

(51) International Patent Classification:
G01J 3/02 (2006.01)(21) International Application Number:
PCT/US2016/033434(22) International Filing Date:
20 May 2016 (20.05.2016)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
62/164,179 20 May 2015 (20.05.2015) US

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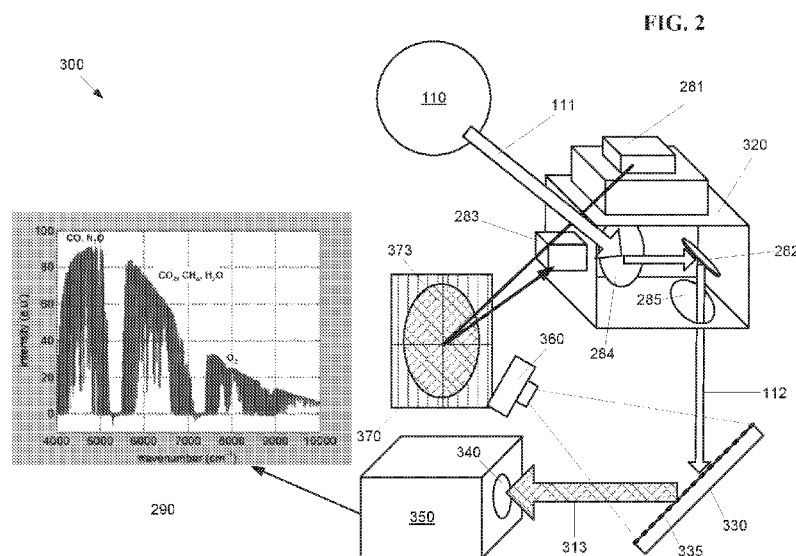
(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— with international search report (Art. 21(3))

(54) Title: DIFFUSER- BASED SOLAR-TRACKING WITH CAMERA FOR ATMOSPHERIC MEASUREMENTS.



(57) Abstract: A device and method for tracking optics for a spectrometer, is disclosed. A plurality of tracking mirrors track a position of a light source relative to the tracking optics, receive light from the light source, and emit reflected light. A reflecting diffuser is configured to receive reflected light from the mirrors and diffuse and reflect the received light toward the spectrometer. A camera is configured to record an image of the light source on the diffuser surface, and a tracking mechanism is configured to adjust the position of one or more of the tracking mirrors according to the image of the light source in the recorded image.

Diffuser-Based Solar-Tracking with Camera for Atmospheric Measurements

GOVERNMENT SUPPORT CLAUSE

This invention was made with government support under Grant No. 1337512 awarded by the National Science Foundation. The government has certain rights in the invention.

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Patent Application serial number 62/164,179, filed May 20, 2015, entitled “Diffuser-Based Solar-Tracking with Camera for Atmospheric Measurements,” which is incorporated by reference herein in its entirety.

FIELD OF THE INVENTION

The present invention relates to optics, and more particularly, is related to spectroscopy.

BACKGROUND OF THE INVENTION

Solar-tracking Fourier transform infrared spectrometers may be used to obtain high-fidelity solar spectra for use in measuring atmospheric gases. The solar tracker follows the sun during the course of a day to provide reflected sunlight to an input of the spectrometer. Remote sensing using solar-tracking Fourier transform spectrometers offers advantages for high-fidelity atmospheric observations. With the sun as a broadband light source, the solar radiation spectrum is a measure of the absorption of the molecules in the vertical column between the spectrometer and the sun.

The measured solar spectrum features wide spectral coverage as well as high spectral resolution. Therefore the measured solar spectrum provides insight into a range of important

atmospheric gases while giving significant information about each compound. The column-averaged concentrations (column measurements) of the atmospheric compounds are insensitive to the daily boundary layer height dynamics and compatible with the scale of the atmospheric model. Therefore, the daily dynamics and spatial gradient of column measurements are more representative for greenhouse gas and pollutant emissions than in-situ surface measurements. The column measurements with the sun as the light source provides insight to the composition of the atmosphere, pollutant emission and transport mechanisms, and the anthropogenic influence on climate, including feedbacks.

FIG. 1 shows a prior art solar Fourier transform infrared spectrometer system 100 that uses a collimator to guide sunlight from the tracker to a field diaphragm aperture and tracks the sun based on the backscattered light not directed into the aperture.

Direct sunlight 111 is reflected by a tracking device 120. Reflected sunlight 112 reflected by the tracking device 120 is directed to a collimator 130, which directs collimated light 113 into a field diaphragm aperture 140 inside of a spectrometer 150. A camera 160 monitors the surface of the field diaphragm 155, producing an image 170 that displays a position of the collimated light 113 with respect to the aperture 140 on the surface of the field diaphragm 155. The tracking device 120 receives the image 170, and adjusts the tracking device 120 to track a position of the sun 110, so that the collimated light 113 is centered in the image 170 with respect to the aperture 140. In particular, the system 100 uses the backscattered light that is not directed into the aperture 140 for tracking, thereby excluding the backscattered light from processing by the photodetector inside of the spectrometer 150. Therefore, there is a need in the industry to address one or more of the abovementioned shortcomings.

SUMMARY OF THE INVENTION

Embodiments of the present invention provide diffuser-based solar-tracking with a camera for atmospheric measurements. Briefly described, the present invention is directed to a device and method for tracking optics for a spectrometer. A plurality of tracking mirrors track a position of a light source relative to the tracking optics, receive light from the light source, and emit reflected light. A reflecting diffuser is configured to receive reflected light from the mirrors and diffuse and reflect the received light toward the spectrometer. A camera is configured to record an image of the light source on the diffuser surface, and a tracking mechanism is configured to adjust the position of one or more of the tracking mirrors according to the image of the light source in the recorded image.

Other systems, methods and features of the present invention will be or become apparent to one having ordinary skill in the art upon examining the following drawings and detailed description. It is intended that all such additional systems, methods, and features be included in this description, be within the scope of the present invention and protected by the accompanying claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings are included to provide a further understanding of the invention, and are incorporated in and constitute a part of this specification. The components in the drawings are not necessarily to scale, emphasis instead being placed upon clearly illustrating the principles of the present invention. The drawings illustrate embodiments of the invention and, together with the description, serve to explain the principals of the invention.

FIG. 1 is a schematic diagram of a prior art solar-tracking spectrometer system.

FIG. 2 is a schematic diagram of an exemplary first embodiment of a solar-tracking spectrometer system.

FIG. 3 is a simplified schematic diagram of the exemplary first embodiment of FIG. 2.

FIG. 4 is a flowchart of a first exemplary method for providing diffused sunlight into a spectrometer.

