

A method and apparatus for automatic tracking of the Sun

Field of the Invention

The present invention relates to an electromechanical controller of a structure for supporting and orienting relative to the visible Sun a reflector or a target of any usable shape, scale and contour, used to concentrate, disperse, absorb or reflect sunlight and it relates more particularly but not exclusively, to the controller of a terrestrial fixed or mobile reflector for concentrating solar radiation.

Background of the Invention

In many instances it is beneficial to employ an apparatus for tracking the apparent Sun position in the sky and accordingly affecting movement of a structure with attached payload - curved or flat active elements which, for performance or other reasons, should desirably be oriented in a certain position relative to the star. This need is most apparent in the application of parabolic solar collectors, where a small deviation from the design prescribed position relative to the Sun results in a quick degradation or seizure of performance. Even in relatively less sensitive applications, such as flat photovoltaic or thermal solar panels, performance degradation is easily noticeable and increasing with the angle of misalignment between the incident sunlight and the main axis of the panel, perpendicular to its plane.

Separately, in static installations or even ones equipped with Sun trackers, there is little remedy for a situation where environmental conditions impede the system use for trivial reasons such as snowfall, dust, debris, wind or combination thereof, days and weeks after the event.

To increase such apparatuses' efficiency, various methods have been used to automatically move their structures into a specific position relative to the Sun as its apparent position in the sky changes throughout the day, and with the seasons. These methods are generally categorized by their implementation as single-axis trackers, exemplified by the one described in U.S. Pat. 20070204860, where the Sun's apparent daily trajectory is followed by an apparatus rotating about an axis inclined to a certain angle to Earth's axis, chosen to provide best results at a certain time of the year, and dual-axis trackers, where said apparatus' movement is a product of two separate rotations – azimuth and elevation.

Commonly, the installation of either type trackers requires careful alignment and specialized knowledge - failure to use precise measurements in the process results in decreased performance. Because of this, portable or mobile applications are difficult to implement and rare

Sun trackers used in the past have employed various types of actuators, including electric motors, exemplified by U.S. Pat. 20070227574, mechanical (spring-loaded) motors, gravity, hydraulics, as described in U.S. Pat. 4063543 for example, thermal expansion and contraction, exemplified by U.S. Pat. 7240674, and others, with various degrees of success.

Similarly, a great variety of means for controlling such actuators exist – from no controllers whatsoever in inertia systems to stand-alone computers in electromechanical ones, such as the one described in U.S. Pat. 7315781. A common problem with such controllers is their inability to operate independently and without supervision for long stretches of time – for example, clocks deviate from real time, the mechanism needs resetting, or relies solely on the visible Sun.

Accordingly, the invention presented herein aims to alleviate at least two of the above prior art shortcomings, more specifically: autonomous, reliable and reproducible precision and ease of deployment.

Summary of the Invention

The present invention aims to provide a new type of automatic Sun tracker controller, suitable for use with payload actuators of any type.

Preferred embodiments of this invention are directed at a controller operating a dual-axis actuator positioner, providing superior precision when determining the apparent position of the Sun without regard to environmental conditions, season or location of the installation. Said embodiments are further directed to eliminating the need for specialized installation activities, allowing for increased ease-of-use and mobility of redeployable solar apparatus and arrays thereof.

Further, the present invention is defined by the use of a computing element configured to affect movement of electromechanical positioner to which the payload is securely attached, in a way such that the tracking axis of the apparatus is always pointed to a point at a predetermined angle relative to the visible Sun.

