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Baun et al.

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- (54) **SELF-ALIGNING TELESCOPE**
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- (*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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G02B 23/00 (2006.01)
- (52) **U.S. Cl.** **359/429; 250/203.6**
- (58) **Field of Classification Search** **359/429, 359/430**

See application file for complete search history.

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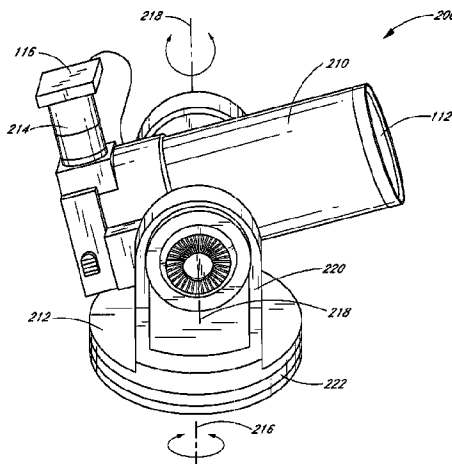
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(57) **ABSTRACT**

Embodiments of the present disclosure include self-aligning telescope control systems and self-alignment methods. In an embodiment, a telescope control system orients a telescope with respect to the celestial sphere by pointing the telescope in the direction of an alignment star or alignment area of the sky. The telescope control system images a field of view in the alignment area, and processes the images to determine the celestial coordinates of a center of the field of view the alignment area. The telescope control system then maps the telescope's coordinate system to the celestial coordinate system. Once mapped, the telescope control system can advantageously slew the telescope to any desired celestial object in the viewable sky based on, for example, user selection, system recommendations, combinations of the same, or the like.

