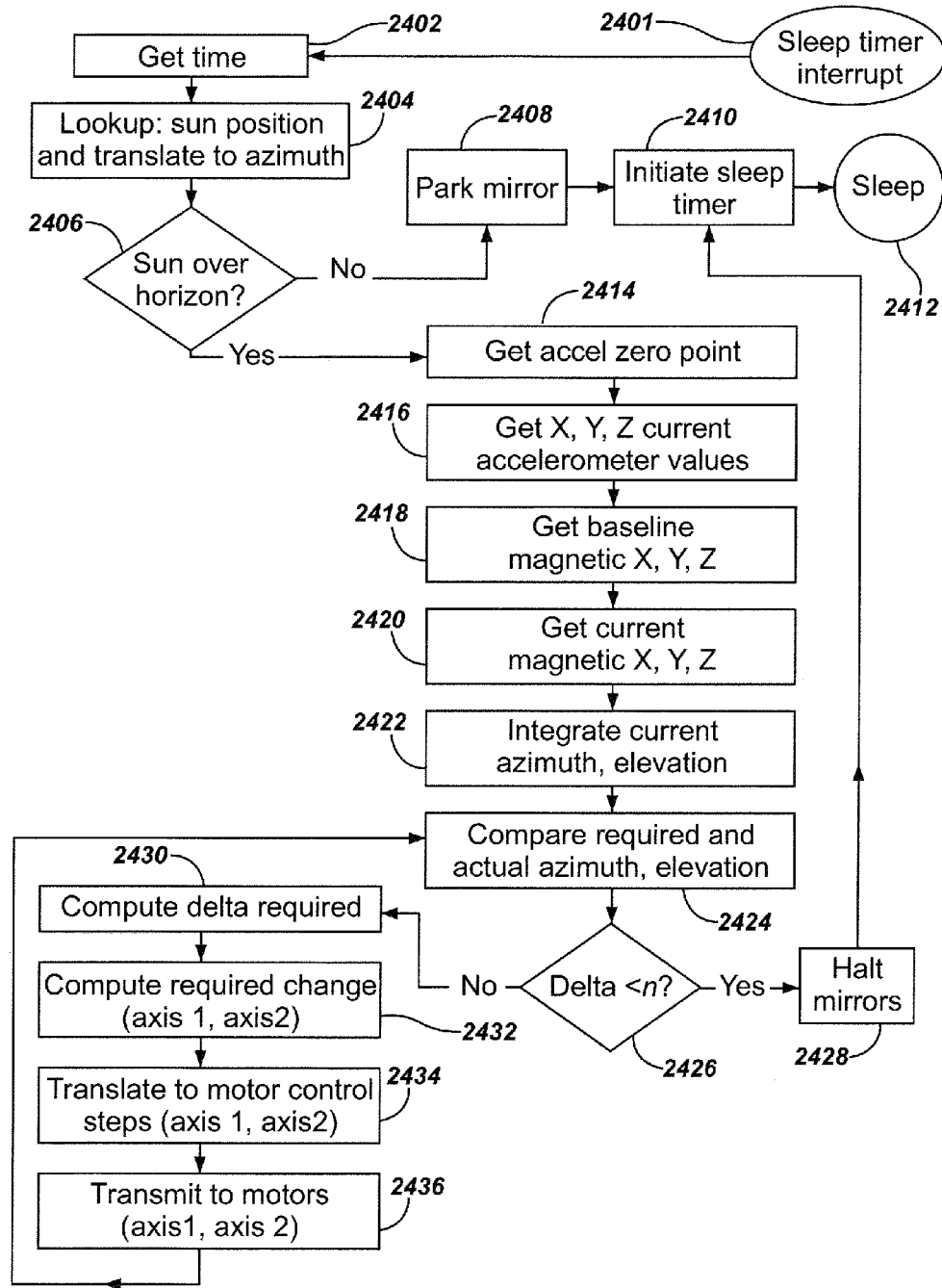


FIG. 24

SOLAR COLLECTION APPARATUS AND METHODS USING ACCELEROMETERS AND MAGNETICS SENSORS

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application is a Continuation-in-Part of U.S. application Ser. No. 11/763,267 of Mark S. Olsson, filed Jun. 14, 2007.

[0002] This application also claims benefit under 35 USC Sections 119(e) and 120 to the filing date of U.S. Provisional Application Ser. No. 60/807,456 filed by Mark S. Olsson on Jul. 14, 2006.

FIELD OF THE INVENTION

[0003] The present invention relates to systems and methods for utilizing the energy of the Sun, and more particularly, to systems and methods for tracking the Sun to re-direct and concentrate incident solar radiation for lighting, heating and photovoltaic applications.