Accordingly, the present invention provides a controller for tracking the apparent position of the Sun, utilizing location and time data provided by at least one GPS receiver, magnetic field data provided by at least one magnetometer, fine tuning data provided by at least one optical alignment sensor, and environmental data provided by a number of sensors as mandated by the application, including but not limited to: a wind direction and speed sensor, a temperature sensor, a relative humidity sensor, and utilizing at least one microprocessor for processing such data according to its programming, suitable means for programming and data storage and retrieval and assorted peripheral components necessary for the operation of said sensors and microprocessor. GPS provides planet-wide coverage and data used to unambiguously determine the location of the apparatus and the current time. The magnetometer provides three-axis magnetic field data which, when compared to a suitably chosen model calculated for the specific location and time, is used to determine the apparatus' orientation and

attitude. The size of the model data may determine hardware requirements – for Earth for example, storing NGDC-720 coefficients is more memory-intensive than storing WMM coefficients, thus more non-volatile storage must be allotted for it. With the calculated location, position and time, a determination is made of the current apparent position of the Sun and the actuators are directed to point the apparatus in that direction. The optical alignment sensor has a four-quadrant output, used to fine-tune the positioning by optically aligning the tracking axis of the apparatus with the visible Sun.

Environmental sensors data is used to implement the safeguarding qualities of the controller, allowing it to affect evasive maneuvers when high winds, precipitation or any other condition is deemed dangerous to the apparatus. Power is supplied by a suitable battery or low voltage DC power supply.

By placing multiple sensors in both the housing of the controller and on, behind or around the payload, differential measurements may be used for calibration purposes and to increase precision, while such configuration also provides a level of redundancy.

Embodiments of the invention may be deployed in 10 minutes or less without any measurements or special tools and are autonomous after installation. Some example components that may be used in embodiments of the invention include the Freescale MC9S08GB32A and MMA7260QT, Honeywell HMC1043, Modulestek MG-A01SP, Intersil HIP4020, Panasonic ECJ series capacitors and ERJ series resistors, NEMA 17 motors, etc. These components are exemplary and non-limiting in that substitute components with acceptable parameters may be substituted in embodiments of the invention.

In addition, one or more embodiments of the invention may comprise mass storage devices including flash drives in order to store extended data sets or record performance data. The apparatus may also comprise the ability to wirelessly transmit and receive data, to participate in multi unit arrays.

Another provided option is a dual axis electromechanical positioner for said optical alignment sensor, allowing usage at various angles to the visible Sun.

A first aspect of this invention is defined in claim 1, defining the method of tracking the Sun using real time location data obtained by way of GPS and position data obtained by way of magnetometry.

In a second aspect of the invention as defined in claim 9, there is provided a microcontroller-based apparatus implementing the method according to the first aspect of the invention.

In a third aspect of invention as defined in claim 16, there is provided a four quadrant optical alignment sensor used for precise alignment with the visible Sun by projecting incident sunlight onto a two-dimensional sensor array.

In a fourth aspect of the invention as defined in claim 23, there is provided a method of utilizing the apparatus according to the second aspect of the invention in conjunction with commonly available components, to assemble a complete Sun tracker system.

Preferred features of the invention have been defined by the dependent claims. In particular, a three-axis static acceleration sensing arrangement may be added to provide a measure of redundancy; artificial neural network elements are used to implement a non-linear operation under different conditions, low power RF transceiver may be used to provide wireless connectivity to an external computer or other controllers, etc;

Brief Description of the Drawings

Preferred embodiments are described by way of example, with reference to the accompanying drawings, of which:

Figure 1 shows a block diagram of the solar tracker controller;

Figure 2 shows a block diagram of the sensors block module;

Figure 3 illustrates the principle of operation of the three-axis magnetometer;

Figure 4 illustrates a side view cross section of the optical alignment sensor;

Figure 5, composed **Figures 5A** and **5B**, illustrates the arrangement of light guide(s) and photosensitive elements in the optical alignment sensor, viewed from the top;

Figure 6, composed **Figures 6A** and **6B**, illustrates the principle of operation of the optical alignment sensor;

Figure 7 illustrates a side view of an implementation of the dual axis optical alignment sensor positioner;

Figure 8 illustrates a front view of the same implementation of the dual axis optical alignment sensor positioner;

Figure 9 shows a block diagram of the user interface [UI] block module;

Figure 10 shows a block diagram of the optional payload interface block module;

Figure 11 illustrates the determination of apparatus' position based on data from the three-axis magnetometer, the GPS receiver and the planetary magnetic field model;

Figure 12 shows a side view of one embodiment;