13 Claims, 9 Drawing Sheets



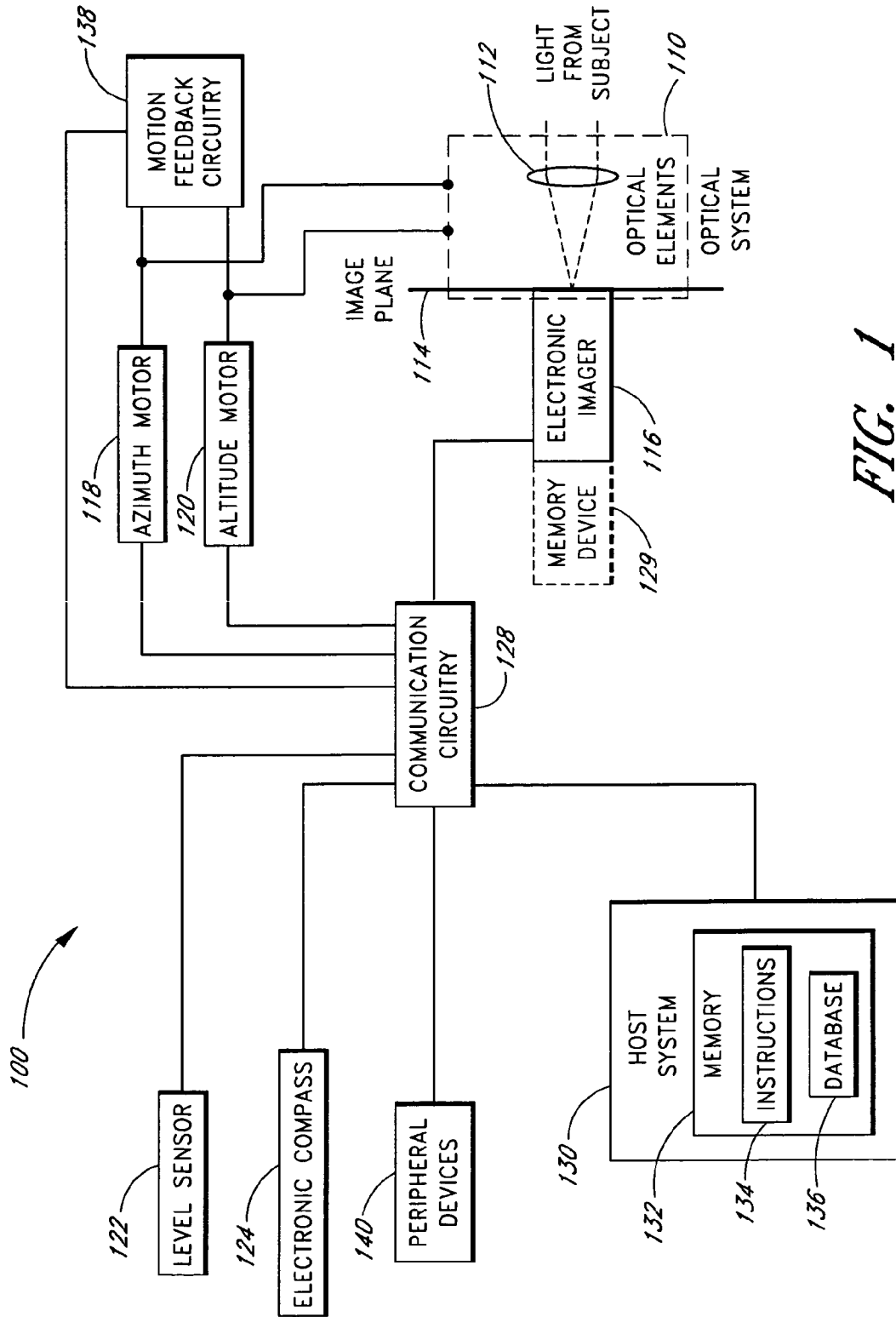


FIG. 1

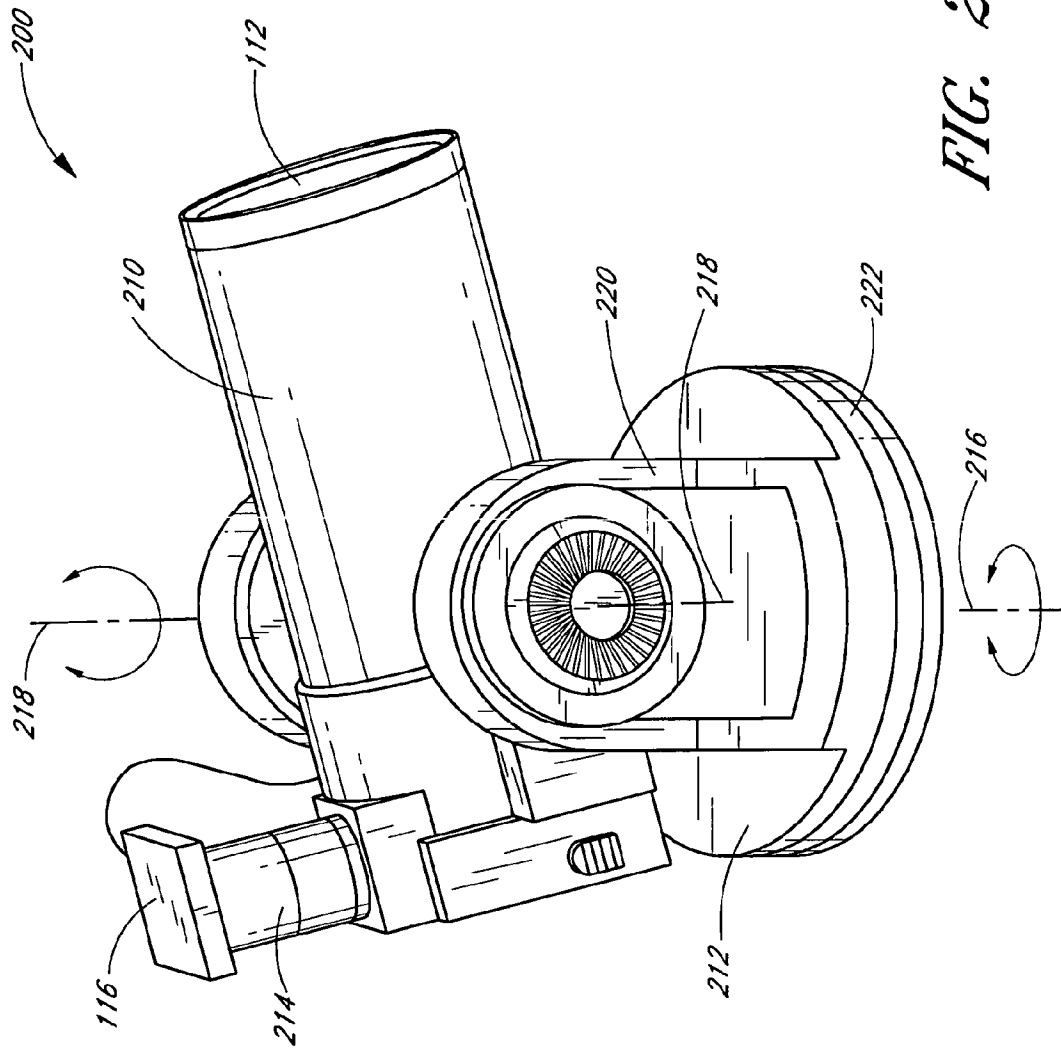
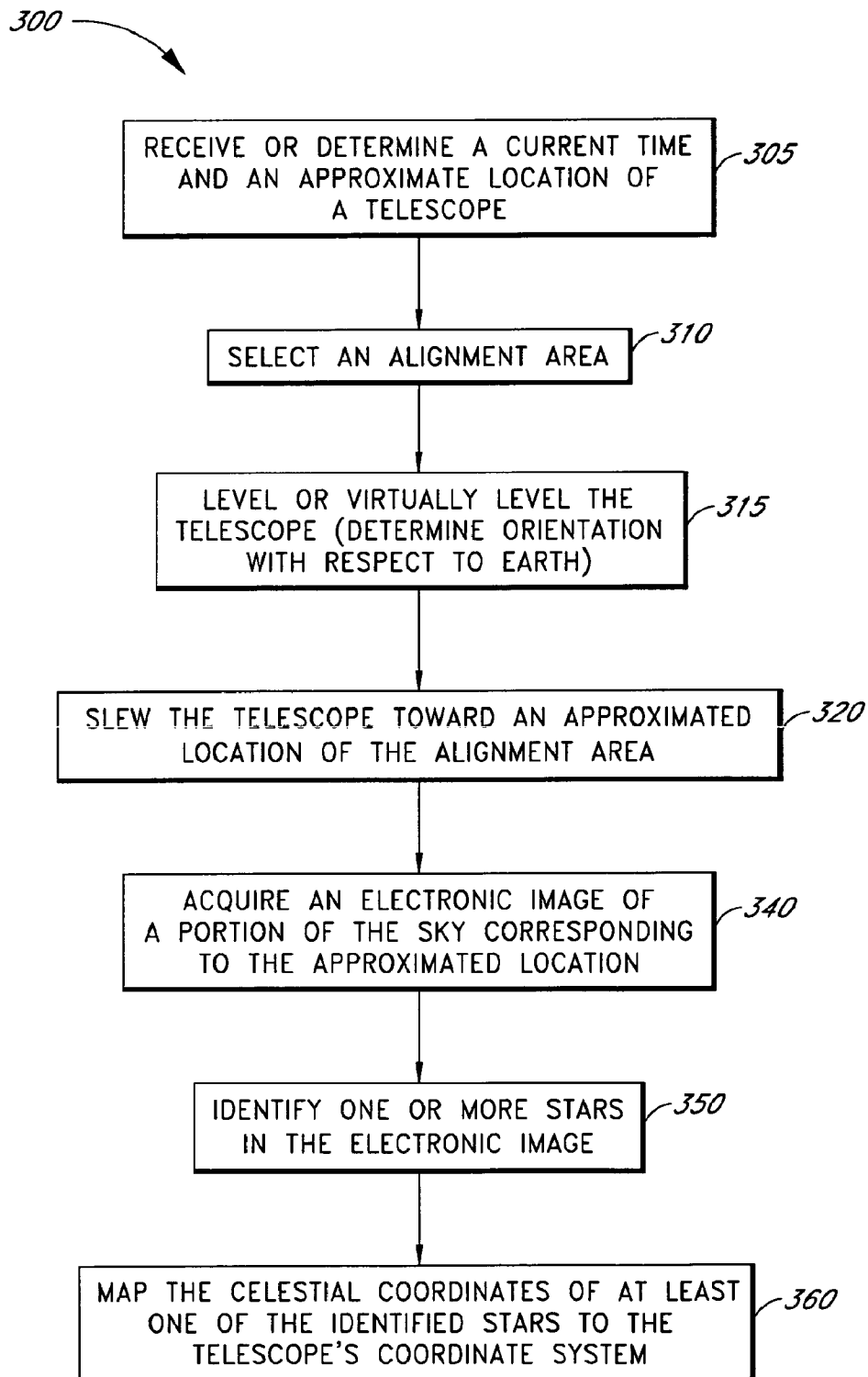