FIG. 5 is a schematic diagram illustrating an example of a system for executing functionality of the present invention.

FIG. 6 is a flowchart diagram of a second exemplary method for providing diffused sunlight into a spectrometer.

DETAILED DESCRIPTION

Reference will now be made in detail to embodiments of the present invention, examples of which are illustrated in the accompanying drawings. Wherever possible, the same reference numbers are used in the drawings and the description to refer to the same or like parts.

Embodiments of the present invention provide a simple, rugged, external sun tracker device and method, which may be used to equip a laboratory-based spectrometer for atmospheric column measurements. The solar tracking instrumentation is compact and inexpensive, allowing column measurements with high spatial and temporal coverage. The tracking method is simpler than the prior art solar Fourier transform infrared spectrometer system 100 (FIG. 1), enabling higher-speed processing. The embodiments presented herein have been tested with a Thermo Scientific Nicolet Fourier Transform Infrared spectrometer.

FIG. 2 is a schematic diagram of an exemplary first embodiment of a solar-tracking spectrometer system 300. A diffuser 330 mixes direct sunlight 111 from across the entire solar

disk 110 and reflects it into a Fourier Transform spectrometer (FTS) 350. The reflected sunlight 112 forms an elliptical bright region on the diffuser 330. A camera 360 records an image 370 of the bright region 373 on the diffuser 330, which provides closed-loop control of an elevation mirror 284, controlled by an elevation motor 283 or other actuator, and an azimuth mirror 282, controlled by an azimuth motor 281 or other actuator. The combination of the elevation mirror 284 and the azimuth mirror 282 provide for tracking the relative motion of the sun 110. Reflected sunlight 112 may exit the tracker 320 via an aperture 285. The spectrometer system 300 may be positioned to observe the sun from a fixed location. For example, the spectrometer system 300 may be mounted on a fixed platform (not shown).

Positions of the elevation mirror 284 and the azimuth mirror 282, may be adjusted so that the bright region 373 in the recorded image remains substantially in the same position. A measured solar radiation spectrum 290 indicates the absorption features from diverse gas molecules and their column density [molec./m^2] as well as column-averaged dry air mole fractions [ppm].

FIG. 3 is a simpler schematic diagram of the exemplary first embodiment 300 of FIG. 2. Direct sunlight 111 is reflected by a tracking device 320, or tracker. Reflected sunlight 112 is directed to a diffuse reflector 330, or diffuser, which diffuses the incoming light and reflects the diffused light 313 into an input aperture 340 or window of a spectrometer 350. A camera 360 monitors a surface 335 of the diffuser 330, producing an image 370 that displays a position of the sun as a bright image 373 with respect to the surface 335 of the diffuser 330. The tracker 320 receives the image 370, and adjusts the tracker 320 to track a position of the sun 110, so that the bright image 373 is centered in the image 370 of the diffuser. While FIG. 3 shows the bright image 373 as a circle, more generally the bright image 373 may be an ellipse. There may

be situations where tracking based on only a part of the bright image 373, e.g. a half ellipse or an elliptical ring, instead of the full bright image 373 is advantageous. These situations may include the scenario when the bright ellipse is disturbed by a ghost image caused by light reflected back from the spectrometer window.

An exemplary camera 360, a monochrome camera 360, may have at least 10 bits of dynamic range and an adequate number of pixels, for example, but not limited to, on the order of 1 megapixel, for an accurate centroid localization of the bright image 373. The camera 360 preferably automatically adjusts for brightness variations by changing either the exposure time or the aperture diameter. To eliminate detection of a ghost image reflected from the spectrometer window 340, the camera 360 is preferably sensitive to one or more wavelengths for which the window 340 is anti-reflection (AR) coated. A visible light camera may be an economical option and works well if the window 340 is AR coated in the visible spectrum, or if the tracking method differentiates between the incident and reflected images on the diffuser 330. Successful operation of the sun tracker 300 may be achieved using, for example, a 12 bit USB camera with 1280x960 3.75um pixels, model number CGE-B013-U from MighTex.

An important element in the sun tracker system 300 is the diffuser 330, which diffusely scatters the reflected light 112 across the solar spectrum while reflecting the diffused light 313 into the spectrometer 350. The diffuser 330 preferably has high, approximately constant reflectivity across the wavelength range of the camera 360 and spectrometer 350. For infrared (IR) and visible wavelengths, approximately constant reflectivity across the wavelength range may be achieved using metals, for example, aluminum, silver, or gold. Formation of an oxide layer on the diffuser surface 335 reduces reflectivity in certain wavelength bands, so the material may preferably be treated to prevent oxide formation, or a non-oxide-forming material

may be used. For example, commercial aluminum foil has an oxidant layer on the matte side, making it inappropriate for this application. The roughness of the diffuser surface 335 preferably provides a Gaussian-like bidirectional reflectance distribution with a full width at half maximum (FWHM) in the order of 10 degrees in order to optimize the tradeoff between signal-to-noise ratio and the area of the sun that is sampled. In alternative embodiments, the planar diffuser 330 may direct light into a collimating optic (not shown), which focuses the diffused light onto a pinhole (not shown) on the spectrometer 350. The diffuser 330 may be concave in order to diffuse and focus the light with only one element.

The diffuser 330 not only serves as part of the optics with the tracker 320, but also provides the image 370 that directs and refines the pointing of the tracker 320. The camera 360 records the bright image 373 due to the directly reflected sunlight on the diffuser 330, which allows closed-loop control of the tracking mirrors 284, 285 (FIG. 2) of the tracker 320. Positions of the mirrors 284, 285 (FIG. 2) of the tracker 320 are adjusted, for example via motors 281-283 (FIG. 2) so that the bright image 373 maintains the same position on the surface 335 of the diffuser 330.

The diffuser-based sun tracker 300 may be adapted to any type of spectrometer, including, but not limited to, Fourier transform spectrometers, laser heterodyne spectrometers, and grating spectrometers. The diffuser-based sun tracker 300 may mount externally to the spectrometer 350 and requires no internal modification of the instrument 350. The diffuser-based sun tracker 300 is simple, rugged and has a relatively small number of optical elements. In addition, the setup is less sensitive to misalignments of the other optics (e.g. mirror, Jacquinot stop), because the diffuser 330 scrambles (diffuses) the light angles before the diffused light 313 enters the spectrometer 350.

The diffuser surface 335 may be irregular, thereby disrupting and/or scrambling the reflected light 112. Furthermore, the overall profile of the diffuser surface 335 may be contoured to appropriately shape and direct the diffused light 313 to the spectroscopy input window 340. For example, the diffuser surface 335 may be shaped to focus and/or collimate the diffused light 313.