BACKGROUND OF THE INVENTION

[0004] Increased usage of renewable energy sources such as solar radiation is important in reducing dependence upon foreign sources of oil and decreasing green house gases. Devices have been developed in the past that track the motion of the Sun to re-direct and concentrate incident solar radiation. FIG. 1 illustrates one example of a prior art device that utilizes a parabolic dish mirror **10** with a central axis **12** that is pointed generally toward the Sun **14**. Incident solar radiation **22** is received and reflected by the parabolic dish mirror **10** and concentrated at its focus **16**, where a thermal target (not illustrated) can be mounted so that it can be heated. The parabolic dish mirror **10** is supported for independent movement by a two-axis tracking support **18** mounted atop a supporting structure **20** such as a tower. Optical encoders (not illustrated) associated with the tracking support **18** provide signals indicative of the direction and amount of rotation of the parabolic dish mirror **10** so that motor drives and a control system (not illustrated) can be used to track the Sun and increase the efficiency of the energy transfer.

[0005] FIG. 2 illustrates another example of a prior art device similar to the device of FIG. 1 except that the device of FIG. 2 utilizes a parabolic trough mirror **30**. Dashed line **32** illustrates a common plane of the focal line **36** of the parabolic trough mirror **30** and the Sun **14**. A single axis tracking support **38** carries the parabolic trough mirror **30** and is mounted atop a tower **40**. Incident light rays from the Sun such as **42** are collected and reflected by the parabolic trough mirror **30** and concentrated on a pipe (not illustrated) that extends along the focal line **36**. This allows a heat transfer fluid such as water or liquid sodium to be heated. The heating efficiency can be improved by mechanisms (not illustrated) that cause the parabolic trough mirror **30** to pivot and track the Sun. FIG. 3 illustrates another prior art device that utilizes a heliostat flat mirror **50** that receives incident light rays **52** from the Sun **14** and reflects them against a thermal target **58** atop a tower **59**. Another tower **54** carries a two-axis tracking support **56** which supports a flat mirror **50**. Drive and control mechanisms (not illustrated) allow the flat mirror **50** to be independently moved about a rotate axis **60** (azimuth) and about a tilt axis **62** (elevation) to ensure that the Sun's rays are reflected onto the target **58** as the Sun moves across the sky.

There are many variations of the foregoing devices, but to date, none has been widely adopted due to the complexity, reliability, accuracy and/or expense of the tracking mechanisms.

SUMMARY OF THE INVENTION

[0006] In accordance with the present invention a solar tracking apparatus has a mirror or other reflecting surface for collecting and reflecting incident solar radiation. The mirror is supported for independent motion about a pair of axes. An accelerometer generates signals representative of an amount and direction of motion of the mirror about each of the axes. Motors or other drive mechanisms independently drive the mirror about each of the axes. A tracking device provides information about the current position of the Sun. A control is connected to the accelerometer, the motors and the tracking device for maintaining a predetermined optimum orientation of the mirror as the Sun moves across the sky.

[0007] According to another aspect of the present invention, one or more magnetic field sensors are used to sense rotation around an approximately vertical axis and one or more accelerometers are used to sense tilt around an approximately horizontal axis to provide signals indicative of heliostat mirror position in a coordinate system to a control system. The control system allows for precise positioning of a heliostat mirror and the directing of solar energy in a desired direction.

[0008] According to another aspect of the present invention, three orthogonal magnetic field sensors are used to sense rotation around an approximately vertical axis and three orthogonal accelerometers are used to sense tilt around an approximately horizontal axis to provide signals indicative of heliostat mirror position in a coordinate system to a control system. The control system allows for precise positioning of a heliostat mirror and the directing solar energy in a desired direction.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] FIGS. 1-3 illustrate examples of prior art solar radiation collecting and redirecting devices.

[0010] FIG. 4 illustrates a first embodiment of the present invention that utilizes a flat mirror to heat a target.

[0011] FIG. 5 illustrates a second embodiment of the present invention that utilizes an array of mirrors to reflect solar radiation through a skylight.

[0012] FIG. 6 illustrates an alternate embodiment wherein an array of flat tracking mirrors reflects incident solar radiation through the windows of a house to provide light and heat.

[0013] FIG. 7 illustrates another embodiment that utilizes an array of heliostat mirrors to heat a thermal target.

[0014] FIG. 8 illustrates another embodiment that utilizes a plurality of heliostat mirrors to reflect solar radiation onto a high temperature photovoltaic panel.

[0015] FIG. 9 is a block diagram of another embodiment in which a network controller controls a plurality of mirror nodes.

[0016] FIG. 10 illustrates another embodiment in which a heliostat mirror is positioned to reflect incident solar radiation onto a target via a vertical array of photo-sensors.

[0017] FIG. 11 is a block diagram illustrating one embodiment of the mirror controller network node of the embodiment of FIG. 4.

[0018] FIG. 12 is a flow diagram illustrating one embodiment of a method of operation of the control of FIG. 11.

[0019] FIG. 13 is a flow diagram of another embodiment of a method of operation of a solar tracking 20 device in accordance with the present invention.

[0020] FIG. 14 is a front isometric view of another embodiment that utilizes a weight-tensioned device to pivot the mirror.

[0021] FIG. 15 is a back isometric view of the embodiment illustrated in FIG. 14.

[0022] FIG. 16 is a front elevation view of the embodiment illustrated in FIG. 14.