FIG. 2

*FIG. 3*

315 →

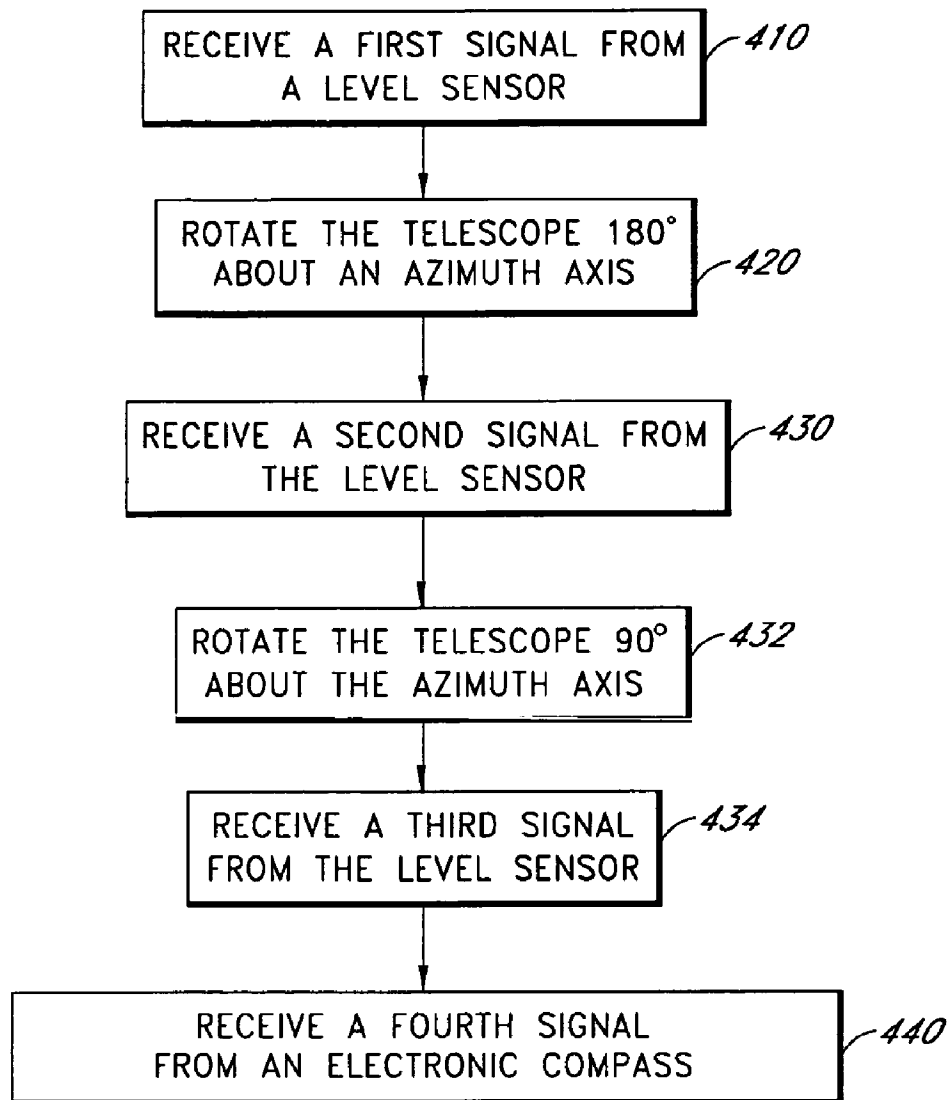


FIG. 4

350

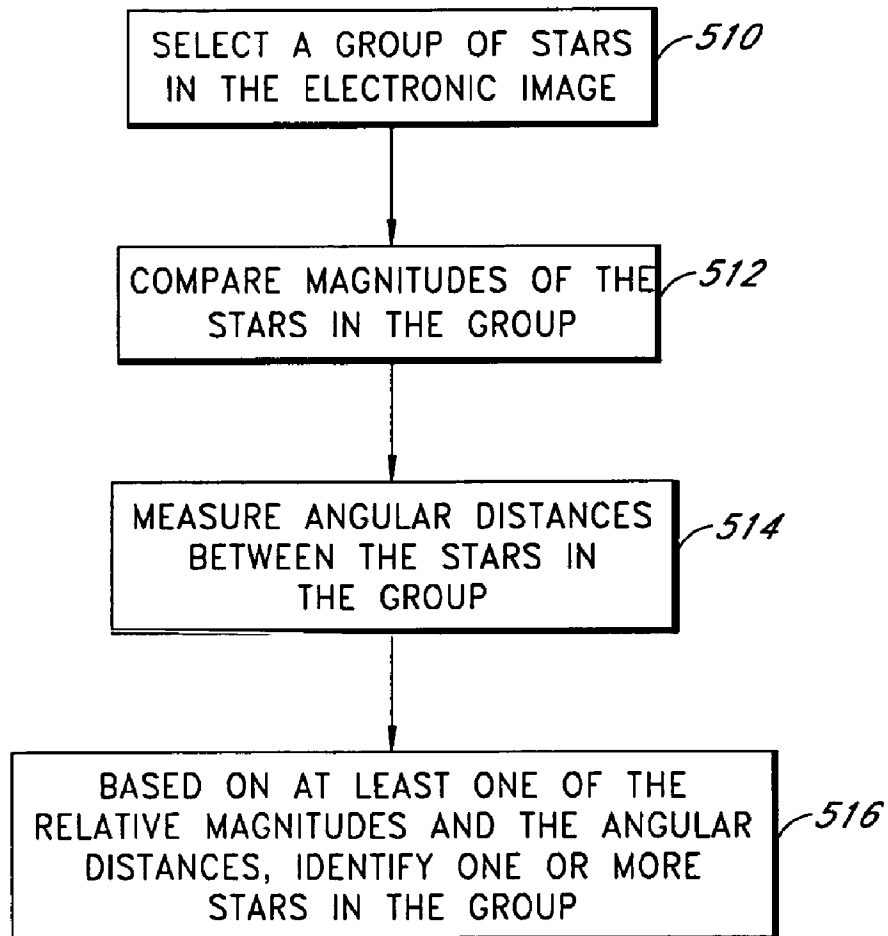


FIG. 5

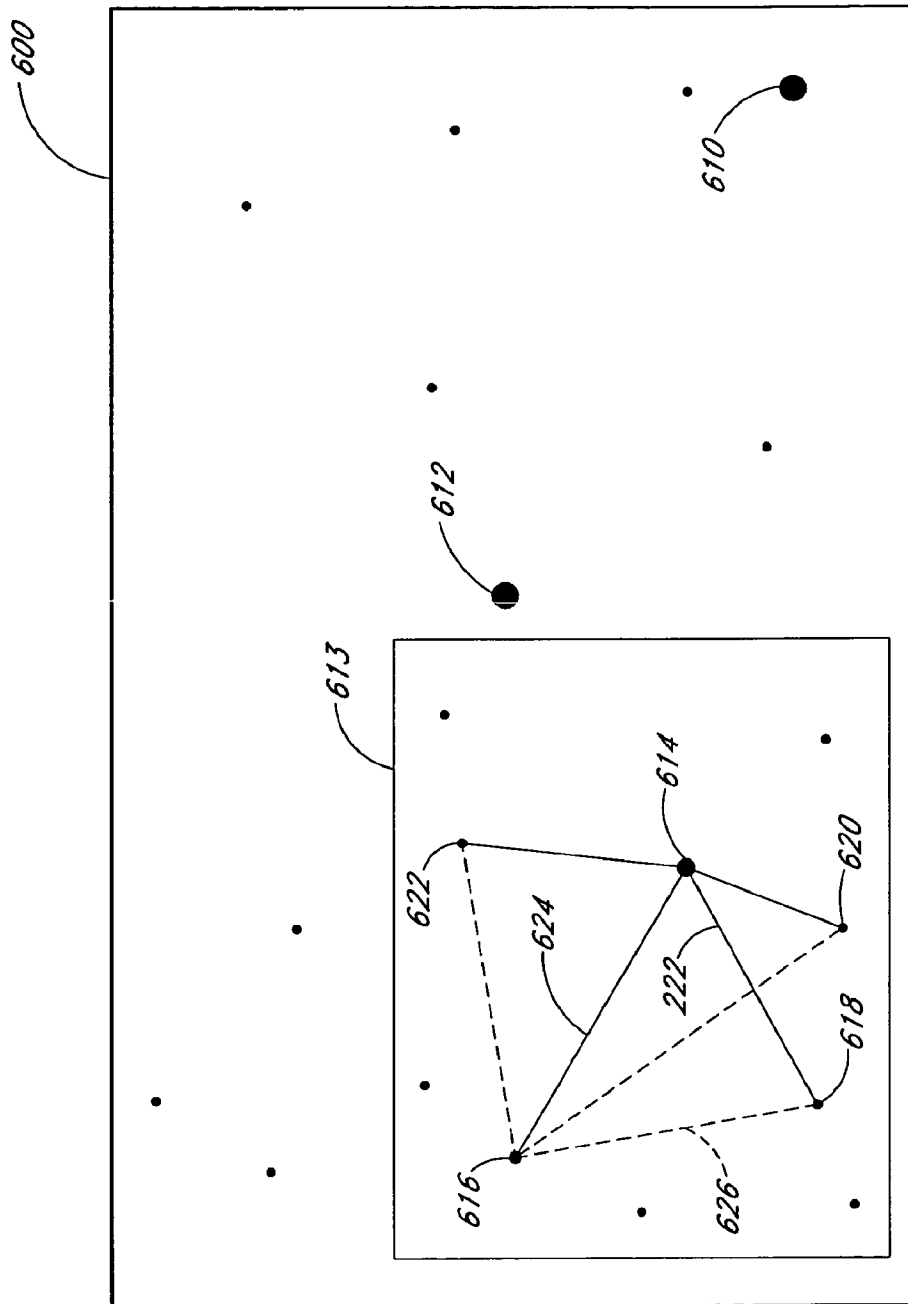
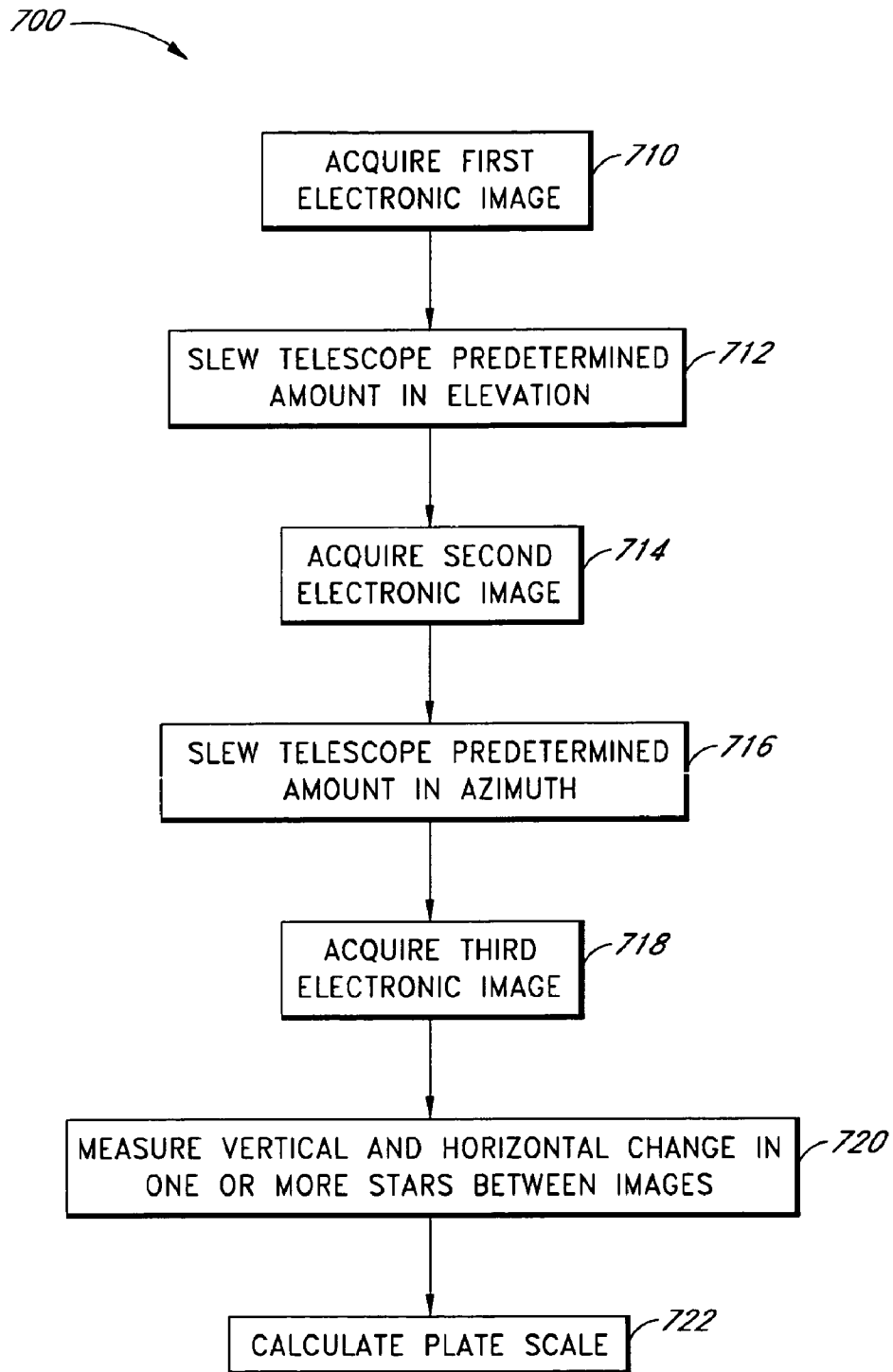