The diffuser 330 may be considered as an optical element of the tracker 320, which scatters the light from the whole solar disk 110 and reflects the light to the spectrometer 350. In alternative embodiments, the diffuser 330 may be incorporated as part of the tracker 320. The diffuser 330 may not only be a part of the reflective optics, but may also be a component for the camera-based active tracking: the bright image 373 on the diffuser surface 335 recorded by the camera 360 provides information for the control of the mirrors 284, 285 (FIG. 2) in the tracker 320. Accurate solar-tracking is ensured by adjusting the mirrors 284, 285 (FIG. 2) such that the bright image 373 on the diffuser surface 335 is always regulated to substantially the same position.

The position of the bright image 373 in the image 370 may be determined by cross-correlating the recorded image 370 with an artificial ellipse. The indices of the maximum value of the cross-correlation matrix are determined, for example, with a computer, which marks a centroid position of the bright image 373. Based on the derivation of the centroid position of the bright ellipse and the desired position Δ , an algorithm computes the necessary adjustment of one or the plurality of the mirrors 284, 285 (FIG. 2). This algorithm can be, but is not limited to, a direct calculation of the optimized mirror positions or an iterative procedure, where the determination of the derivation Δ and an approximate adjustment of the mirror positions

alternate. The centroid position of the bright image 373 may be regulated within a predetermined distance Δ (e.g. +/- 1 pixel) of the desired position.

This method is simpler than the prior art solar Fourier transform infrared spectrometer system 100 (FIG. 1), in which the centroids of inner and outer ellipses are detected and aligned to each other. Therefore, less processing power and memory are required for the computing unit of the tracker.

When the recorded image 370 is partially disturbed e.g. by a ghost image, the undisturbed part of the recorded image 370 can be utilized for tracking purposes. The correlation template can be an artificial ellipse or a part of the artificial ellipse e.g. elliptical ring, half ellipse etc. The correlation template could also be an initial picture of the recorded image 370 or a part of the recorded image 370.

A computer may be incorporated into the tracker 320, or the computer may be external to the tracker 320. For instance, the computer, an example of which is illustrated by FIG. 5, may receive the image 370 from the camera and provide information to the tracker 320, causing the tracker 320 to adjust the mirrors 284, 285 (FIG. 2) as directed by the computer in order to optimize the position of the bright image 373 within the image 370.

Since the light angles are scattered by the diffuser 330 instead of merely being collimated and redirected as in prior art systems, the setup is less sensitive to misalignments of the rest of the optics, including the tracker mirrors 284, 285 (FIG. 2) and Jacquinot Stop. An additional advantage of the diffuser approach over the conventional approach (see FIG. 1) is that the whole sun is recorded instead of the center of the sun. Therefore, the measurement results are less sensitive to inhomogeneity across the solar disk.

FIG. 4 is a flowchart diagram of a first exemplary method 400 for providing diffused sunlight into a spectrometer. It should be noted that any process descriptions or blocks in flowcharts should be understood as representing modules, segments, portions of code, or steps that include one or more instructions for implementing specific logical functions in the process, and alternative implementations are included within the scope of the present invention in which functions may be executed out of order from that shown or discussed, including substantially concurrently or in reverse order, depending on the functionality involved, as would be understood by those reasonably skilled in the art of the present invention.

Direct light 111 of the sun 110 is received by a tracker 320 and directed upon a diffuser 330 by the tracker 320, as shown by block 410. The tracker 320 includes one or more tracking mirrors 284, 285 (FIG. 2). An image 370 of the reflected sunlight is recorded on the diffuser 330 by a camera 360, as shown by block 420. Angles of the reflected sunlight 112 are scrambled by the diffuser 330, as shown by block 430. The diffused light 313 from the diffuser 330 is reflected into a spectrometer 350, as shown by block 440. The position of one or more of the tracking mirrors 284, 285 (FIG. 2) of the tracker 320 is adjusted based on the position of the bright ellipse/shape 373 in the recorded image 370.

As previously mentioned, the present system for executing the functionality described in detail above may be a computer, an example of which is shown in the schematic diagram of FIG. 5. The system 500 contains a processor 502, a storage device 504, a memory 506 having software 508 stored therein that defines the abovementioned functionality, input and output (I/O) devices 510 (or peripherals), and a local bus, or local interface 512 allowing for communication within the system 500. The local interface 512 can be, for example but not limited to, one or more buses or other wired or wireless connections, as is known in the art. The local interface 512

may have additional elements, which are omitted for simplicity, such as controllers, buffers (caches), drivers, repeaters, and receivers, to enable communications. Further, the local interface 512 may include address, control, and/or data connections to enable appropriate communications among the aforementioned components.

The processor 502 is a hardware device for executing software, particularly that stored in the memory 506. The processor 502 can be any custom made or commercially available single core or multi-core processor, a central processing unit (CPU), an auxiliary processor among several processors associated with the present system 500, a semiconductor based microprocessor (in the form of a microchip or chip set), a macroprocessor, or generally any device for executing software instructions.

The memory 506 can include any one or combination of volatile memory elements (*e.g.*, random access memory (RAM, such as DRAM, SRAM, SDRAM, *etc.*)) and nonvolatile memory elements (*e.g.*, ROM, hard drive, tape, CDROM, *etc.*). Moreover, the memory 506 may incorporate electronic, magnetic, optical, and/or other types of storage media. Note that the memory 506 can have a distributed architecture, where various components are situated remotely from one another, but can be accessed by the processor 502.

The software 508 defines functionality performed by the system 500, in accordance with the present invention. The software 508 in the memory 506 may include one or more separate programs, each of which contains an ordered listing of executable instructions for implementing logical functions of the system 500, as described below. The memory 506 may contain an operating system (O/S) 520. The operating system essentially controls the execution of programs within the system 500 and provides scheduling, input-output control, file and data management, memory management, and communication control and related services.

The I/O devices 510 may include input devices, for example but not limited to, a camera, keyboard, mouse *etc.* Furthermore, the I/O devices 510 may also include output devices, for example but not limited to control electronics for the tracker motors, a printer, display, *etc.* Finally, the I/O devices 510 may further include devices that communicate via both inputs and outputs, for instance but not limited to, a modulator/demodulator (modem; for accessing another device, system, or network), a radio frequency (RF) or other transceiver, a telephonic interface, a bridge, a router, or other device.

When the system 500 is in operation, the processor 502 is configured to execute the software 508 stored within the memory 506, to communicate data to and from the memory 506, and to generally control operations of the system 500 pursuant to the software 508, as explained above. The operating system 520 is read by the processor 502, perhaps buffered within the processor 502, and then executed.