[0023] FIG. 17 is a back elevation view of the embodiment illustrated in FIG. 14.

[0024] FIG. 18 is a side elevation view of the embodiment illustrated in FIG. 14.

[0025] FIG. 19 is an exploded back isometric view of the embodiment illustrated in FIG. 14.

[0026] FIG. 20 is a vertical sectional view (stepped cut) of the embodiment illustrated in FIG. 14 showing internal components thereof.

[0027] FIG. 21 illustrates another embodiment that employs magnetic sensors and accelerometers.

[0028] FIG. 22 is a block diagram of the control system of the embodiment of FIG. 21.

[0029] FIG. 23 is a block diagram of control circuitry.

[0030] FIG. 24 is a flow chart of data integration of magnetic sensor and accelerometer data and their resolution.

DETAILED DESCRIPTION

[0031] The entire disclosure of U.S. patent application Ser. No. 11/763,267 of Mark S. Olsson, filed Jun. 14, 2007, and published Jan. 17, 2008 as US-2008-0011288-A1 is hereby incorporated by reference.

[0032] FIG. 4 illustrates a first embodiment of the present invention that utilizes a flat mirror to heat a target. A solar tracking apparatus has a reflective surface in the form of a mirror 70 for collecting and reflecting incident solar radiation 82 from the Sun 14. The mirror in this embodiment has a planar configuration, although this embodiment could be adapted to use other mirror configurations including parabolic dish, parabolic trough, etc. in order to concentrate the incident solar radiation. The mirror could be conventional silver coated glass, or could be plastic, or could be Mylar® polyester film on a support substrate, or some other form of reflective material that is durable, lightweight and inexpensive.

[0033] The mirror 70 (FIG. 4) is supported by a pair of pivot mechanisms 72 for independent motion about a pair of tilt axes 88 and 90. The pivot mechanisms 72 are mounted atop a support or tower 76. An accelerometer 74 generates signals representative of an amount and direction of motion of the mirror about each of the axes 88 and 90. In effect the Earth's gravity is sensed and used to provide an indication of the current orientation of the mirror 70. Electric motors 78 (only one of two illustrated) independently drive the mirror 70 about each of the axes utilizing, for example, a worm gear 80 and a circular rack gear 81. A mirror controller network node 86 includes a tracking device, typically an electronic processor, that provides information about the current position of the Sun 14. The mirror controller network node 86 also includes a control that is connected to the accelerometer 74, the motors 78 and the tracking device for maintaining a predetermined optimum orientation of the mirror as the Sun moves across the

sky. The architecture and method of operation of the mirror controller network node 86 are discussed hereafter in greater detail. Incident solar radiation with an angle of incidence 96 is reflected off the surface of the mirror 70 at an angle of reflection 94 so that it strikes a thermal target 84 such as a container or conduit of a heat transfer fluid or an array of photovoltaic cells.

[0034] The accelerometer 74 (FIG. 4) is preferably a micro-electro-mechanical systems (MEMS) accelerometer device. Utilizing micro-fabrication techniques a position sensor component and signal conditioning circuit can be fabricated on a single integrated circuit chip. Such MEMS accelerometer devices are relatively inexpensive, durable and sufficiently accurate for purposes of manufacturing commercial embodiments of the present invention. Suitable MEMS accelerometer devices are the KXM52-1040 dual-axis (XY) MEMS accelerometer device and the KXM52-1 050 tri-axis (XYZ) MEMS accelerometer device, both of which are commercially available from Kionix, Inc., 36 20 Thronwood Drive, Ithica, N.Y. 14850 USA. See U.S. Pat. Nos. 6,149,190 granted Nov. 21, 2000 to Galvin et al. and 6,792,804 granted Sep. 21, 2004 to Adams et al., both of which are assigned to Kionix, Inc., the entire disclosures of which are hereby incorporated by reference. Also suitable are the ADXL321 (two-axis) and ADXL330 (three-axis) MEMS accelerometer devices, both of which are commercially available from Analog Devices, Inc., One 25 Technology Way, Norwood, Mass. 02062 USA. See U.S. Pat. Nos. 6,837,107 granted Jan. 4, 2005 to Green and 6,845,665 granted Jan. 25, 2005 also to Green, both of which are assigned to Analog Devices, Inc., the entire disclosures of which are hereby incorporated by reference.

[0035] While it is possible over certain rotational limits, with appropriate calibration and alignment to use single axis sensors, it is desirable to use three axis sensors for both magnetic field and gravity. It is anticipated with ongoing reductions in the cost of sensors and greater system integration that three axis sensors will be widely available at low cost. For example, an Aichi Steel Corporation, Electro-Magnetic Products, AMI601 sensor would be suitable for this application. See http://www.aichi-mi.com/3_products/ami%20catalogue%20e.pdf.