FIG. 6

*FIG. 7*

800

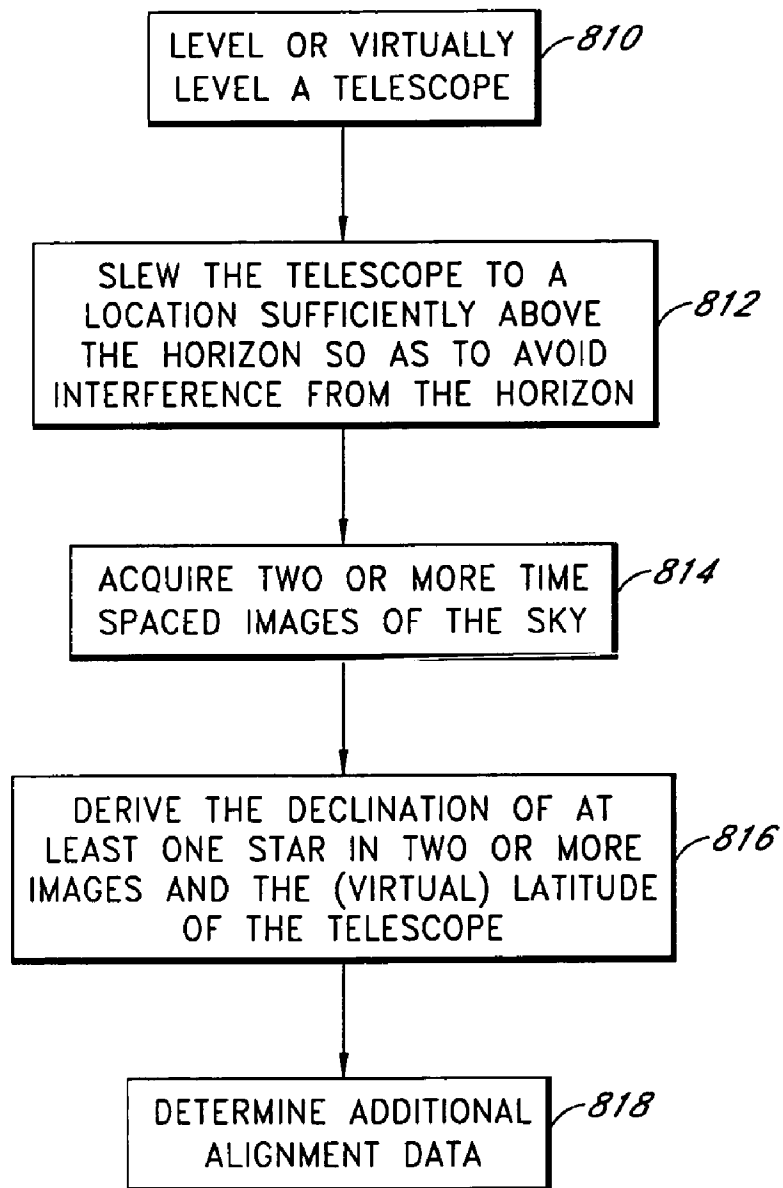



FIG. 8

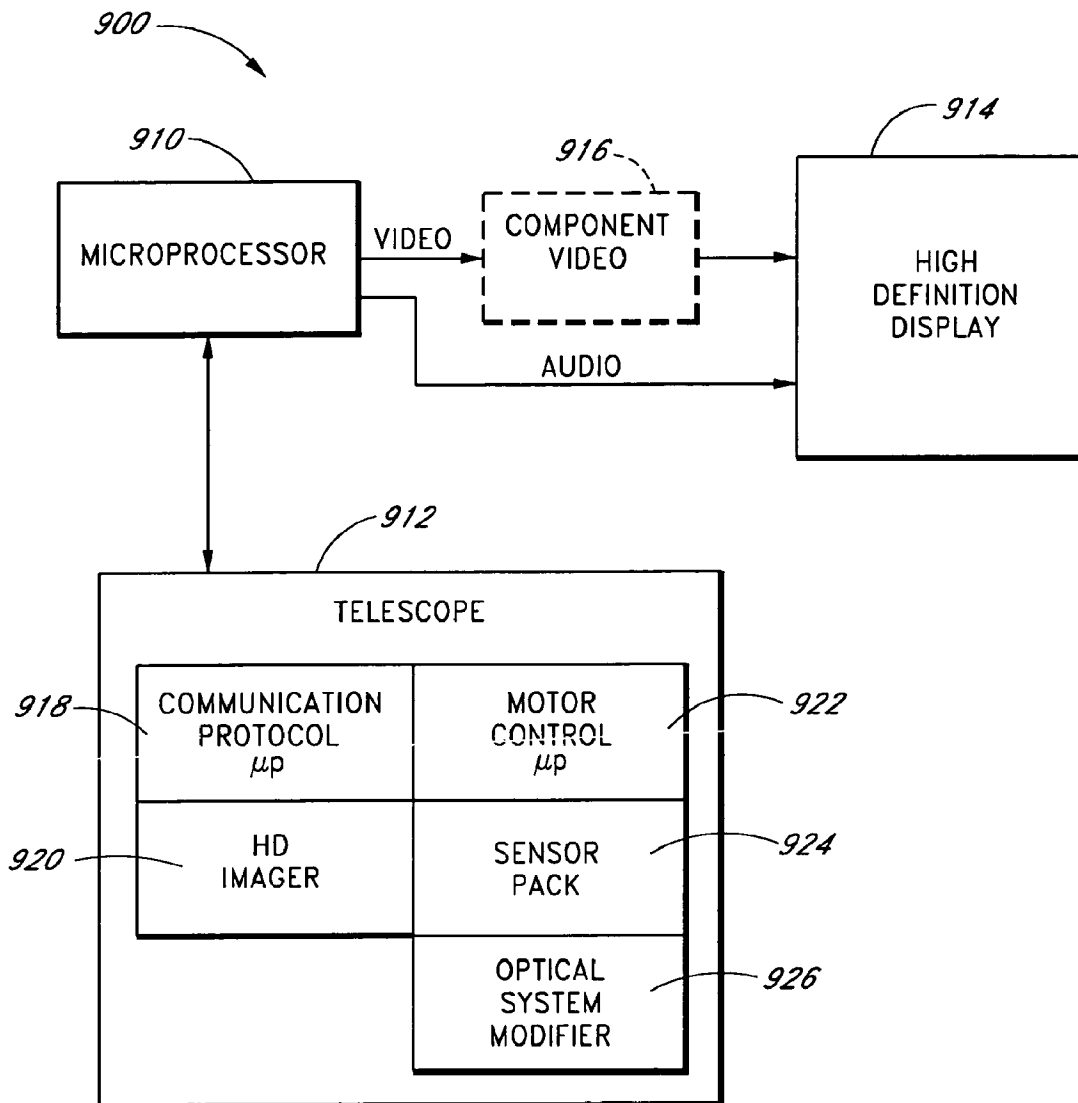


FIG. 9

SELF-ALIGNING TELESCOPE

REFERENCE TO RELATED APPLICATIONS

The present disclosure relates to U.S. patent application 5
Ser. No. 11/110,484, filed herewith titled "High Definition
Telescope," incorporated by reference herein.

BACKGROUND

1. Field of the Disclosure

The present disclosure relates to telescope control systems
and, more particularly, to systems and methods for aligning
and orienting telescopes.

2. Description of the Related Art

The continuing evolution of low cost, high performance
telescopes has decreased the complexity of finding and
tracking stars, planets and other celestial objects. Thus, the
popularity of amateur astronomy has increased. Some con-
ventional telescope systems are easy to use and are capable
of finding and tracking stars and other celestial bodies once
they are initially oriented with the celestial sphere. However,
the initial orientation is generally manual and conventional
routines that align a telescope with a desired celestial object
generally include user intervention, such as manually center-
ing the telescope on an alignment star.

Often, to view or otherwise image celestial objects, mea-
surements obtained in a telescope's coordinate system (ex-
pressed, for example, in altitude and azimuth coordinates)
are converted into the celestial coordinate system (ex-
pressed, for example, in right ascension and declination
coordinates) and vice versa. Such conversions depend at
least in part on the initial orientation of the telescope. For
example, the initial orientation of the telescope may be set
by manually pointing the telescope in a predetermined
direction, such as north or south, and leveling the telescope
such that it points toward the horizon. When a telescope
processing system knows the current date, the current time,
the location of the telescope with respect to the earth, the
right ascension of a desired celestial object, and the decli-
nation of the desired celestial object, the processing system
can convert the location of the desired celestial object from
the celestial coordinate system to the telescope's coordinate
system to indicate a change in altitude and azimuth that will
point the telescope away from its current orientation toward
the desired celestial object. Such orientation and alignment
of the telescope can be complicated to a less experienced
user.

To attempt to remedy difficulties experienced in aligning
a telescope, manufacturers have suggested aligning tele-
scopes with the celestial sphere by randomly scanning the
sky in search of bright stars. For example, when a telescope
finds a first bright star, recognized through for example, user
interaction, the telescope monitors changes in altitude and
azimuth as it scans for additional bright stars. Upon receiv-
ing an indication of alignment with an additional bright star,
the telescope compares its respective altitude and azimuth
measurement changes to determine an angle between the
now located two bright stars. After the telescope has
recorded multiple angles between randomly found bright
stars, the collection of determined angles may produce
shapes that the telescope may recognize from, for example,
data of known shapes between known bright stars. Once the
shape is recognized, manufacturers believe the telescope
will have sufficient information to align itself with the sky.
However, because of many difficulties, including random
searching with limited fields of view and potentially large

comparison data sizes, such shape-oriented alignment sys-
tems may be extraordinarily slow and potentially inaccurate.