When the system 500 is implemented in software 508, it should be noted that instructions for implementing the system 500 can be stored on any computer-readable medium for use by or in connection with any computer-related device, system, or method. Such a computer-readable medium may, in some embodiments, correspond to either or both the memory 506 or the storage device 504. In the context of this document, a computer-readable medium is an electronic, magnetic, optical, or other physical device or means that can contain or store a computer program for use by or in connection with a computer-related device, system, or method. Instructions for implementing the system can be embodied in any computer-readable medium for use by or in connection with the processor or other such instruction execution system, apparatus, or device. Although the processor 502 has been mentioned by way of example, such instruction execution system, apparatus, or device may, in some embodiments, be any computer-based

system, processor-containing system, or other system that can fetch the instructions from the instruction execution system, apparatus, or device and execute the instructions. In the context of this document, a “computer-readable medium” can be any means that can store, communicate, propagate, or transport the program for use by or in connection with the processor or other such instruction execution system, apparatus, or device.

Such a computer-readable medium can be, for example but not limited to, an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system, apparatus, device, or propagation medium. More specific examples (a nonexhaustive list) of the computer-readable medium would include the following: an electrical connection (electronic) having one or more wires, a portable computer diskette (magnetic), a random access memory (RAM) (electronic), a read-only memory (ROM) (electronic), an erasable programmable read-only memory (EPROM, EEPROM, or Flash memory) (electronic), an optical fiber (optical), and a portable compact disc read-only memory (CDROM) (optical). Note that the computer-readable medium could even be paper or another suitable medium upon which the program is printed, as the program can be electronically captured, via for instance optical scanning of the paper or other medium, then compiled, interpreted or otherwise processed in a suitable manner if necessary, and then stored in a computer memory.

In an alternative embodiment, where the system 500 is implemented in hardware, the system 500 can be implemented with any or a combination of the following technologies, which are each well known in the art: a discrete logic circuit(s) having logic gates for implementing logic functions upon data signals, an application specific integrated circuit (ASIC) having appropriate combinational logic gates, a programmable gate array(s) (PGA), a field programmable gate array (FPGA), etc.

The correlation method described above (centroid detection by correlation with an ellipse) may be implemented with a mini computer. The mini computer may be very inexpensive with low computational power. It may be as simple as a single-board computer containing a microcontroller or FPGA. A WIFI module (using local network) or UMTS module (using cell network) may be integrated to send and receive data at high speed and bandwidth, enabling easy remote control and the establishment of a sensor network.

FIG. 6 is a flowchart diagram of a second exemplary method 600 for solar tracking. Sunlight is directed onto a diffuser 330 using a solar tracker 320 with multiple mirrors 284, 285 (FIG. 2), as shown by block 610. The pointing positions of the mirrors 284, 285 (FIG. 2) may be determined, for example, by ephemeris calculation. The diffuser 330 scrambles the sunlight angles and reflects the light into a spectrometer 350, as shown by block 620. A camera 360 records the image 370 of the reflected sunlight on the diffuser 330, as shown by block 630. The correlation template may be an artificial ellipse, a part of an artificial ellipse, or an initial photo of the recorded image 370. A centroid $[x, y]$ of the bright ellipse 373 is given by the indices of the maximum value of the cross-correlation matrix between the real image 370 and a correlation template e.g. an artificial ellipse, as shown by block 640.

The distance between the centroid position of the bright ellipse 373 $[x, y]$ and the wanted position $[x_0, y_0]$ is compared with a certain threshold Δ as shown by block 650. Δ can be defined as 1 or more pixels. The comparison may be performed, for example, using

$$\sqrt{|x - x_0|^2 + |y - y_0|^2} \leq \Delta \quad \text{Eq. 1.}$$

If the image centroid is not in the desired position, one or more of the tracking mirrors 284, 285 (FIG. 2) of the solar tracker 320 is adjusted using an algorithm, as shown by block 660. This algorithm can be a direct calculation of the optimized mirror positions or an iterative

procedure, where the determination of the derivation Δ and an adjustment of the mirror positions alternate. If the image centroid is in the desired position, the method is done, and the spectrometer may record a spectrum, as shown by block 670.

As previously mentioned, based on the derivation of the centroid position of the bright ellipse/shape and the desired position, an algorithm computes the adjustment of one or the plurality of the mirrors 284, 285 (FIG. 2). This algorithm can be, but is not limited to, a direct calculation of the optimized mirror positions or an iterative procedure, where the determination of the derivation and an approximate adjustment of the mirror positions alternate.

While the above embodiments have been directed to tracking the position of the sun with respect to a fixed platform, it will be apparent to those skilled in the art that various modifications and variations can be made to the structure of the present invention without departing from the scope or spirit of the invention. For example, one alternative embodiment may track the position of a stationary light source with respect to a moving platform. Similarly, another alternative embodiment may track a moving light source with respect to a moving platform. In view of the foregoing, it is intended that the present invention cover modifications and variations of this invention provided they fall within the scope of the following claims and their equivalents.

CLAIMS

What is claimed is:

1. Tracking optics for a spectrometer, comprising:
a plurality of tracking mirrors configured to:
track a position of a light source relative to the tracking optics;
receive light from the light source; and
emit reflected light reflected from the light source;
a reflecting diffuser comprising a diffusing surface configured to receive reflected light
from the plurality of tracking mirrors and diffuse and reflect the received light
toward the spectrometer;
a camera configured to record an image of the light source on the diffusing surface; and
a tracking mechanism configured to adjust the position of one or more of the tracking
mirrors according to the image of the light source in the recorded image.
2. The optics of claim 1, wherein the reflecting diffuser is configured to scramble the
angles of the received reflected light directed toward the spectrometer.
3. The optics of claim 1, wherein the tracking mechanism further comprises a
processor and a memory configured to store non-transitory instructions which, when executed by
the processor perform the steps of:
receiving an image of the light source on the diffusing surface recorded by the camera;
and

adjust a position of one or more of the tracking mirrors according to a position of the image of the light source on the diffusing surface.

4. The optics of claim 3, wherein the processor is further configured to perform the steps of:

cross-correlating the received image with a correlation template;

computing the indices of the maximum value of the cross-correlation matrix, marking a centroid position of the image of the light source on the diffusing surface; and

regulating the centroid position of the image of the light source on the diffusing surface within a predetermined distance, for example, ± 1 pixel, of a desired position.

5. The optics of claim 4, wherein the template comprises part or all of an artificial ellipse, a part of an artificial ellipse, or part or all of a recorded image.

6. The optics of claim 1, wherein the tracking mechanism further comprises a mirror actuator configured to adjust a position of one or the plurality of mirrors.