[0036] The AMI602, which would also serve in this application, is also from Aichi and is a 6-axis motion sensor which incorporates 3-axis magnetometer and 3-axis accelerometer. The controller IC of the AMI602 consists of a circuit for sensor elements, an amplifier capable of compensating each sensors offset and setting appropriate sensitivity values, a temperature sensor, a 12 bit AD converter, an PC serial output circuit, a constant voltage circuit for power control and an 8032 micro-processor controlling each circuit.

[0037] Again referring to FIG. 4, the pivot mechanisms 72 are configured and arranged so that throughout the useful range of tracking tilts, the accelerometer 74 is not rotated in an unknown fashion about a vertical axis. If the accelerometer is rotated about a vertical axis, the pointing direction of the mirror 70 becomes ambiguous or indeterminate. The addition of a magnetic sensor in an alternate embodiment avoids this problem, as discussed later. Modern compass MEMS devices which combine accelerometers with magnetic compass sensors are known in the art, and allow the array to be corrected for tilt, and such a device could be used in place of the accelerometer 74.

[0038] It will be understood that a wide variation of modifications of the embodiment illustrated in FIG. 4 are possible. For example, the accelerometer 74 need not be directly mounted to the mirror but could be coupled thereto through a mechanical or optical linkage. The pivot mechanisms 72 could be replaced with an alternate pivot mechanism such as a ball and socket or flexible joint, instead of those employing independently movable mechanical pivots. Thus the mirror 70 need not strictly rotate about two axes, as is the case with the embodiment of FIG. 4 wherein rotation of the mirror 70 about one axis rotates the other axis. It will be appreciated that it is not necessary that both axes of tilt are substantially in the same horizontal plane when the mirror 70 is in a normal or horizontal orientation. Other forms of motor means for driving the mirror 70 can be employed besides the electric motor 78 and gears 80 and 81, such as hydraulic and pneumatic systems. The mirror 70 need not move in azimuth and elevation, it being sufficient that it be capable of independent movement about two non-parallel axes.

[0039] FIG. 5 illustrates a second embodiment of the present invention that utilizes an array 104 of individual mirrors 106 to reflect solar radiation 110 through a skylight 102 on the roof of a building 100 to provide internal lighting. This greatly increases the amount of solar radiation otherwise directly entering the interior of the building through the skylight 102 as illustrated by incident light rays 108. The mirrors 106 may each be independently supported and moved as illustrated in FIG. 4 or they may be simultaneously supported and moved by a common tracking system so that reflected light 114 strikes a fixed angle target mirror 112 and is reflected as downwardly projected light 116. The skylight 102 may be of the type sold under the SOLATUBE® trademark which employs a conduit with a highly reflective surface. Optionally a hot mirror 118 may be inserted in to the reflected light transmission path to reflect away the infrared component during the summer to avoid unwanted heating of the interior of the building 100.

[0040] FIG. 6 illustrates an alternate embodiment wherein an array 144 of flat tracking mirrors 142 reflect incident solar radiation 146 as reflected radiation 148 that passes through the window 140 of a house to provide light and heat. Again the mirrors 142 are supported and moved in the fashion described in connection with FIG. 4.

[0041] FIG. 7 illustrates another embodiment that utilizes an array 170 of heliostat mirrors 168 to heat a thermal target 162. The amount of incident solar radiation 164 that is redirected as reflected solar radiation 166 is maximized by mounting an accelerometer 160 on each heliostat mirror 168 and using its signals, along with tracking information to tilt each mirror 168 about its two-axis tilting support 172.

[0042] FIG. 8 illustrates another embodiment that utilizes a plurality of heliostat mirrors 206 equipped as described in connection with FIG. 4 in order to re-direct a maximum amount of incident solar radiation 202 as reflected radiation 204 onto a high temperature photovoltaic panel 200.

[0043] FIG. 9 is a block diagram of another embodiment in which a network controller 222 controls a plurality of mirror nodes 220. The network controller 222 may be connected to the mirror nodes 220 by a network link 226 which may be wired or wireless, fiber optic, laser or any other well known data communications scheme. One example is the ZIG-BEE™ data link. Bluetooth links or other wireless means could be used as well according to the scale of the application. An optional mirror node training interface 224 is provided

that can be used to load the network controller 222 with tracking data from local or remote sources that give the predicted location of the Sun throughout the day for a given latitude, longitude, date and time. This information is used by the controller to compare the actual position of the mirrors with their optimum positions so that they can be moved to maximize the collection and/or concentration of solar radiation. Alternatively this information may be preprogrammed into the network controller 222 or the mirror controller network node 86 (FIG. 4).

[0044] The present invention differs from conventional heliostats that require a vertical tracking axis. In the present invention, the Sun is tracked in both azimuth and elevation, however, tracking is required in both axes as neither component is separately derived.

[0045] FIG. 10 illustrates another embodiment in which a heliostat mirror 246 is positioned to re-direct incident solar radiation 250 as reflected solar radiation 252 to strike a target 248 utilizing mechanisms similar to those described in connection with FIG. 4. A vertical array of photo-sensors 240 detect reflected radiation 252 and their signals are used to position the mirror 246 so that the reflected radiation will strike the target 248. A Sun hood 254 may be used with each photo-sensor 240 to prevent it from detecting significant amounts of incident solar radiation 250. The spacing 242 between the photo-sensors 240 can be optimized relative to the dimension 244 of the mirror 246.