Detailed Description of the Embodiments

Embodiments of the invention provide an automatic sun tracker controller for use with a dual axis positioner suitably chosen to support and move the payload (reflector or a collector of any practical shape or size, a photovoltaic panel , telescope or an antenna, or an array thereof) so a line perpendicular to the defining plane of said payload remains at a certain desired angle and orientation in reference to a line passing through the center of the visible Sun and the center of the controller's optical alignment sensor. Said optical alignment sensor is mounted on said positioner in a manner such that its orientation and particularly its main axis is set either permanently, or by way of a separate small X-Y positioner to the desired angle and position of orientation, relative to the said defining plane of the payload.

In the exemplary description contained herein, numerous specific details are set forth in order to provide a more thorough understanding of embodiments of the invention. It should be apparent, however, to an artisan of ordinary skill that the present invention may be practiced without incorporating all aspects of the specific so described details. Any mathematical references made herein are approximations that can in some instances be varied to any degree that enables the invention to accomplish the function for which it is designed. In other instances, specific features, quantities, or measurements well-known to those of ordinary skill in the art, or quantities and qualities of existing well-known apparatus have not been described in detail so as not to obscure the invention.

Accordingly, with reference to the block diagram of the preferred embodiment, shown in **Figure 1**, the CPU **10**, aided by its peripherals **30**, and utilizing the storage element(s) **20** where applicable, processes input signals and data from the sensors **40** and makes a determination if, how and by what amount should the actuators of the payload positioner **80** be activated in order to satisfy its purpose, i.e. pointing said payload to a given point. The user interface [UI] **50** displays status information and provides a

convenient interface for control, field updates and/or diagnostics, when needed. The optional optical alignment sensor positioner **70** provides a full 180 degree range of defining a relative angle between the apparent position of the Sun and said target point. Also optional, the Payload Interface **60** provides signals and data to the CPU to complete a feedback loop used to assure safe and efficient operation.

The CPU **10** is a suitably chosen 8, 16 or 32 bit microcontroller [MCU], which embodies not only a CPU but also peripheral interfaces, RAM, ROM (EEPROM) and flash memory. Thus, the elements of CPU **10**, Storage **20** and Peripherals **30** are commonly integrated on a single die and available as cost-effective integrated circuits [ICs]. Using highly integrated circuits decreases component count and simplifies the design of the controller.

In some circumstances the amount of needed storage can exceed the storage capacity of even the most endowed MCU. For example, if implementing a complex magnetic model with anomaly data per location, the total amount of data to store may easily reach several megabytes, in which case a separate storage means must be employed. Such means include but are not limited to FLASH memory ICs, hard drive(s), plug-in memory cards, etc.

Likewise, most MCUs have rich sets of embedded peripherals which in the vast majority of cases will deem the addition of special peripheral elements unnecessary. Yet, the chosen MCU may lack a specific functionality deemed otherwise required by the particular design – for example , CAN, or Ethernet networking capability. In such cases the appropriate peripheral has to be added as a separate element shown as **30** on **Figure 1**.

Figure 2 illustrates the contents of the sensors element **40**. To implement the designed functionality, one must employ at least one GPS receiver **41** with an associate passive or active antenna **42**. Commonly, suitable receivers are available with an embedded patch antenna, RF amplifier,

filters and a communications interface - using such integrated GPS receivers **43** simplifies the design and saves components and labor costs. One such integrated GPS receiver is Atmel's AntarisIV SuperSense for example. The multichannel integrated GPS receiver establishes a position lock automatically and provides UTC time and position data (longitude, latitude and altitude) to the CPU on demand or at predetermined intervals.

The term 'GPS' is used to denote any satellite-based radionavigation system, including but not limited to the GPS deployed by the U.S.A., Galileo deployed by EU, and GLONASS developed by Russia.

Further, at least one magnetometer **44** is employed, which may be based on any available technology – magnetoresistive, inductive, etc. To simplify the assembly, a 3-axis magnetometer is preferably used, however a combination of a dual-axis magnetometer and a single axis one installed perpendicularly to the first or a three separate single-axis magnetometers installed perpendicularly to each other will yield the same result. Such a configuration will mandate calibration as part of the manufacturing process to compensate for mechanical misalignment.