7. The optics of claim 1, wherein the light source is the sun and the image of the light source on the diffusing surface appears as a bright ellipse.

8. A method for providing sunlight into a spectrometer, comprising the steps of:
directing sunlight upon a diffuser with a tracker further comprising a plurality of tracking mirrors;

recording an image of the sun as a bright ellipse/shape on the diffuser with a camera;
scrambling the sunlight angles with the diffuser;
reflecting the scrambled light from the diffuser into the spectrometer; and
adjusting the position of one or more of the plurality of tracking mirrors based on a
position of the bright ellipse/shape in the recorded image.

9. The method of claim 8, wherein the scrambled light from the diffuser is directed into an input aperture of the spectrometer.

10. The method of claim 8, further comprising the step of providing the recorded image of the bright ellipse/shape on the diffuser to the tracker.

11. The method of claim 8, further comprising the step of cross-correlating the recorded image with a template.

12. The method of claim 11, wherein the template comprises part or all of an artificial ellipse, a part of an artificial ellipse, or part or all of a recorded image.

13. The method of claim 7, further comprising the step of determining a maximum value of a cross correlation matrix, marking a centroid position of the bright ellipse/shape on the diffuser.

14. The method of claim 13, further comprising the step of regulating the centroid position of the bright ellipse within a predetermined distance, for example, +/- 1 pixel, of a desired position.

15. A system for tracking a light source for a spectrometer, comprising:
a plurality of tracking mirrors configured to receive light from the light source and emit reflected light reflected from the light source;
an actuator configured to adjust a position of at least one of the plurality of tracking mirrors;
a reflecting diffuser comprising a diffusing surface configured to receive reflected light from the plurality of tracking mirrors and diffuse and to reflect the received light toward the spectrometer;
a camera configured to record an image of the light source on the diffusing surface; and
a tracking mechanism comprising a processor and a memory configured to store non-transient instructions which when executed perform the steps of:
receiving from the camera the image of the light source on the diffusing surface;
via the actuator, adjusting the position of one or more of the plurality of tracking mirrors based on a position of the image of the light source in the recorded image.

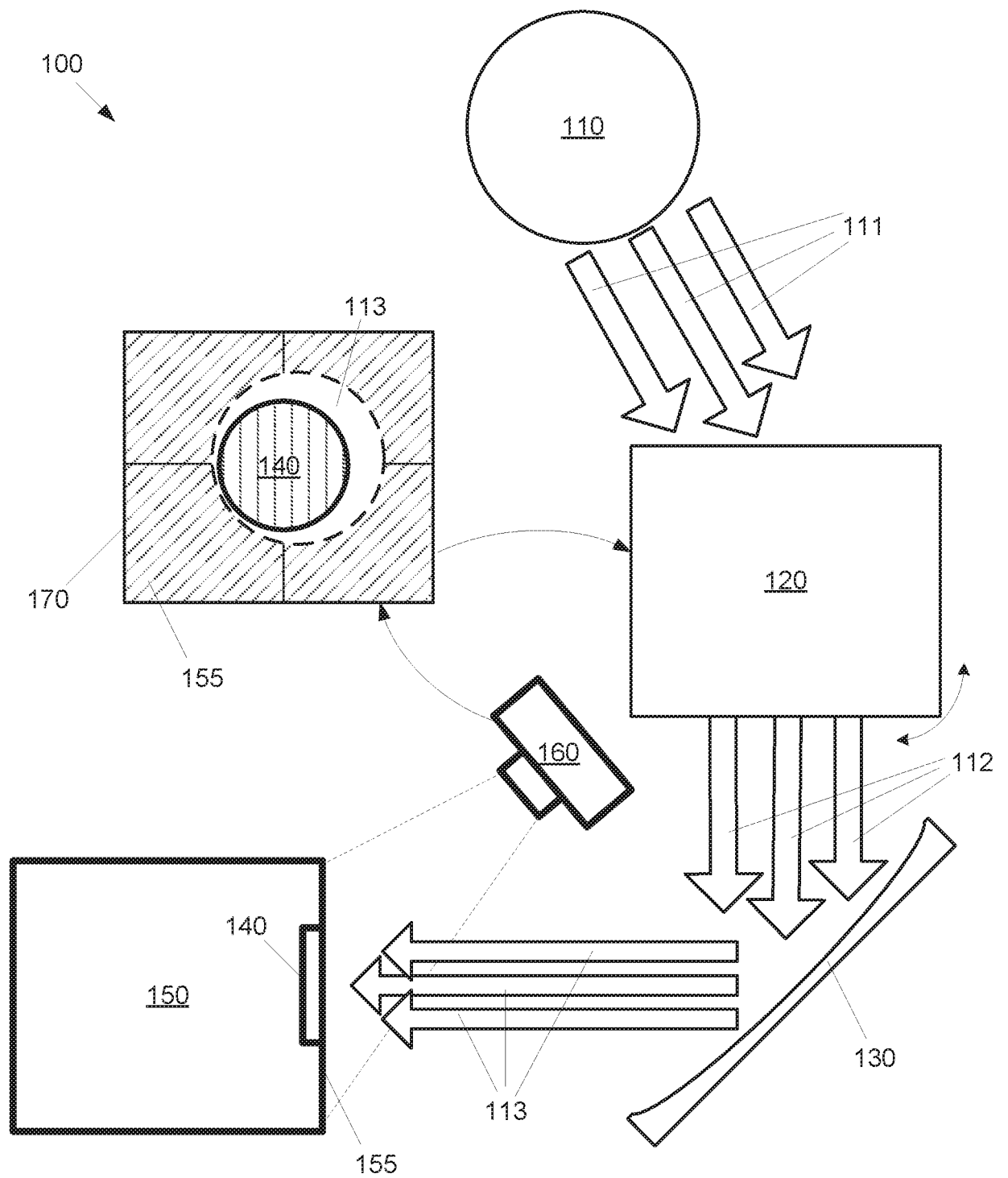
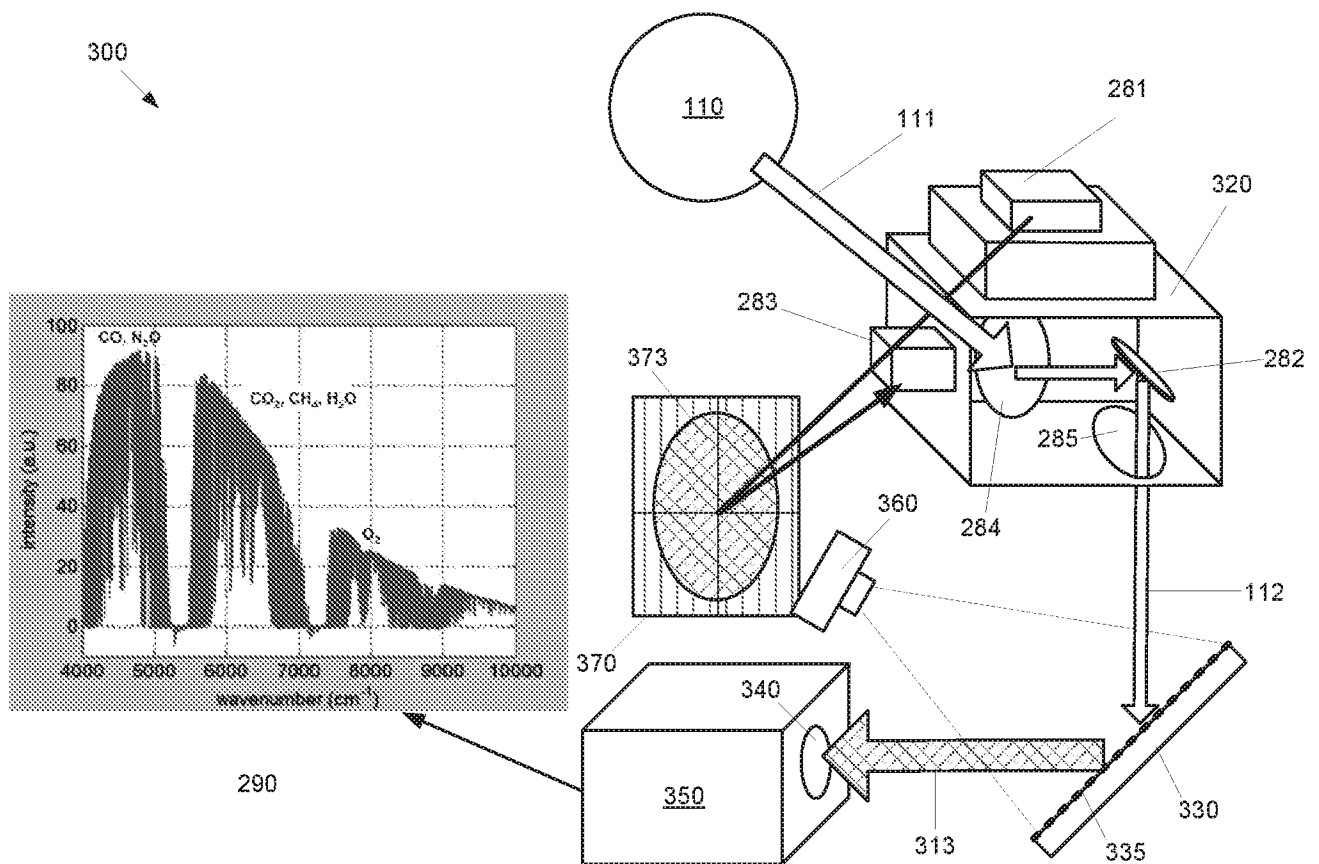