SUMMARY OF THE DISCLOSURE

Embodiments of the present disclosure include advanta-
geous self-aligning telescope control systems that quickly
and accurately orient a telescope. For example, in an
embodiment, a telescope control system acquires at least one
image of stars in an alignment area, attributes intensity
values to some of the stars, determines relationships based
on the intensity values, and matches the relationships with
known relationships about celestial bodies to quickly orient
the telescope with known celestial mappings of the sky.
Once oriented, the telescope control system can then slew to
a desired celestial object based on, for example, user or
system selected objects. In an embodiment, the telescope
control system may slew to additional alignment areas, and
quickly reorient the telescope to increase the accuracy of the
telescope's self alignment.

Certain embodiments provide self-aligning telescope con-
trol systems with additional information such as, for
example, time, date, location with respect to the earth,
celestial coordinates of an alignment star or alignment area,
relative brightness of a group of stars in an alignment area,
distances between the stars in the group of stars in the
alignment area, patterns formed by stars in vicinity of the
alignment star, combinations of the foregoing, or the like. In
certain embodiments, determining a telescope's location
with respect to earth may include use of a virtual location,
thereby substantially avoiding often confusing initial preci-
sion leveling techniques. For example, a telescope control
system may orient with respect to the horizon and/or a
predetermined compass direction in response to receiving
information from a level sensor, an electronic compass, or
the like. Such self orientation creates a virtual location for
the telescope, where the virtual location at least roughly
corresponds to a location where the telescope's position with
respect to the horizon would be considered accurately lev-
eled.

In still other embodiments, the control system may advan-
tageously perform additional or alternative alignments, such
as, for example, measuring a sidereal drift of an alignment
star to improve the accuracy of the mapping.

Once aligned, other embodiments of the telescope control
system may advantageously slew the telescope to view any
desired celestial object, such as an object especially inter-
esting for the particular imaging time and imaging location.
For example, an imager of the telescope control system may
acquire potentially high quality celestial images or data.
Moreover, the telescope control system may process the
image data to advantageously increase the aesthetics of a
displayed image, highlight various comparative data,
increase the image's accuracy, sharpness, detail, contrast, or
the like. Once prepared, the telescope control system outputs
video or other signals to one or more displays in a multi-
media or other image presentation, such as an entertainment,
commercial, academic, or other presentation. In certain
preferred embodiments, such display comprises high defi-
nition displays, or the like.

Also, other features and advantages of the present dis-
closure will become apparent to those of ordinary skill in the art
through consideration of the ensuing description, the accom-
panying drawings, and the appended claims. Neither this
summary nor the following detailed description defines the
scope of the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

Systems and methods which embody the various features of the disclosure will now be described with reference to the following drawings:

FIG. 1 is a block diagram illustrating a telescope control system according to an embodiment of the disclosure;

FIG. 2 is a perspective view of an exemplary telescope according to an embodiment of the disclosure usable by the telescope control system shown in FIG. 1;

FIG. 3 illustrates an exemplary self-alignment process according to an embodiment of the disclosure;

FIG. 4 illustrates an exemplary initial orientation determination process of the self-alignment process of FIG. 3, according to an embodiment of the disclosure;

FIG. 5 illustrates an exemplary field of view identification process of the self-alignment process of FIG. 3, according to an embodiment of the disclosure;

FIG. 6 is an exemplary graphical representation of an alignment area used in the field of view identification process of FIG. 5, according to an embodiment of the disclosure;

FIG. 7 illustrates an exemplary plate scale determination process according to an embodiment of the disclosure;

FIG. 8 illustrates an exemplary self-alignment process according to another embodiment of the disclosure; and

FIG. 9 is a block diagram illustrating a high definition telescope system according to an embodiment of the disclosure.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Embodiments of the present disclosure involve a telescope control system that orients a telescope with respect to the celestial sphere. To orient the telescope, certain embodiments of the telescope control system point the telescope in the direction of an alignment star or alignment area of the sky. The telescope control system images a field of view in the alignment area, and processes the images to determine the celestial coordinates of a point such as a center of the field of view the alignment area. The telescope control system then maps the telescope's coordinate system to the celestial coordinate system. Once mapped, the telescope control system can advantageously slew the telescope to any desired celestial object in the viewable sky based on, for example, user selection, system recommendations, combinations of the same, or the like.

In certain embodiments, the telescope control system seeks to improve the accuracy of the foregoing self alignment procedure. For example, the telescope control system may advantageously slew to an additional alignment area and realign, may advantageously measure the drift of one or more alignment stars or the desired celestial object, combinations of the same, or the like.

In certain embodiments, the telescope control system may also advantageously determine a first orientation of the telescope with respect to the earth. For example, the system may determine the telescope's position with respect to the horizon and its pointing position. For example, if the telescope is located in the northern hemisphere, its orientation with respect to a level plane and magnetic north may be approximately determined. Given the date, time and location of the telescope with respect to the earth, the telescope control system can move the telescope from its initial orientation toward a celestial object having known celestial coordinates, such as an alignment star, group of alignment

stars, alignment area, or the like. In certain embodiments, a user provides the date, time and location information. In other embodiments, a host system or peripheral device may advantageously provide at least one of the date information, the time information and the location information.

Once aligned, the telescope control system may advantageously slew the telescope to view any desired celestial object. Moreover, the telescope control system may advantageously suggest interesting or otherwise desired objects based on the time, date, and location of the telescope. The control system may also configure or suggest configurations for its own processing, for the telescope, for telescope accessories such as magnification devices, optical filters, or the like, for environmental concerns, or the like. The telescope control system may also employ an imager to develop potentially high quality celestial images or data. Such images or data may be compiled from one or more pictures, may be resized, recolored, or the like, may be the result of a mosaic of pictures, may be processed data such as spectral or other views, may be combined image data such as a mosaic-ed image of Jupiter with added images of one or more of its moons in actual or altered colors, combinations of the same, or the like. Such data and image processing may advantageously increase the aesthetics of the displayed image, may highlight various comparative data, may increase the image's accuracy, sharpness, detail, contrast, or the like. Once prepared, the telescope control system may advantageously output video or other signals to one or more displays in a multi-media or image presentation. In certain preferred embodiments, such display comprises high definition displays, or the like. For example, such display may comprise entertainment, academic or other presentations that may be self selected based on programs like "Tonight's Best" commercially available from Meade Instruments Corporation of Irvine, Calif., may be selected through user interaction, combinations of the same, or the like.

The telescope control system may also be located in a first area or device, the telescope may be located in the same or other area or device, and the presentation may be located in one of the disclosed areas or devices or in additional other areas or devices. For example, the telescope control system may be comprised of computer software executing on a computing device such as a laptop, and controlling electronic controls of a remotely located telescope, such as, for example, a personal, academic, or governmental telescope. The image data may be displayed on the computing device, or displayed on remote display devices such as, for example, high definition display devices located in a personal, entertainment, academic, or other viewing setting.

To facilitate an understanding of the disclosure, the remainder of the detailed description references the drawings, wherein like reference numbers are referenced with like numerals throughout. Moreover, the drawings show, by way of illustration, specific embodiments or processes in which the disclosure may be practiced. The present disclosure, however, may be practiced without the specific details or advantages or with certain alternative equivalent components and methods to those described herein. In other instances, well-known components and methods have not been described in detail so as not to unnecessarily obscure aspects of the present disclosure.

FIG. 1 is a block diagram illustrating a telescope system 100 according to an embodiment of the disclosure. The telescope system 100 includes an optical system 110 configured to collect light from a subject through optical elements 112 and to focus the light at an image plane 114. The telescope system 100 also includes an electronic imager 116,

5

an azimuth motor **118**, an altitude motor **120**, a level sensor **122** and an electronic compass **124** coupled to communication circuitry **128**. In an exemplary embodiment, the level sensor **122** comprises an accelerometer such as a dual axis accelerometer, part number MXD2020E/F, available from MEMSIC, Inc. of North Andover, Mass. In addition, or in another exemplary embodiment, the electronic compass **124** comprises, for example, a magneto-inductive sensor, part number SFN-I., available from Precision Navigation, Inc. of Santa Rosa, Calif., although an artisan will recognize from the disclosure herein other level sensing devices could be used.

The electronic imager **116** is configured to generate an electronic image of the light from the subject. Thus, the electronic imager **116** is positioned with respect to the image plane **114** so as to receive a focused optical image of the subject. In certain embodiments, the electronic imager **116** comprises, for example, a charge coupled device (CCD) camera, a complimentary metal oxide semiconductor (CMOS) image array, or the like. In certain embodiments, the electronic imager **116** includes a memory device **129** for storing images generated by the electronic imaging device **116**. The memory device **129** may comprise, for example, a removable or non-removable flash memory device, a miniature hard-drive, or another memory device associated with digital cameras, digital camcorders, cell phones, personal digital assistants (PDAs), other computing devices, or the like.