Said magnetometer **44** measures the vector of the planetary magnetic field $\mathbf{H_P}$ and maps it to an orthogonal reference with an origin at a point on the sensor, as shown in **Figure 3**. Thus, every measurement yields three separate values for the strength of the magnetic field along $\mathbf{X}$, $\mathbf{Y}$ and $\mathbf{Z}$, denoted as $\mathbf{H_{Px}}$, $\mathbf{H_{Py}}$ and $\mathbf{H_{Pz}}$ correspondingly. The inclination angle δ between the vector of the magnetic field $\mathbf{H_P}$ and the level direction of magnetic North $\mathbf{N_M}$ is computed directly, while the magnetic deviation angle λ between the magnetic North $\mathbf{N_M}$ and true North $\mathbf{N}$ for that location is calculated from the declination data stored in nonvolatile memory. These values are used by the CPU to triangulate the magnetic field vector and compare it to the one predicted by the chosen magnetic field model. From this comparison, the apparatus' orientation in 3D space for its location, and corrective angle values are computed, further used for operating the payload positioner actuators.

The magnetometer is physically affixed to the non-moveable base of the payload positioner. As local magnetic anomalies can cause errors of 5 degrees or more, desirably a second magnetometer is affixed to the moving part of said positioner, in close proximity to the payload (as shown in **Figure 12**). Then, by comparing data from the two magnetometers, the CPU can minimize the error and the controller will perform well with a less sensitive optical alignment sensor.

Said at least one optical alignment sensor **45** is employed to provide direct means for optically aligning the payload with the desired point. One embodiment of the optical alignment sensor is illustrated on **Figure 4** (side view), where four photosensitive elements **451** are mounted on a printed circuit board [PCB] **452** and the PCB is mounted within an enclosure **453** so that the respective photosensitive elements face toward the circular opening **454** on top of said enclosure with diameter Y. A light guide array **455** also of a circular shape and a diameter Z, with four defined sectors each measuring 90 degrees is installed on top of said photosensitive elements in a manner such that each so defined sector covers one and only one of said photosensitive elements, generally positioned in the centers of their respective light guide sectors, as shown in **Figure 5A** (top view). The four photosensitive elements **451** are arranged on a circle with center coinciding with the center of the light guide array at relative angles of 90 degrees and are marked **N**, **E**, **S** and **W** according to the orientation of the PCB **452** of **Figure 4**.

Alternatively, four identical and separate light guides **455-I** can be used, arranged in a similar fashion as to perform the same function of guiding the light of a 90 degree sector to only one of said photosensitive elements **451**, as illustrated in **Figure 5B**. The dead zone **459** of the light guide segment **455-I** (or array **455**) is used to attach it to the PCB and have no optical qualities contributing to the performance of its function.

With reference to **Figure 4**, the distance X between the opening **454** and light guide **455** is chosen to determine the sensitivity range of the sensor using the formula

$$X = (Z/2)/\tan(\varphi)$$

where φ is the angle of required sensitivity range and W is the diameter of the light guide.

For practical considerations, a sensitivity range of ± 10 degrees is sufficient to ensure reliable operation. Using this as a requirement, and assigning W a practical value of 30 (mm):

$$X = (30/2)/\tan(10) = 15/0.1763 \approx 85 \text{ (mm)}$$

Thus, a distance X of 85mm will deliver the required sensitivity range with the chosen light guide. The sensitivity range also depends on the diameter V of the opening **454** – the latter should be set at about 15% of the diameter W of the light guide array **455**, i.e.

$$Y \approx 15W/100$$

Using above sample data,

$$Y \approx (15*30)/100 = 4.5 \text{ (mm)}$$

The so described optical alignment sensor works by providing four measurements of luminosity – one from each photosensitive element – to the CPU for evaluation. This principle is illustrated in **Figure 6**:

In **Figure 6A** the projected light spot **LS** is shown split about 80/20 between segments **W** and **N** correspondingly of the light guide array **455**. This condition produces proportionate currents in the photosensitive

elements **451 W** and **N** and no signal (or quiescent current only) from the elements **451 E** and **S**. Comparing the four currents, the CPU estimates in what direction and by what amount should the payload positioner actuators be operated in order to equalize the signal from said four photosensitive elements. Since the optical alignment sensor is attached to the payload positioner such a condition is a measure of the angle between the payload's main axis and the line passing through the center of the Sun and the center of the opening **454** on top of the optical alignment sensor **40** illustrated in **Figure 4**.

Accordingly, in **Figure 6B** the projected light spot **LS** is shown in the middle of the light guide array **455**, corresponding to a precise alignment of the sensor with the Sun. Each segment **455 W, N, E** and **S** receives about 15% of the total amount of light projected onto the array **455**. Therefore, the proportionate currents in the photosensitive elements **151 W, N, E** and **S** will be the same and the CPU will not affect further movement of the positioner for as long as this condition persists. The magnitude of said photosensitive elements' currents is used to estimate the amount of received radiation.

In most cases the optical alignment sensor **40** will be rigidly and orthogonally affixed to the payload positioner, so operation of the controller will result in light from the Sun being orthogonally incident to the payload. In cases when a different angle of incidence is desired, the optical alignment sensor is mounted on a suitably scaled dual axis positioner **70** of its own, driven by two X-Y motors each fitted with a suitable gear to affect precise and measurable movement of the optical alignment sensor along two axes X and Y, each aligned with the X and Y axes of the payload positioner. Since the Sun tracker controller operates by aligning said optical alignment sensor with the Sun, the angle between said sensor and the payload is the angle between the Sun and the point at which the payload is aimed. With reference to **Figure 7**, the turret enclosure **701** houses all parts of the dual axis positioner, pivotably mounted on the base **702**. A motor **710** fitted

with a driving gear **711** drives a gear **712** rigidly attached to a worm gear **713**, which in turn drives the output gear **714** (sector gear type shown but not necessary). Said output gear is attached to the output shaft **715** which in turn is attached to the positioner arm **703**, affecting its rotation within a range of 180 degrees in a plane perpendicular to the plane of the base **702**. Limit switches **716** (mechanical, magnetic or optical) provide a suitable signal when the output gear **714** reaches a limit or index position. The worm gear shaft **717** is suspended on thrust bearings **718**, while the output shaft **715** is suspended on deep groove ball or sleeve-type bearings **719**, as shown on **Figure 8**.

Further in reference to **Figure 8**, a motor **720** fitted with a driving gear (not shown) drives a gear **722** rigidly attached to a worm gear **723**, which in turn drives the output gear **724**. Said output gear is attached to the base shaft **725** which in turn is attached to the base **702**. Limit switches (not shown) **724** provide a suitable signal when the output gear **724** reaches a limit or index position. The worm gear shaft **727** is also suspended on thrust bearings (not shown), while the base shaft **725** is suspended on deep groove ball bearings **729**.

Rotation of the motor **720** (X) is transferred by the gear train to the base shaft **725**, which is forcing the turret **201** to turn about in a plane parallel to the base **702** (azimuth, or X motion). Similarly, rotation of the motor **710** (Y) is transferred by the gear train to the output shaft **715**, which in turn causes the positioner arm **203** to rotate as previously said. In this manner, and with suitable control signals, a payload (the optical alignment sensor **70**, for example) attached to said arm **203** can be pointed to any point within a full hemisphere with a zenith aligned with the axis of the base shaft **725**.

Both motors **710** and **720** may be based on any available technology, however stepper motors are especially suitable since they can be used in an open loop mode. DC motors must be fitted with a shaft encoder providing

signals indicative to the angle of shaft rotation to facilitate a closed loop servo control.