[0046] FIG. 11 is a block diagram illustrating one embodiment of mirror controller network node 86 of the embodiment of FIG. 4. A PIC micro-computer based control 300 provides the basic intelligence and control through appropriate input/output interfaces. Position information is received from the accelerometer 302. First and second axis motors 304 and 306 are appropriately driven. AC power or some other power source 310 such as solar or battery power provides power to the control 300. In order for the mirror to be optimally pointed, it is necessary for the control 300 to compare the actual position of the mirror to the current position of the Sun and make the appropriate adjustments. Data regarding the predicted location of the Sun is pre-programmed into the control 300, in which case a user interface (not illustrated) is necessary for a user to enter the correct latitude, longitude, date and time during initial set up. This interface could be a keypad or a connection to a PC or PDA, for example. Optionally, a Global Positioning System (GPS) and time base receiver 312 may be connected to the control 300 to provide this information. A wired or wireless network link 308 connects the control to a remote location for monitoring or control.

[0047] FIG. 12 is a flow diagram illustrating one embodiment of a method of operation of the control of FIG. 11. Initially in step 314 the starting parameters are acquired, including latitude and longitude, time, tilt axis orientation to the North, and the estimated azimuth and elevation of the mirror. Latitude, longitude and time can be obtained via the network. In step 316 the processor calculates the position of the Sun. In step 318, using signals from the accelerometer, and data from a look up table, the control calculates the movement of the mirror about each axis necessary to achieve the optimum orientation. In step 320, the motors are driven by the control to move the mirror as needed to obtain the optimum orientation. If the accelerometer signals do not indicate mirror motion, an ERROR message is generated and trans-

mitted and/or displayed. In step 322, the control continues to track the Sun in order to engage the target.

[0048] FIG. 13 is a flow diagram of another embodiment of a method of operation of a solar tracking device in accordance with the present invention.

[0049] FIGS. 14-20 illustrate another embodiment of the present invention that utilizes weight-tensioned mechanisms to pivot the mirror. The embodiment 400 includes a planar square mirror 402 whose corners are supported by four cable hook corners 404. A small yoke 406 (FIGS. 15 and 19) has a square surface which is secured to the center of the rear side of the mirror 402 by suitable adhesive. Small yoke 406 is connected for independent rotation about two axes to a tall yoke 408 by a cross piece 410. The base of the tall yoke 408 is secured by screws 412 and nuts 414 (FIG. 19) to a cylindrical cap plate 416. The cylindrical cap plate 416 is mounted on the upper end of a support structure in the form of a hollow vertical support post 418.

[0050] A lower tension wire 420 (FIG. 18) has one end connected to the uppermost cable hook corner 404 and its other end connected to the lowermost cable hook corner 404. An upper tension wire 422 (FIGS. 18 and 19) has an intermediate segment wrapped around an upper drive pulley 424 (FIG. 20) and its ends connected to respective ones of the laterally spaced cable hook corners 404. The lower tension wire 420 is connected to a lower counter-weight drive assembly 426 (FIG. 20). The upper tension wire 422 is connected to an upper counter-weight drive assembly 428 on which the upper drive pulley 424 is mounted. The lower tension wire 420 passes through large rectangular apertures 430 (FIG. 18) on opposite sides of the lower portion of the support post 418. The upper tension wire 422 passes through large rectangular apertures 432 formed on opposite sides of the upper portion of the support post 418, and spaced ninety degrees from the apertures 430. The intermediate segment of the lower tension wire is wrapped around a lower drive pulley 434 (FIG. 20) mounted on the lower counter-weight drive assembly 426.

[0051] Each of the counter-weight drive assemblies 426 and 428 (FIG. 19) has a similar construction, and therefore, only one need be described. The lower counter-weight drive assembly 426 includes a lower micro-motor 436 (FIG. 20), a lower rotation restraint mechanism 438, a shaft connector 440, and a lower worm gear drive 442. These mechanisms allow the lower tension wire 420 to be driven by the lower drive pulley 434 to pivot the mirror 402 about a horizontal axis. Similar mechanisms in the upper counter-weight drive assembly 428 allow the upper drive pulley 424 to drive the upper tension wire back and forth to pivot the mirror 402 about a tilted (off vertical) axis. The lower counter-weight drive assembly 426 includes a cylindrical drive mount 444 (FIG. 20) and a ring-shaped counter-weight 446. The cylindrical drive mount 444 has oval apertures 448 (FIG. 14) formed on opposite sides thereof to allow ingress and egress of the lower tension wire 420.

[0052] The lower and upper counter-weight drive assemblies 426 and 428 are capable of reciprocal vertical motion within the bore of the support post 418. A control circuit (not illustrated) receives input from a MEMS accelerometer as previously described and causes the micro-motors of the lower and upper counter-weight drive assemblies 426 and 428 to move the mirror 402 into the optimum position for reflecting solar radiation onto a target (not illustrated in FIGS. 14-20), such as a photovoltaic array, heat exchanger, etc.