FIG. 1
(PRIOR ART)



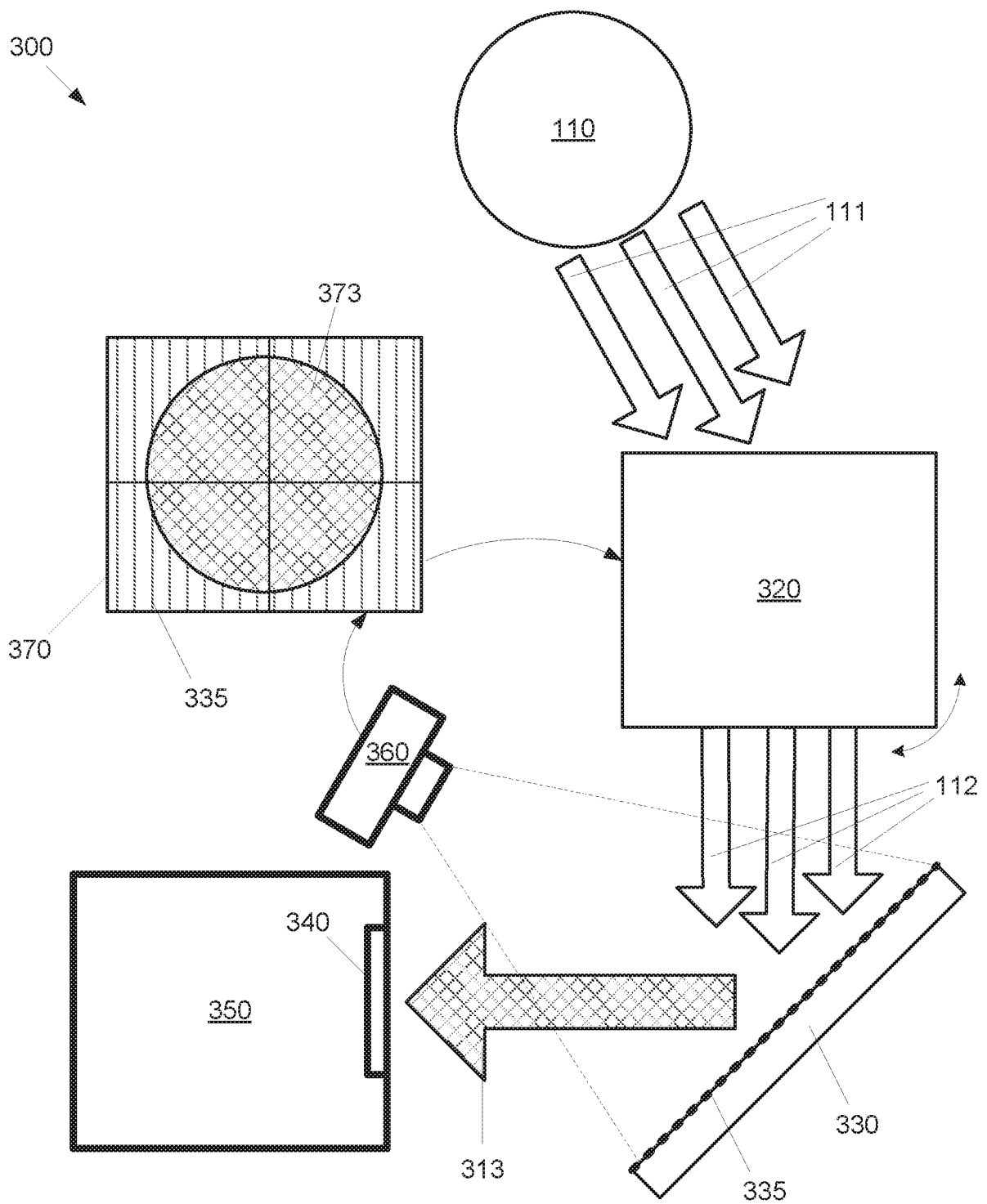