Further, with reference to **Figure 2**, the accelerometer **46** is an optional sensor that, when used, can provide supplemental data to estimate the tilt of the Sun tracker controller or its supporting structure, or both. A single-axis sensor may be used to supplement or verify calculated position reading in any one of the three axes, a dual-axis sensor data will apply to any two axes, while a triaxial sensor would be useful in absolute orientation calculations. Although several single-axis sensors may be utilized, using integrated multiple-axis devices will deliver greater precision by eliminating or minimizing inherent errors due to manufacturing tolerances. To be useful as a sensor in this context, the accelerometer must have static gravity sensitivity.

The thermometer **47** is another optional sensor. Its data can be used to estimate environmental conditions and control payload position to either affect the process efficiency or take evasive action should inclement weather conditions prevail and threaten the apparatus' integrity. The thermometer can be implemented as simply as a diode-connected bipolar transistor, or as stand-alone IC with a digital output, without affecting the overall controller performance.

Another optional sensor is the anemometer **48**. The wind speed and direction data provided from an anemometer in either analog or digital format is processed by the CPU on its own or in conjunction with other sensors' data to determine when the system operates outside design parameters. Namely, such data can be used to cause the positioner to turn away from potentially damaging winds, or stow the payload in a specific position.

The wind speed and direction sensor may use any available technology, however ultrasonic measurement is preferred for its reliability and durability. When used, the wind sensor must be installed in a position

aligned with the major axes of the positioner and where it is not obscured by any part of the payload or its support structure.

Yet another optional sensor is the hygrometer **49**. Its data can be used, particularly in conjunction with data from a thermometer **47**, to detect dangerous or efficiency-impairing environmental conditions and initiate appropriate action. The hygrometer can be of any type, and multiple sensors can be used at different points of the payload or its supporting structure if such an arrangement is needed to build a more complete picture of the surrounding environmental conditions.

A typical user interface **50** illustrated on **Figure 9** comprises means for communicating controller status to, and for accepting commands and instructions from the end user. A multicolor LED **52** provides sufficient level of status information, or a LCD display may be added to provide additional details. Momentary buttons **53** are used for manual reset, 'go to' commands or other desirable functions, while one or more switches **54** control power to the controller, its modules or the backup battery.

A multi pin connector **51** can be used to connect an external cable to a personal computer or non-volatile memory media for updates of controller programming and data. Alternatively, a short-range low power RF transceiver **55**, for example one implementing IEEE 802.11.x or 802.15.x standards can be used to allow wireless communications with a suitably interfaced personal computer. Using an OEM module **57** having the antenna **56** integrated with said transceiver yields cost savings and design simplicity.

The payload interface **60** is an optional element, used to provide means for accepting status or command signals from or sending those to the payload. This is especially useful when the combination of payload and controller/positioner is to work as a single integrated system, e.g. the amount of heat generated by a concentrating solar collector can be varied

or regulated by monitoring the focal temperature and moving the reflector off the Sun when lower temperature is needed, and vice-versa.

For that purpose, at least two suitably interfaced CPU signal inputs/outputs **61** are reserved for a connection to payload interface, when used. Both power **63** and ground **64** are also provided. For better noise immunity and flexibility, a standard bus interface **62** is also provided, as shown on **Figure 10**. In the preferred embodiment a simple LIN interface is enough to provide basic Master-Slave functionality when needed. Any other desirable standard bus hardware layer and protocol may be implemented, including but not limited to CAN, RS-232 or 485, IIC, etc.

Normally the bus protocol is taken care of either automatically by the interface hardware layer or by software in the CPU.

The payload positioner **80** is also not subject to the disclosure presented herein – any suitable dual axis positioner can be used successfully, for example one similar to the optical alignment sensor positioner **70** described herein (suitably scaled up), with care taken to ensure the control signals for its motors and feedback signals from its sensors are suitably formatted. This includes calibration and/or modification of the controller firmware to accommodate different positioner requirements as necessary.

One embodiment, suitable for mounting on the moving portion of the payload positioner is illustrated on **Figure 12**, showing the relative placing of the CPU **10**, magnetometer **44**, GPS receiver with embedded patch antenna **43** and the optical alignment sensor **45**, mounted on a single printed circuit board **100**. The optical alignment sensor's cone may be made as part of the controller enclosure whenever the former is not used as a separate component. Also shown is a battery module **90** used to supply power to all electronic components. Connecting cables, solder joints and other detail are not shown in this illustration.