[0053] Referring now to FIG. 21, a heliostat mirror (1000) is supported by a vertical tubular support (1002). A motorized tilt mechanism (not shown) provides rotation around an approximately horizontal axis (1004) for tracking solar elevation. A second motorized rotation mechanism (not shown) provides rotation around an approximately vertical axis (1006) for tracking the sun (1018) in azimuth across the sky. The mirror need not be flat but might have some curvature in one or more directions to allow the solar energy to be brought to a tight focus. A sensor and control package (1008) can be mounted anywhere on the mirror or the supporting structure. Preferably, all the sensors and controls are integrated into a single package to reduce cost and the need for interconnecting cables. In this case, the sensor and control package needs to be mounted so that it is subject to both tilt and rotation during mirror positioning. One or more magnetic sensors 1010 are used to sense the earth's magnetic field (1012) to determine rotational position around an approximately vertical axis. One or more accelerometers included in the sensor package 1008 are used to sense the gravity vector (1014) and determine rotational position around an approximately horizontal tilt axis 1004. The magnetic sensor may be a three-axis magnetic field sensor which provides x, y, and z data in response to measurement of the earth's magnetic field.

[0054] A separate sensor such as the Honeywell HMC5843 available from Honeywell International Inc., 101 Columbia Road, Morristown, N.J. 07962 or the AK8973S available from Asahi Kasei Microsystems (AKM Semiconductor) at 1731 Technology Drive, San Jose, Calif. 95110, are examples which would serve. Alternatively a combined integrated circuit including both three-axis accelerometer and three-axis compass, such as the AMI602 6-axis motion sensor which incorporates 3-axis magnetometer and 3-axis accelerometer (available from Aichi Steel Corporation at 1 Wano-wari, Arao-machi, Tokai-shi, Aichi-ken, 476-8666 Japan) or the STMicroelectronics LSM303DLH geomagnetic module combining magnetic-field and linear-acceleration sensing would serve. Where a combined sensor unit is used, separate magnetic sensors 1010 are dispensed with as both the gravitic vector 1014 and the magnetic vector 1012 are measured by the combined unit.

[0055] For maximum durability, the sensor and control package can be mounted behind an uncoated transparent section of glass mirror. Optical sensors to determine the position of the sun can be integrated into the sensor and control package. The same suite of optical sensors can further be used to determine the relative position of the solar energy target. Various means of building optical sensors to sense light direction are known in the art. Optionally, photovoltaic cells can be integrated into the sensor and control package or optionally mounted in an adjacent fashion (1011). Batteries or capacitors can be used to store the energy from the photovoltaic cells to provide power to operate both motorized rotation axes. Alternatively wired power (not shown) can be used. A wireless link (1016) or a wired link (not shown) can be used to remotely control each mirror and exchange data between each mirror's control system and a centralized control facility. If a wireless link is employed, a mesh networking topology is preferably used to allow data and control signals to be communicated across a heliostat array of large area extent. A large heliostat array might be usefully employed to produce hydrogen fuel by photo-catalytic means.

[0056] Control signals from the mirror control system to each motorized rotation axis might be by wireless means. For

lowest possible cost and long terms reliability it is desirable to reduce the number of cables, wires, and connectors as possible. Power to run the axis rotation motors may be provided by a hardwired means while control might be provided by wireless means. Rotation motors may alternatively each have their own small photovoltaic panel and energy storage means.

[0057] FIG. 22 illustrates a block diagram of the control system for the embodiment of FIG. 21. In FIG. 22, a controller block (2216) receives data from magnetic sensors (2200) which sense rotation around an approximately vertical axis and acceleration sensors (2202) to sense tilt around an approximately horizontal axis to provide signals indicative of heliostat mirror position. Optionally, photo sensors (2204) may be used to establish the position of the heliostat relative to the sun, or to a target with an optical beacon. In FIG. 22, the option of using photovoltaics to power the system is illustrated including photovoltaic cells (2218), a power-conditioning block (2220), and a power storage unit (2222) which in turn communicates and supplies power to the controller block (2216). Further, in FIG. 22, the controller block (2216) is illustrated with a communication link via a ZigBee module (2214) which in turn is in communication with a mesh network (2224) allowing coordination of the local system with a remote solar array controller (2226). The dashed line represents an alternative energy source (2230) by usual wired connection to the energy grid, a local generator, or other energy supply. The controller block (2216), by means of emitted control signals, governs the activation of a motor drive (2208) which in turn controls two axes, one approximately vertical (2210) and one approximately horizontal (2212). An optional wireless link (2232) is also shown for data relay between the controller block and the motor control electronics if separate power is available.