In addition to or as an alternative to storing images in the memory device **129** of the electronic imager **116**, the communication circuitry **128** transmits data from the electronic imager **116** to a telescope control or host system **130**. The host system **130** is configured to receive image data, provide control signals to the azimuth and altitude motors **118**, **120**, analyze the data, and optionally, to display images generated by the electronic imager **116**. The analysis may include, for example, identifying an alignment star or group of alignment stars and calculating how far to rotate the azimuth motor **118** and the altitude motor **120** to align the optical system **110**, as described herein. The host system **130** may be configured to interface with input devices (not shown) such as an Internet or other network connection, a mouse, a keypad or any device that allows an operator to enter data. The host system **130** may also include output devices such as printers, displays or other devices or systems for generating hard or soft copies of images or other data. In certain embodiments, the host system **130** is configured to interface with a television, such as a high-definition television, to display images from the electronic imager **116** thereon.

In an exemplary embodiment, the host system **130** comprises a handheld device. In other embodiments, the host system **130** may comprise, for example, a computer system, a personal computer, a laptop computer, a set top box for a television, a personal digital assistant (PDA), a network, combinations of the same, or the like. The communication circuitry **128** may, for example, transmit the data to the host system **130** wirelessly, through a direct electrical connection, or through a network connection. In certain embodiments, the communication circuitry **128** comprises a universal serial bus (USB) adapter. In other embodiments, the communication circuitry **128** comprises a wireless Ethernet adapter or other network adapter.

In certain other embodiments, the host system **130** comprises a controller housed with the optical system **110** and/or the electronic imager **116**. For example, the host system **130** may comprise one or more controllers, program logic, hardware, software, or other substrate configurations

6

capable of representing data and instructions which operate as described herein or similar thereto. The host system **130** may also comprise controller circuitry, processor circuitry, digital signal processors, general purpose single-chip or multi-chip microprocessors, combinations of the foregoing, or the like. In such embodiments, the communication circuitry **128** comprises a system bus or other electrical connections.

As shown in FIG. 1, in certain embodiments, the host system **130** includes an internal memory device **132** comprising, for example, random access memory (RAM). The host system **130** can also be coupled to an external memory device (not shown) comprising, for example, drives that accept hard and floppy disks, tape cassettes, CD-ROM or DVD-ROM. The internal memory device **132** or the external memory device, or both, comprise program instructions **134** for aligning the optical system **110**, composing images of the subject and other functions as described herein.

In certain embodiments, the internal memory device **132** or the external memory device, or both, also comprise one or more databases **136** including at least one database of the celestial coordinates (expressed, for example, in right ascension and declination or other well known coordinate systems) of known celestial objects that might be of interest to an observer and/or that are useful to align the optical system **110**. For example, the database **136** may include celestial coordinates and intensities of an alignment star or a group of alignment stars. The database **136** may also define a pattern made by at least one group of alignment stars. For example, the database **136** may include relationship information for the group of alignment stars such as brightness relative to one another, angular distances to one another, angles between each other, combinations of the foregoing, or the like. Other exemplary relationships between celestial objects are discussed herein. As discussed below, in certain embodiments, the host system **130** is configured to automatically recognize a pattern of alignment stars and center the optical elements **112** on a desired celestial object selected from the database **136**. In certain embodiments, the host system **130** also uses information from the database **136** to drive a focus motor (not shown) to automatically focus the optical system **110** on the desired celestial object.

The database **136** may also include, for example, a database of the geographical coordinates (latitude and longitude) of a large number of geographical landmarks. These landmarks might include known coordinates of cities and towns, geographic features such as mountains, and might also include the coordinates of any definable point on the earth's surface whose position is stable and geographically determinable. Thus, a user can estimate the position of the optical system **110** with respect to the earth by referencing a nearby geographical landmark in the database. As discussed below, in other embodiments, location information is provided automatically from a global positioning system (GPS) receiver. In certain embodiments, the database **136** is user accessible such that additional entries of particular interest to a user might be included.

As discussed in detail below, the host system **130** controls the azimuth motor **118** and the altitude motor **120** to align the optical elements **112** with the light from the subject. The azimuth motor **118** and the altitude motor **120** are configured to rotate the optical system **110** in two mutually orthogonal planes (e.g., azimuth and altitude). In certain embodiments, the azimuth motor **118** and the altitude motor **120** are each self-contained motor packages including, for example, a DC brush-type motor, an associated electronics package on a printed circuit board, and a drive and reduction gear assem-

bly. An artisan will recognize from the disclosure herein that other known motor and/or servo systems can also be used. In certain embodiments, the azimuth motor **118** and the altitude motor **120** are coupled to motion feedback circuitry **138**, such as an optical encoder or the like. The motion feedback circuitry **138** measures the actual travel of the optical system **110** in both planes. Thus, the position of each axis (and the telescope aspect) is determinable with respect to an initial position.

In certain embodiments, the host system **130** automatically determines an orientation of the optical elements **112** using data received through the communication circuitry **128** from the level sensor **122** and the electronic compass **124**. During an initial alignment, the host system **130** determines the orientation of the optical elements **112** with respect to the horizon based on one or more signals received from the level sensor **122**. This becomes the initial altitude position. The host system also determines the orientation of the optical elements **112** with respect to north (e.g., if in the northern hemisphere) or south (e.g., if in the southern hemisphere) based on one or more signals received from the electronic compass **124**. This becomes the initial azimuth position.

In certain embodiments, the communication circuitry **128** is configured to interface with peripheral devices **140** to align the optical system **110**. The peripheral devices **140** may include, for example, a GPS receiver configured to accurately indicate the longitude and latitude of the telescope system **100** and/or a clock configured to accurately indicate the date and time. It should also be understood that a GPS receiver is able to provide timing signals which can function as precision timing reference signals. Thus, coupling a GPS receiver to the telescope system **100** provides not only coordinated timing data but also user position data from a single device. Thus, these parameters may advantageously be determined without manual entry.

In addition, or in other embodiments, the peripheral devices **140** may include, for example, an electronic focusing system, a laser configured to emit laser light in the direction of the subject being observed, an audio input and/or output device, a joystick or other controller configured to manually drive the azimuth motor **118** and the altitude motor **120**, a speech recognition module along with an associated audio output module, an automatic alignment tool (tube leveler and/or axis planarizer), a photometer, an autoguider, a reticle illuminator, a cartridge reader station (e.g., for courseware, revisions, new languages, object libraries, data storage, or the like), and/or another imager or camera that is not coupled to the optical system **110** and that can be used, for example, to view terrestrial objects in the vicinity of the telescope system **100**. An artisan will recognize that some or all of the peripheral devices **140** may be external accessories or may be housed with the optical system **110** and/or the electronic imager **116**. An artisan will also recognize that some or all of the peripheral devices **140** may be coupled directly to the host system **130** rather than to the communication circuitry **128**.

Although the host system **130** specifically and the telescope system **100** in general are disclosed with reference to their preferred and alternative embodiments, the disclosure is not limited thereby. Rather, an artisan will recognize from the disclosure herein a wide number of alternatives for host and telescope systems **130**, **100**, including alternative devices performing a portion of, one of, or combinations of the functions and alternative functions disclosed herein.

FIG. 2 is a perspective view of an exemplary telescope **200** usable by the telescope system **100** shown in FIG. 1,

according to an embodiment of the disclosure. The telescope **200** comprises a telescope tube **210** and a mount **212** configured to support and move the telescope tube **210**. The telescope tube **210** houses an optical system that collects light from distant objects through the optical elements **112** and focuses the light onto the image plane **114** (shown in FIG. 1). In certain embodiments, the electronic imager **116** is located within the telescope tube **210** at the image plane **114**. However, as shown in FIG. 2, in other embodiments, the electronic imager **116** is detachably attached to the exterior of the telescope tube **210** through a lens **214**. In certain such embodiments, the lens **214** is adjustable to selectively provide additional optical magnification or reduction of the image provided at the image plane **114**. Thus, a user or the host system **130** can change the field of view as desired.

As discussed above, in certain embodiments the electronic imager **116** comprises, for example, a CMOS image array, a CCD camera, or the like. Such imaging devices are generally more sensitive to light than the human eye. Thus, as shown in FIG. 2, in certain embodiments the telescope **200** does not include an eyepiece and images of celestial objects are viewed on a display screen (not shown). Since there is no eyepiece, the telescope **200** may not be positioned at a convenient viewing height for a user. Thus, the telescope **200** can advantageously be used without a conventional tripod and can simply be placed on the ground or another stable object, further reducing the cost and complexity of operating the telescope **200** as compared to conventional telescope systems. However, in other embodiments, the optical system **110** splits the light such that it can be viewed both through an eyepiece (not shown) and on a display screen.

Although not shown in FIG. 2, the electronic imager **116** may include a display screen for viewing images. In addition, or in other embodiments, the telescope tube **210** or mount **212** may include a display screen for viewing images generated by the electronic image **116**. Such display screens may comprise, for example, a liquid crystal display (LCD) or similar device, such as those associated with digital cameras, camcorders, laptops, cell phones, personal digital assistants (PDAs), other computing devices, or the like.