Principle of Operation

Accordingly, the Sun tracker affects the movement of the payload positioner 80 in a manner such that the payload is automatically kept aligned with (pointing to) a point at a given angle relative to the Sun as follows:

On demand, the GPS receiver **43** provides location, altitude and time fix, and the magnetometer provides 3D magnetic field strength data to the CPU. With reference to **Figure 11**, suitable magnetic field model data, for example IGRF, or WMM, is stored in the non-volatile memory and used by the CPU to calculate a theoretical value for the magnetic field vector $\mathbf{H}_{pc}$ at that location and time. Calculating the theoretical magnetic field model establishes an artificial horizon where both X and Y axes, with origin at the GPS receiver antenna are level, with X pointing to the payload, Y pointing 90 degrees clockwise and the Z axis pointing toward the ground (down). Thus, the CPU calculates theoretical components $\mathbf{H}_{pxc}$, $\mathbf{H}_{pyc}$ and $\mathbf{H}_{pzc}$ correspondingly, the inclination angle δ and the magnetic deviation angle λ . Next, the magnetometer **44** data yields actual values for the measured magnetic field $\mathbf{H}_{px}$, $\mathbf{H}_{py}$ and $\mathbf{H}_{pz}$ along the X, Y and Z axes with an origin at the sensor. The error due to the distance $\mathbf{D}$ between the GPS receiver antenna and the magnetometer is negligible for this application, so we can superimpose the origins of both coordinate systems and compare the calculated magnetic field vector $\mathbf{H}_{pc}$ and the measured vector $\mathbf{H}_p$. From that comparison the CPU makes a determination of the orientation of the magnetometer **44** (thus the solar tracker) in reference to both level and North. True North is calculated using the calculated value for the magnetic deviation angle λ .

Further, the CPU calculates the apparent position of the Sun using said location and time data from the GPS receiver **43**. The calculation is straight forward:

- Calculate the Julian Date Number;
- Calculate the Mean Anomaly;
- Calculate the Equation of Center;

- Determine the ecliptical coordinates of the Sun, using stored planet-centric perihelion and Obliquity of the Ecliptic values;
- Rotate the ecliptical coordinates to equatorial coordinates, to find the Right Ascension [R.A.] and declination values;
- Using sidereal time, calculate the horizontal coordinates, in terms of azimuth and elevation;

Knowing the mechanical ratio of the payload positioner and its current position (by keeping a track of offset from a known position, e.g. center, or limit), the CPU can calculate the number of revolutions or part thereof each motor must make in order to move the payload the difference between current position and said horizontal coordinates of the Sun.

Additionally, once a day the sunrise and sunset times are computed, to determine the system operational parameters. The optional self organizing map [SOM] can be used to automatically calibrate the system by using sunrise and sunset times in conjunction with insolation data from the optical alignment sensor. Thus, the system self-calibrates to compensate for stationary obstructions, such as landscape or buildings, specific to the installation location.

Any errors from magnetic anomalies or system mechanics are compensated for by the optical alignment sensor, which is used to fine tune the payload position by iteratively obtaining a reading from its four photosensitive elements and affecting a unit payload positioner movement until the signals from said four photosensitive elements are equalized. Due to its design, this condition is only possible when the optical alignment sensor is precisely aligned so incident sunlight is strictly orthogonal to the plane of its photosensitive elements. By affecting movement of the optical alignment sensor X-Y positioner **70** (when used), the CPU can define and maintain any prescribed angle between the payload and the visible Sun within a +/- 90 degree range in both azimuth and elevation. To achieve larger angles, the payload is simply flipped by 180 degrees.

With fine tuning achieved as described, the CPU records the difference between the calculated and actual positions of the Sun and these data are used as calibration coefficients as long as the apparatus remains at that location. This approach is especially useful in times when dead reckoning must be performed (under cloudy skies and night time).