[0058] FIG. 23 illustrates a detailed block diagram of exemplary components of magnetic sensors and accelerometers and their relationship to the axis motors of an embodiment similar to FIG. 21. In FIG. 23 an integrated circuit system 2314 contains both magnetic sensors and accelerometers and their appropriate circuitry. In FIG. 23 the integrated circuit 2314 is an AMI602 6-axis sensor with integrated amplifier, 12-bit analog-digital converter and an 8032 microprocessor controlling the circuits of the integrated circuit 2314.

[0059] Three sensors measure values for magnetic orientation relative to the earth's magnetic field on an X axis 2318, a Y axis 2320, and a Z axis 2320. Three accelerometer sensors measure acceleration at the same time along the X axis 2324, Y axis 2326, and Z axis 2328. These sensor signals are processed through a converter into digital data transmitted to a microcontroller 2310. In FIG. 23, the microcontroller 2310 is a 64-pin PIC 18F6722 available from Microchip Technology Inc., 2355 West Chandler Blvd., Chandler, Ariz., USA 85224-6199. The microcontroller 2310 communicates with the AMI602 integrated circuit 2314 through a standard I²C bus 2323. A real-time clock chip 2316 also communicates with the microcontroller 2310 on the I²C bus 2323. In FIG. 23 the real-time clock chip 2316 is a DS 1340C with built-in calendar and clock, available from Maxim/Dallas Semiconductor, at Maxim Integrated Products, Inc., 120 San Gabriel Drive, Sunnyvale, Calif. 94086.

[0060] The microcontroller 2310 also receives digital GPS time base information from an optional GPS/time base receiver 2312; alternatively it may receive data streams from an onboard clock 2316 and perform look-up operations using

an on-board or remote data lookup table. An optional ZigBee communication module 2319 and the optional GPS/time base receiver 2312 communicate to the microcontroller 2310 by means of an on-board universal synchronous/asynchronous receiver/transmitter, or USART 2321. The microcontroller 2310 is capable of sending pulse-width modulated data on two output pins, P3A and P3D, shown in FIG. 23 as a combined PWM port 2325. Motor control commands are transmitted by means of the PWM port 2325 to a first axis motor 2327 controlling the horizontal axis of the solar collector, and a second axis motor 2329 controlling the vertical axis thereof.

[0061] FIG. 24 is a flow chart of the control logic. By calculating the present orientation of the sun and the measured present orientation of the line-of-direction axis of the mirror such as 1000 in FIG. 21, the microprocessor may derive delta values for each axis to align the mirror 1000 (FIG. 21) with the sun 1018 (FIG. 21). These delta values are in turn used to compute motor commands to drive the horizontal axis motor 2326 and the vertical axis motor 2334 in FIG. 23. In FIG. 24 the control cycle begins with a step 2402 of getting the real-time clock value and a following step 2404 of looking up the sun's real-time position and translating to azimuth and elevation values. A test step 2406 is done to determine whether the sun is over the horizon or not; if it is not, the mirrors are parked (step 2408) and a sleep timer is initiated (step 2410). The system is placed in a sleep state 2412 until such time as a sleep timer interrupt 2401 occurs. The sleep timer interrupt may be caused by passage of a specified period, or by an external signal, or a pre-defined clock moment, or by a photo-sensor trigger event, for example. If test step 2406 determines the sun is over the horizon, the system must then get the zero baseline value for the accelerometers (step 2414) and their current values (step 2416). Likewise, it gets baseline values for the magnetic sensors (step 2418) on three axes, and their current values (step 2420). Based on these values the system computes current azimuth and elevation in Step 2422, and compares them to the required azimuth and elevation in step 2424. A test is then done in Step 2426 to determine whether the delta between the required azimuth and elevation and their present values is below a pre-defined tolerance threshold. If the delta is within tolerable limits the motors are halted (step 2428) and the sleep timer initiation step 2410 is executed. If the delta exceeds tolerable limits the system must then compute the amount of change required in azimuth and elevation (step 2430) and translate that change into a change for the horizontal axis and the vertical axis (step 2432). These values must in turn be translated into motor control values in Step 2434 resulting in motor control transmissions sent to the first axis motor 2326 (FIG. 23) and the second axis motor 2328 (FIG. 23) in Step 2436.

[0062] It will be clear to one skilled in the art that the use of other particular sensors and other configurations will also prove workable. The particular components described are mentioned as examples of different embodiments.

[0063] While several preferred embodiments of the present invention have been described, and some variations thereof, further modifications will occur to those skilled in the art. For example, any of the embodiments described herein can utilize accelerometers alone, or accelerometers and magnetic sensors. Therefore the protection afforded the subject in invention should only be limited in accordance with the following claims.