The telescope tube **210** is supported by the mount **212** which facilitates movement of the telescope tube **110** about two orthogonal axes, an azimuth axis **216** and an altitude axis **218**. The axes **216**, **218** of the mount **212**, in combination, define a gimbaled support for the telescope tube **210** enabling it to pivot about the azimuth axis **216** in a horizontal plane and, independently, to pivot about the altitude axis **218** through a vertical plane. In certain embodiments, a user may not level the mount **212** with respect to the earth. For example, the mount **212** may be tilted forward or backward with respect to the direction of the telescope tube **210**. The mount may also be tipped in a perpendicular direction to the telescope tube **210**. In certain embodiments, one or more signals from the level sensor **122** (shown in FIG. 1) are used to measure the tip and tilt of the mount **212** with respect to a level position.

It should be noted that the telescope tube **210** is configured as a reflecting-type telescope, particularly a Maksutov-Cassegrain telescope. In this regard, the form of the telescope's optical system is not particularly relevant to practice of principles of the present disclosure. Thus, even though depicted as a reflector, the telescope **100** of the present disclosure is suitable for use with refractor-type telescope optical systems. The specific optical systems used might be Newtonian, Schmidt-Cassegrain, Maksutov-Cassegrain, or

any other conventional reflecting or refracting optical system configured for telescopic use. For example, the telescope 100 may comprise a dome telescope such as are generally operated by professional astronomers.

Although not shown in FIG. 2, the telescope 200 includes the azimuth motor 118 and the altitude motor 120 discussed above. The azimuth motor 118 and the altitude motor 120 are respectively coupled to the azimuth axis 216 and altitude axis 218 so as to pivotally move the telescope tube 210 about the corresponding axis. In certain embodiments, the altitude motor 120 is disposed within a vertically positioned fork arm 220 of the mount 212 and the azimuth motor 118 is disposed within a horizontally positioned base 222 of the mount 212. Motor wiring is accommodated internal to the structure of the mount 212 (including the fork arm 220 and the base 222) and the system's electronic components are packaged accordingly.

Although the exemplary telescope 200 is disclosed with reference to its preferred and alternative embodiments, the disclosure is not limited thereby. Rather, an artisan will recognize from the disclosure herein a wide number of alternatives for the telescope, including optical viewing devices including academic or governmental installations to personal magnification devices, dome-mounted devices, all manner of telescope devices, or the like.

FIG. 3 illustrates an exemplary self-alignment process 300 according to an embodiment of the disclosure. The process 300 is usable by a telescope system, such as the telescope system 100 of FIG. 1. The alignment process 300 comprises, in short, receiving or determining a current time and an approximate location of a telescope, selecting an alignment area, leveling or virtually leveling the telescope (determining the orientation of the telescope with respect to earth), slewing the telescope toward an approximated location of the alignment area, acquiring an electronic image of a portion of the sky corresponding to the approximated location, identifying a center of a current field of view, and mapping the celestial coordinates of the center of a current field of view to the telescope's coordinate system. An artisan will recognize from the disclosure herein a wide variety of alternate mapping procedures, including for example, identifying a particular alignment star and using it to create the appropriate mapping, identifying a particular pattern of stars and using that information to create the appropriate mapping, identifying a sidereal drift and using that information to create the appropriate mapping, or the like.

In certain embodiments, the self-alignment process 300 moves the telescope or adjusts any of its optical components. For example, a user may advantageously place a telescope, such as the telescope 200 of FIG. 2, on the ground or another stable object and connect it to a laptop or other computing device. The user may then be provided with a graphical user interface on a display screen of the laptop, for example, that allows the user to select a celestial object from a list of celestial objects that may be viewable from the user's location at a particular date and time. The date, time and location of the user may be entered into the laptop, for example, by the user or automatically provided by a GPS receiver connected to the laptop. Once the user selects a desired celestial object from the list, the alignment process 300 automatically aligns the telescope tube 210 with the desired celestial object without further action from the user. An image of the desired celestial object may then be displayed, for example, on the display screen of the laptop.

Referring to FIG. 3 at block 305, the self-alignment process 300 includes receiving or determining a current time and an approximate location of a telescope. The current time

includes, for example, the current date. As discussed above, in certain embodiments, this information is provided by a GPS receiver. In other embodiments, the current time and/or approximate location of the telescope may be received directly from a user, other peripheral devices, or the like. At block 310, the process 300 includes selecting an alignment area used to orient a telescope with the celestial coordinate system. In certain embodiments, the alignment area is selected from viewable portions of the sky based on the current time and the approximate location of the telescope with respect to the earth. In addition, or in other embodiments, the alignment area is selected based at least in part on a celestial object selected by a user for viewing. For example, the alignment area may be selected because it is near the celestial object selected for imaging by the user. In other embodiments, the telescope is simply slewed toward the sky to a location above an approximation of potential horizon interference (such as, for example, above approximately 30° over the horizon) and sufficiently below an approximate vertical to generate accurate alignment data (such as, for example, below 75° over the horizon).

In certain embodiments, the selected alignment area includes stars with known celestial coordinates and relationships. For example, an alignment area may include an alignment star and one or more additional stars in the vicinity of the alignment star that help identify the alignment star. For example, in certain embodiments, the alignment star is associated with one or more other stars that form a recognizable pattern. Data related to such patterns may be stored and used to later recognize the patterns. The data may include, for example, differences in magnitude or brightness between a group of stars in the alignment area, angular distances between the group of stars, a shape formed by the group of stars, angles formed between the stars in the group, combinations of the foregoing, and the like.

At block 315, the self-alignment process 300 includes leveling or virtually leveling the telescope. In certain embodiments, the telescope is in an unknown orientation with respect to the earth. For example, as discussed above, a user may set the telescope on the ground or on a tripod without precision leveling the telescope. Thus, the telescope may be tilted in a first direction and tipped in a second direction such that the rotation axes of the telescope form angles with the horizon. The user may also set the telescope on the ground or on the tripod without pointing the telescope at any particular object (e.g., the north star or another known celestial object) or in a known direction (e.g., with respect to the north pole or the south pole). As discussed in greater detail below, in certain embodiments, the telescope control system is capable of determining the tip and tilt without further input from the user. The telescope control system is also capable of determining the direction in which the telescope is pointing, for example, with respect to north or south. Thus, it is possible to approximately determine the orientation of the telescope with respect to the earth.

When the level measurement, the compass direction measurements, the current time, and the location information are sufficiently accurate, then the alignment is complete and the telescope control system may advantageously slew to any set of celestial coordinates. However, in certain embodiments, such measurements and information include approximations and are not sufficiently accurate so as to allow the telescope control system to center the telescope's field of view on a selected celestial object.

Therefore, at block 320, the self-alignment process 300 includes slewing the telescope toward an approximated location of an alignment area. As mentioned in the forego-

ing, the alignment area may be a specific alignment star or group of stars, or may simply be a location above an approximation of potential horizon interference and sufficiently below an approximate vertical.

At block **340**, the self-alignment process **300** includes acquiring an electronic image of a portion of the sky corresponding to the approximated location. The electronic image, such as a digital photograph or the like, includes image data corresponding to the alignment area including, for example, stars in the vicinity of the alignment star. At block **350**, the process includes identifying one or more stars in the electronic image. An artisan will recognize from the disclosure herein that other alignment mapping could be used, such as, for example, locating the celestial position of a predetermined star or pattern of stars, an error from the predetermined star or pattern of stars, combinations of the same or the like. As discussed in detail below, in certain embodiments, the one or more stars are identified by comparing relative magnitudes among the stars and/or angular distances between the stars with known relative magnitudes and/or angular distances.

However, an artisan will recognize from the disclosure herein that other relationships between celestial objects and other pattern recognition techniques can be used to analyze the image data in order to, for example, determine the celestial coordinates of the current center of the telescope's field of view. For example, relationships between stars may include brightness, and/or color (e.g., color index, spectral class, redshift). Relationships between galaxies may include, for example, size, brightness, eccentricity of ellipse, orientation angle of ellipse, structure, and/or Hubble classification. Relationships between planetary nebulae may include, for example, color, brightness, size and/or shape. Relationships between globular star clusters may include, for example, size, brightness, star count, density as a function of radial distance, and/or color index. Relationships between planets may include, for example, size, color, diameter, brightness, and/or motion relative to adjacent stars. Relationships between minor planets and/or asteroids may include, for example, brightness, color, and/or motion relative to adjacent stars. Relationships for the earth's moon at different times include, for example, lunar phase, brightness, and/or diameter. Relationships for visible moons of the planets in the solar system include, for example, brightness and/or position relative to the parent planet and other moons. Relationships between double stars and/or multiple star asterisms include, for example, brightness, angular separation, angle of the asterism with respect to lines of right ascension/declination, angle of the asterism with respect to lines of azimuth/elevation, and/or angles of the vertices of subsets of three stars.

Once a point or the current center of the telescope's field of view has been identified, at block **360** the self-alignment process **300** includes mapping the celestial coordinates of at least one of the identified stars to the telescope's coordinate system, as discussed above. Thus, the alignment is complete and the telescope can be slewed to the celestial coordinates of any desired visible celestial object.