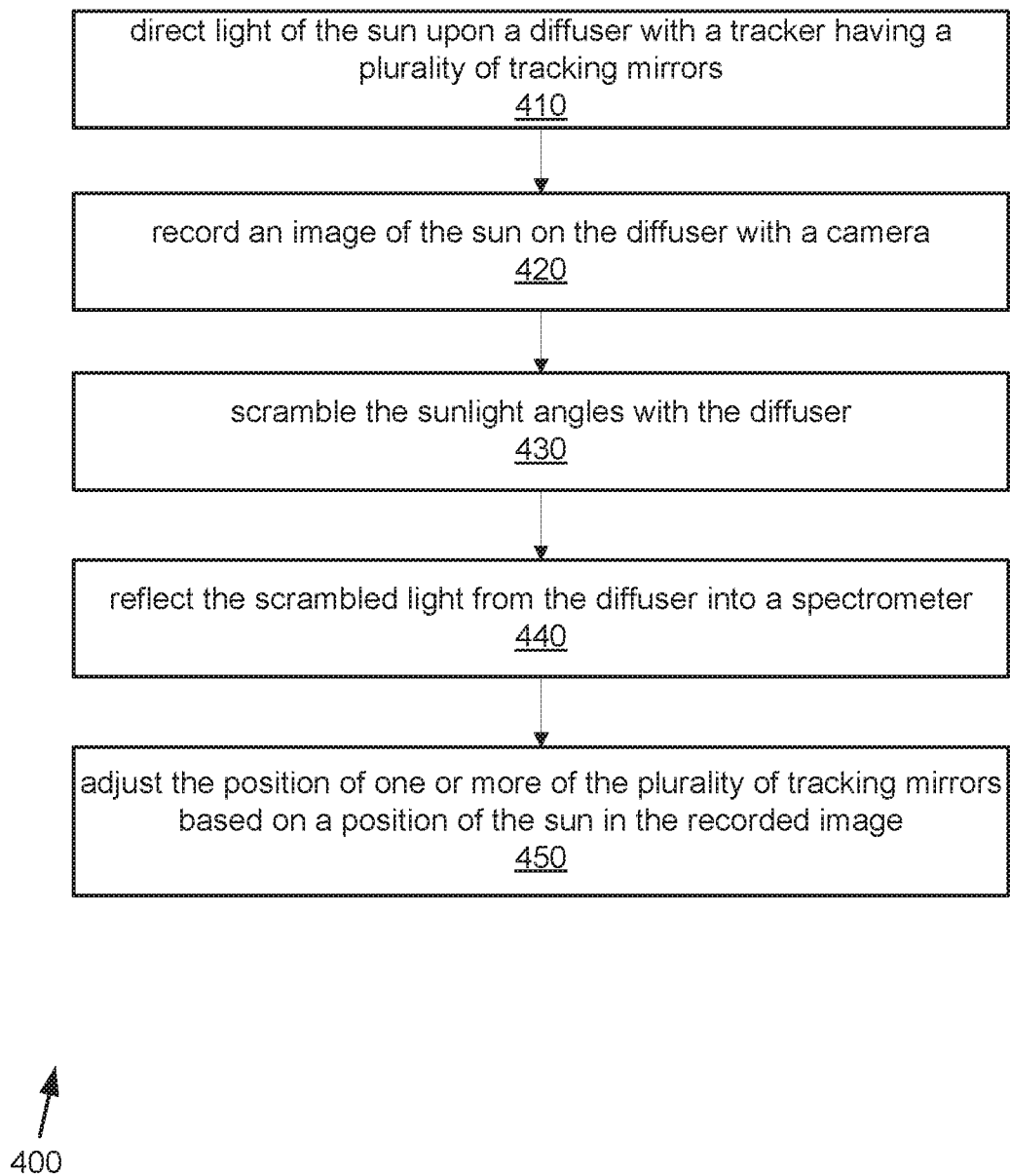
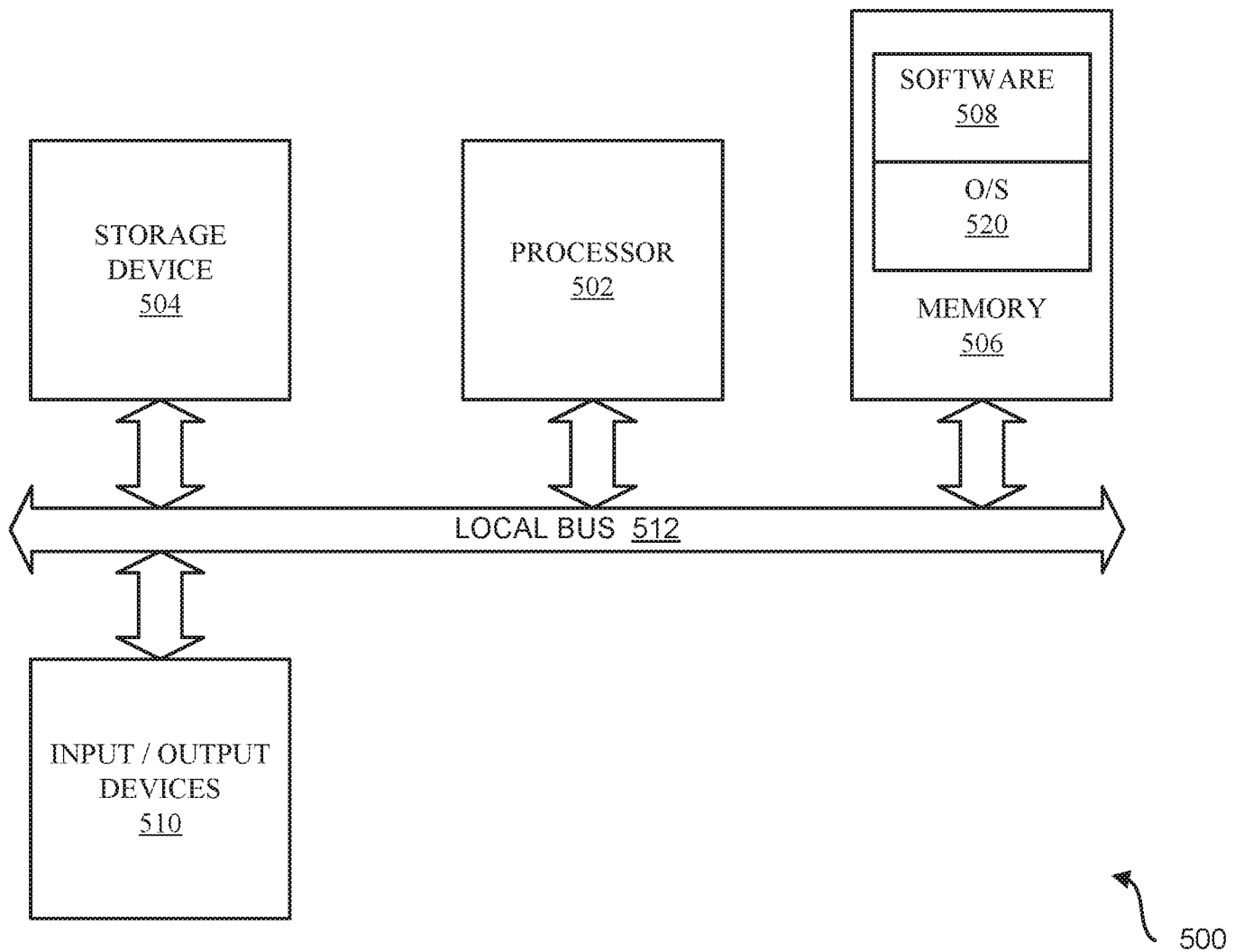