What is claimed is:

1. A solar tracking apparatus, comprising:
means for collecting and reflecting incident solar radiation;
means for supporting the solar radiation collecting and reflecting means for independent motion about a pair of axes; accelerometer means for generating signals representative of an amount and direction of motion of the solar radiation collecting and reflecting means about each of the axes;
motor means for independently driving the solar radiation collecting and reflecting means about each of the axes;
tracking means for providing information about the current position of the Sun; and
control means connected to the accelerometer means, the motor means and the tracking means for maintaining a predetermined optimum orientation of the solar radiation collecting and reflecting means as the Sun moves across the sky.
2. The solar tracking apparatus of claim 1 wherein the solar radiation collecting and reflecting means is configured for concentrating incident solar radiation.
3. The solar tracking apparatus of claim 1 wherein the accelerometer means is mounted on the solar radiation collecting and reflecting means.
4. The solar tracking apparatus of claim 1 wherein the support means includes a pair of pivot mechanisms.
5. The solar tracking apparatus of claim 1 wherein the accelerometer means includes a MEMS accelerometer device.
6. The solar tracking apparatus of claim 1 wherein the motor means includes first and second electric motors and first and second drive linkages for coupling the electric motors, respectively, to the support means.
7. The solar tracking apparatus of claim 1 wherein the solar radiation collecting and reflecting means is supported so that both axes are substantially in the same horizontal plane when the solar radiation collecting and reflecting means is in a horizontal orientation.
8. The solar tracking apparatus of claim 7 wherein the solar radiation collecting and reflecting means is a mirror with a configuration selected from the group consisting of planar, parabolic and parabolic trough.
9. The solar tracking apparatus of claim 1 and further comprising means for sensing a reference position of the solar radiation collecting and reflecting means relative to the earth's magnetic field vector and for generating signals representative of the reference position and supplying them to the control means.
10. The solar tracking apparatus of claim 9 wherein the accelerometer means and the reference position sensing means are provided by three-axis sensors.
11. A heliostat mirror pointing system employing both accelerometer and magnetic sensors to determine mirror position relative to the earth's gravitational vector and the earth's magnetic field vector.
12. The heliostat mirror pointing system of claim 11 wherein one axis of rotation is approximately vertical.
13. The heliostat mirror pointing system of claim 11 wherein one axis of rotation is approximately horizontal.
14. The heliostat mirror pointing system of claim 11 wherein the magnetic sensor is used to sense rotation around said vertical axis.
15. The heliostat mirror pointing system of claim 11 wherein the accelerometer sensor is used to sense rotation around said horizontal axis.
16. The heliostat mirror pointing system employing 3-axis magnetic sensors to determine mirror position relative to the earth's magnetic field vector.
17. The heliostat mirror pointing system of claim 16 wherein one axis of rotation is approximately vertical.
18. The heliostat mirror pointing system of claim 16 wherein one axis of rotation is approximately horizontal.
19. The heliostat mirror pointing system of claim 16 wherein the magnetic sensor is used to sense rotation around horizontal and vertical axis.
20. A heliostat mirror control system employing both accelerometer and magnetic sensors to determine mirror position relative to the earth's gravitational vector and the earth's magnetic field vector.
21. The heliostat mirror control system of claim 20 wherein said control system is a member of a mesh network.
22. The heliostat mirror control system of claim 20 wherein said control system uses a wireless control means.
23. The heliostat mirror control system of claim 20 wherein photovoltaic devices are used to provide power to said control system.
24. The heliostat mirror control system of claim 20 wherein photovoltaic devices are used to store energy in one or more capacitors to provide power for said control system.
25. The heliostat mirror control system of claim 20 wherein photovoltaic devices are used to store energy in one or more rechargeable batteries to provide power for said control system.
26. A solar tracking apparatus, comprising:
a reflective surface for collecting and reflecting incident solar radiation;
a pivot mechanism that supports the reflective surface for independent motion about a pair of axes;
an accelerometer that generates signals representative of an amount and direction of motion of the reflective surface about each of the axes;
at least one motor coupled to independently drive the reflective surface about each of the axes;
a data source that provides information about the current position of the Sun; and
a control circuit connected to the accelerometer, the motor and the data source for maintaining a predetermined optimum orientation of the reflecting surface as the Sun moves across the sky.
27. The solar tracking apparatus of claim 26 wherein the reflective surface is configured for concentrating incident solar radiation.
28. The solar tracking apparatus of claim 26 wherein the accelerometer is mounted on the reflective surface.
29. The solar tracking apparatus of claim 26 wherein the reflective surface is supported by a pair of pivot mechanisms.
30. The solar tracking apparatus of claim 26 wherein the accelerometer is a MEMS accelerometer device.
31. The solar tracking apparatus of claim 29 wherein the apparatus includes first and second electric motors and first and second drive linkages for coupling the electric motors to corresponding ones of the pair of pivot mechanisms.
32. The solar tracking apparatus of claim 26 wherein the reflective surface is supported so that both axes are substantially in the same horizontal plane when the reflective surface is in a horizontal orientation.

33. The solar tracking apparatus of claim **26** wherein the reflective surface is a mirror with a configuration selected from the group consisting of planar, parabolic and parabolic trough.

34. The solar tracking apparatus of claim **26** and further comprising means for sensing a reference position of the solar radiation collecting and reflecting means relative to the

earth's magnetic field vector and for generating signals representative of the reference position and 4 supplying them to the control circuit.

35. The solar tracking apparatus of claim **34** wherein the accelerometer and the reference position sensing means are provided by three-axis sensors.

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