However, in certain embodiments, it is advantageous to increase the accuracy of the alignment by identifying another group of stars in the same alignment area or in a different alignment area. For example, one iteration of blocks **310**, **320**, **340**, **350** and **360** may provide, for example, an alignment accuracy on the order of approximately one arcminutes. However, in certain embodiments, it is desirable to have an alignment accuracy on the order of approximately one or more arcseconds.

To increase the alignment accuracy according to certain embodiments, the telescope or host system repeats at least blocks **310**, **320**, **340**, **350** and **360** of the self-alignment process **300** shown in FIG. **3**. For example, at block **310**, the telescope control system selects a new alignment area. In an embodiment, the new alignment area is preferably of a longer arc length from the original alignment area. For example, long arc lengths between the previous alignment area and the new alignment area generally provide increased accuracy as compared to shorter arc lengths. While the new alignment area according to certain embodiments is closer than approximately 130° from the previous alignment area, and according to other embodiments is within the same field of view of the telescope as the previous alignment area, in certain embodiments the new alignment area is advantageously selected at an arc length of approximately 130° from the previous alignment area.

FIG. **4** illustrates an exemplary initial orientation determination process **315** of the self-alignment process **300** of FIG. **3**, according to an embodiment of the disclosure. The initial orientation determination process **315** measures the difference between the direction that the telescope is pointing relative to the horizon in one plane and a compass direction in another plane. At block **410**, the process **315** includes receiving a first signal from a level sensor. The level sensor is positioned with respect to the telescope such that it indicates when the telescope is approximately level with the horizon. In certain embodiments, additional measurements increase accuracy. In such embodiments, at block **420**, the process **315** includes rotating the telescope about 180° about an azimuth axis. At block **430**, the process **315** includes receiving a second signal from the level sensor. By taking level measurements about 180° apart, errors in the direction above the horizon cancel, at least partially, with errors in the direction below the horizon. Thus, an accurate measurement of tilt, as discussed above, can be acquired. At block **432**, in certain embodiments, the process **315** includes rotating the telescope about 90° about the azimuth axis. At block **434**, the process **315** includes receiving a third signal from the level sensor. By taking a level measurement about 90° from the other level measurements, an accurate measurement of the tip, as discussed above, can be acquired. Thus, the virtual location of the telescope with respect to the earth is determined.

At block **440**, the process **315** includes receiving a fourth signal from an electronic compass. As discussed above, the electronic compass is positioned with respect to the telescope such that it indicates the direction that the telescope is pointing in the azimuth plane with respect to magnetic north, for example. Once the orientation of the telescope with respect to the earth (e.g., its tip, tilt and direction with respect to magnetic north) has been measured, the telescope can be rotated in azimuth and/or elevation to point at a selected position (at least approximately) in the celestial coordinate system.

FIG. **5** illustrates an exemplary field of view identification **350** process of the self-alignment process **300** of FIG. **3**, according to an embodiment of the disclosure. Moreover, FIG. **6** is an exemplary graphical representation of an alignment area used in the field of view identification process of FIG. **5**. Referring generally to FIGS. **5** and **6**, the process **350** includes selecting a group of stars in the electronic image at block **510**. In certain embodiments, a predetermined number of bright stars or stars having the greatest magnitude relative to other stars in the electronic image are selected. In certain embodiments, approximately two to five of the brightest stars in an electronic image are

selected for pattern recognition. As shown in FIG. 6, an alignment area 600 comprises a plurality of stars including, for example, a first alignment star 610 and a second alignment star 612. For illustrative purposes, a potential exemplary field of view 613 of an electronic image is shown within the alignment area 600. In the example shown in FIG. 6, an attempt is made to slew the telescope toward the alignment area 600 such that the alignment star 612 is in the center, for example, of the field of view 613. However, due to approximations in factors such as the telescope's initial orientation with respect to the horizon and north (or south), the current time, the telescope's position or virtual position with respect to the earth, combinations of the foregoing, and the like, the alignment star is not within the field of view 613. The telescope control system can still determine its orientation by identifying one or more stars in the field of view, such as, for example, stars 614, 616, 618, 620, 622 and relating their positions in the field of view 613 to their to their known celestial coordinate values.

For example, at block 512, the process 350 includes comparing the magnitudes of the stars in the group (e.g., stars 614, 616, 618, 620, 622). The perceived magnitude of a given star may change over time or when acquiring images using different imaging devices. For example, factors such as atmospheric conditions, lighting conditions, combinations of the foregoing, and the like, can affect the perceived or measured magnitude of a star. Thus, it is difficult to identify stars or patterns of stars by their absolute magnitudes. However, since the electronic image acquires image data for the stars 614, 616, 618, 620, 622 at the same time, using the same imaging device, the change or difference in magnitude between each of the three stars 614, 616, 618, 620, 622 remains substantially constant and can be used for pattern recognition.

At block 514, the process according to certain embodiments includes measuring angular distances between the stars 614, 616, 618, 620, 622 in the selected group. In certain embodiments, the angular distance from a given star is measured to each star in the group that is less bright than itself. Thus, for example, the system may determine that the star 614 is the brightest star in the field of view 613 and may measure the angular distances (shown as solid lines) from the star 614 to the other stars 616, 618, 620, 622 in the group. Then, the system may determine that the star 616 is the next brightest star in the field of view 613 and may measure the angular distances (shown as dashed lines) from the star 616 to the stars 618, 620, 622. The system may repeat this process for the other stars 618, 620, 622 in the selected group. An artisan will recognize that in other embodiments the relative magnitudes of the stars 614, 616, 618, 620, 622 and/or the angular distances between the stars 614, 616, 618, 620, 622 can be measured in any order.

The plate scale of the field of view 613 is used to measure the angular distances between the stars 614, 616, 618, 620, and 622 in the selected group. The plate scale relates the size of the imager detector (generally measured in either pixels or physical units such as millimeters) to the angular dimensions of the field of view (generally measured in units such as arcseconds or arcminutes). Thus, for example, if the number of pixels (both vertically and horizontally) between the star 614 and the star 616 are known, the plate scale of the detector can be used to convert the number of pixels into an angular distance that can be compared to know angular distances between known stars in the alignment area 600.

In certain embodiments, the plate scale is determined before a telescope and/or imaging device is provided to a user. Thus, plate scale values can be stored in the telescope

system for use during alignment procedures. In addition, or in other embodiments, a user may enter plate scale values into the telescope control system, may acquire them from the Internet or the like, for use during alignment procedures. As discussed in detail below with reference to FIG. 7, in certain embodiments, the telescope system is configured to determine plate scale values. By self-determining the plate scale data, the telescope control system of FIG. 7 can advantageously continue to perform self-alignment even when electronic imaging devices are interchanged or the plate scale is otherwise unknown or altered.

At block 516, the process 350 includes identifying one or more stars in the group based on at least one of the relative magnitudes and the angular distances. For example, in certain embodiments, the telescope system searches portions of a database corresponding to the selected alignment area for a set of stars having magnitudes relative to one another that match or are similar to the measured relative magnitudes of the group of stars in the electronic image. Once a match is found, the stored celestial coordinates relating to the match are read from the database, and the positioning of the matched star or stars within the field of view can be used to specifically identify celestial coordinates of the center of the current field of view of the telescope, thereby mapping the telescope's coordinate system to the celestial sphere.

FIG. 7 illustrates an exemplary plate scale determination process 700 according to an embodiment of the disclosure. At block 710, the process 700 includes acquiring a first electronic image. At block 712, the process 700 comprises slewing a telescope a predetermined amount in elevation. At block 714, the process 700 includes acquiring a second electronic image. At block 716, the process 700 includes slewing the telescope a predetermined amount in azimuth. At block 716, the process 700 includes acquiring a third electronic image.

At block 720, the process 700 includes measuring vertical and horizontal changes in one or more stars between the images. Thus, for a given change in elevation, a star in the first image will change a measurable number of pixels in the vertical direction between the first electronic image and the second electronic image. Also, for a given change in azimuth, the star in the second image will change a measurable number of pixels in the horizontal direction. At block 722, the process 700 includes calculating the plate scale based on the observed change in the position of the one or more stars between the images. Thus, the number of arcseconds per pixel in either direction can be measured and used to determine, for example, the angular distances between the stars 614, 616, 618, 620, 622 shown in FIG. 6.

After measuring the plate scale, the first, second or third electronic image can then be used, for example, to recognize the pattern of stars 614, 616, 618, 620, 622 in the field of view 613 and map their celestial coordinates with the coordinate system of the telescope, as described herein. For example, in certain embodiments, a telescope system acquires a first image in an alignment area, adjusts the azimuth and elevation of the telescope predetermined amounts, acquires a second image in the alignment area, calculates the plate scale, and uses the second image to identify one or more stars. An artisan will also recognize from the disclosure herein that fewer or more electronic images can be acquired. For example, in certain embodiments, a telescope system may acquire only two images that are displaced from one another in both elevation and azimuth.

While certain embodiments for aligning telescopes have been described above, other embodiments within the scope