FIG. 3

**FIG. 4**

**FIG. 5**

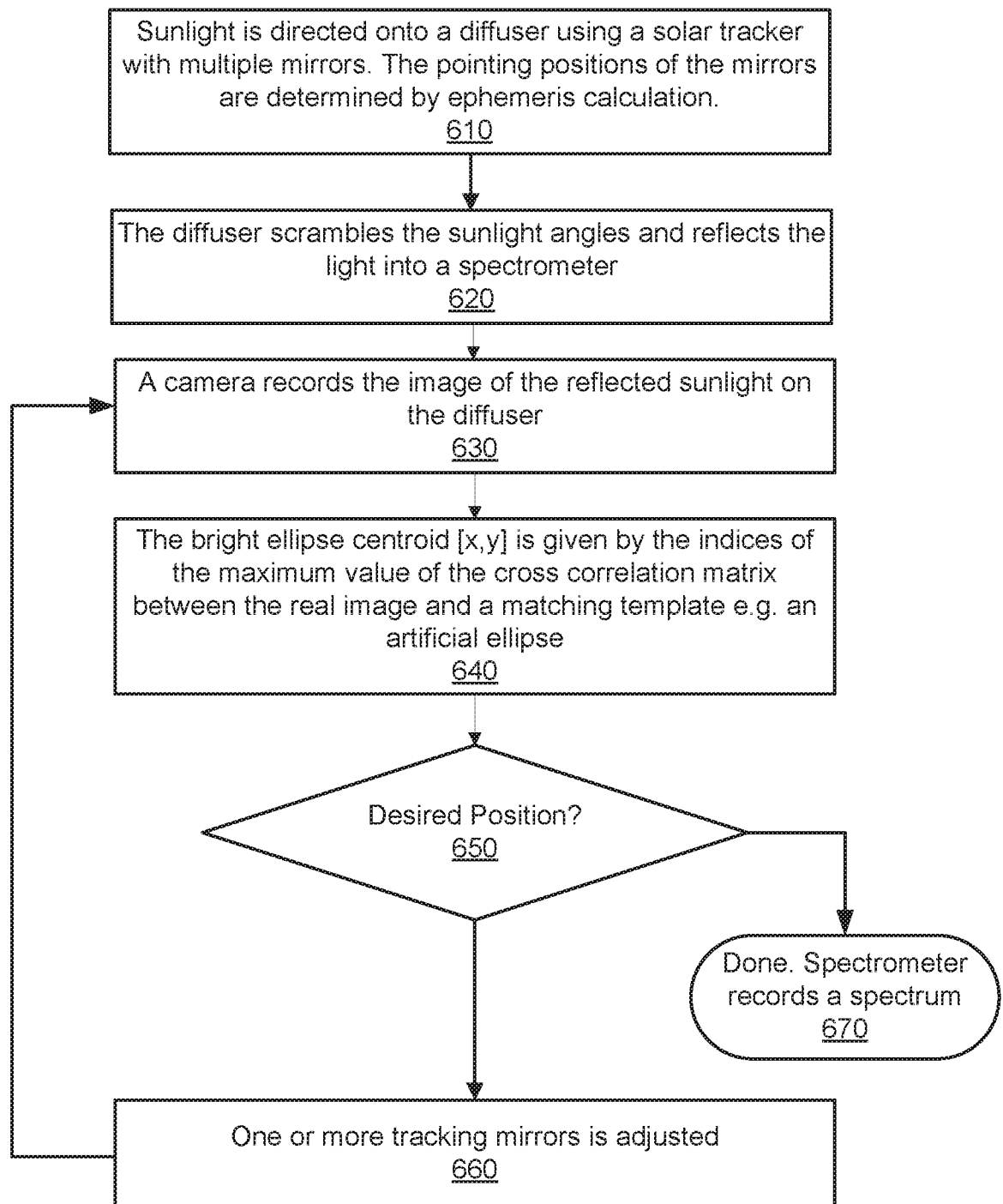


FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2016/033434

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - G01J 3/02 (2016.01)

CPC - G01J 3/0289; G01J 3/0248; G01J 3/0205; G01J 3/0202 (2016.05)

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC - F24J 2/38; G01J 3/02

CPC - F24J 2/38; G01J 3/0202; G01J 3/0205; G01J 3/0208; G01J 3/021; G01J 3/0248; G01J 3/0289; G01J 3/0291

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

USPC - 126/574; 126/578; 356/416 (keyword delimited)

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

Patbase, Google Patents, Google

Search terms used: solar, sun, tracking, diffuser, reflector, mirror

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2006/0152726 A1 (LARSEN et al) 13 July 2006 (13.07.2006) entire document	1-15
Y	US 2011/0000478 A1 (REZNIK) 06 January 2011 (06.01.2011) entire document	1-15
A	US 8,797,550 B2 (HAYS et al) 05 August 2014 (05.08.2014) entire document	1-15
A	US 8,174,693 B1 (MATTHEWS) 08 May 2012 (08.05.2012) entire document	1-15

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

☐ See patent family annex.

* Special categories of cited documents:

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

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

"&" document member of the same patent family

Date of the actual completion of the international search

26 July 2016

Date of mailing of the international search report

23 AUG 2016

Name and mailing address of the ISA/

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