Although this tracking method can be employed with reasonable accuracy when the Sun is below the horizon, in most cases the controller will have to reposition the payload after the Sun is no longer visible, as per application requirements. Further, adequate repositioning is also possible in response to environmental factors detected by the optional wind gauge, thermometer(s) and hygrometer(s), or end user input, such as 'go to' or 'maintenance' commands.

Claims

1. A method for tracking the Sun's apparent position in the sky using timing and position data from at least one GPS receiver, orientation data from at least one magnetometer, ephemeris data and planetary magnetic field model data, analyzing such data in real time and affecting movement of a dual axis positioner by means of electrical control signals.
2. The method of claim 1 further comprising using data from an optical alignment sensor, used to achieve precise alignment with the visible Sun.
3. The method of claim 1 further comprising: calculating Sun ephemeris data from locally stored metadata and position data from said at least one GPS receiver, where said metadata comprises planet-specific coefficients and formulae.
4. The method of claim 1 further comprising: calculating the planetary magnetic field vector for that location using locally stored magnetic field model data, where such data comprises coefficients and formulae.
5. The method of claim 1 further comprising: comparing the calculated planetary magnetic field vector with the one measured with said at least one magnetometer, to ascertain the apparatus position relative to the horizon and true North.
6. The method of claim 1 further comprising an artificial neural network structure – Self Organizing Map – to automatically calibrate the system for optimal operation in its specific location.
7. The method of claim 1 further comprising using data from a three axis accelerometer, to minimize errors when operating in dead reckoning mode.
8. The method of claim 1 further comprising: field updating locally stored metadata and programming data via hardware user interface.

9. A solar tracker controller implementing the method of claim 2, comprising a computing element configured to align a payload to point at a given point, the location of which is described in coordinates relative to the Sun's apparent position in the sky.

10. The solar tracker controller of claim 9 further comprising: at least one GPS receiver; at least one magnetometer and, said computing element configured to utilize time and position information from said at least one GPS receiver and orientation information from said at least one magnetometer in order to align said payload with said point.

11. The solar tracker controller of claim 9 further comprising a storage device configured to store planetary magnetic field model coefficients and formulae data.

12. The solar tracker controller of claim 9 further comprising a storage device configured to store metadata regarding its operation.

13. The solar tracker controller of claim 11 further comprising a current dataset of said planetary magnetic field model.

14. The solar tracker controller of claim 9 further comprising a central processing unit [CPU] and peripheral components coupled with said CPU.

15. The solar tracker controller of claim 9 further comprising at least one optical alignment sensor.

16. The optical alignment sensor of claim 15 comprising: an opaque enclosure with a small opening covered by a transparent lens; at least four photosensitive elements mounted in a plane parallel to the plane of said transparent lens and set at some distance from it, within said enclosure; a light guide divided in four sectors and mounted on top of said photosensitive elements in a manner such that each such element receives

light only from its overlapping sector; and active and passive electronic components used to condition the electric signal from each of said photosensitive elements.

17. The optical alignment sensor of claim 16 having said photosensitive elements arranged at an angle of 90 degrees relative to each other, on a circle with a center at the center of the orthogonal projection of said small opening of the enclosure onto the mounting plane of said photosensitive elements.

18. The solar tracker controller of claim 9 further comprising a dual axis positioner for the optical alignment sensor of claim 15.

19. The solar tracker controller of claim 9 further comprising at least one accelerometer.

20. The solar tracker controller of claim 9 further comprising at least one wind speed and direction sensor.

21. The solar tracker controller of claim 9 further comprising at least one temperature sensor.

22. The solar tracker controller of claim 9 further comprising at least one humidity sensor.

23. A method for utilizing the solar tracker controller of claim 9 comprising: coupling a payload with a dual axis electromechanical positioner controlled by said solar tracker controller; at least one positioning arm coupled with said payload; an elevation motor coupled with said positioning arm and housed within a positioner enclosure; an azimuth motor housed in said positioner enclosure; a positioner base coupled with said azimuth motor.