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(54) Title: MULTI-SENSOR IRRADIANCE ESTIMATION

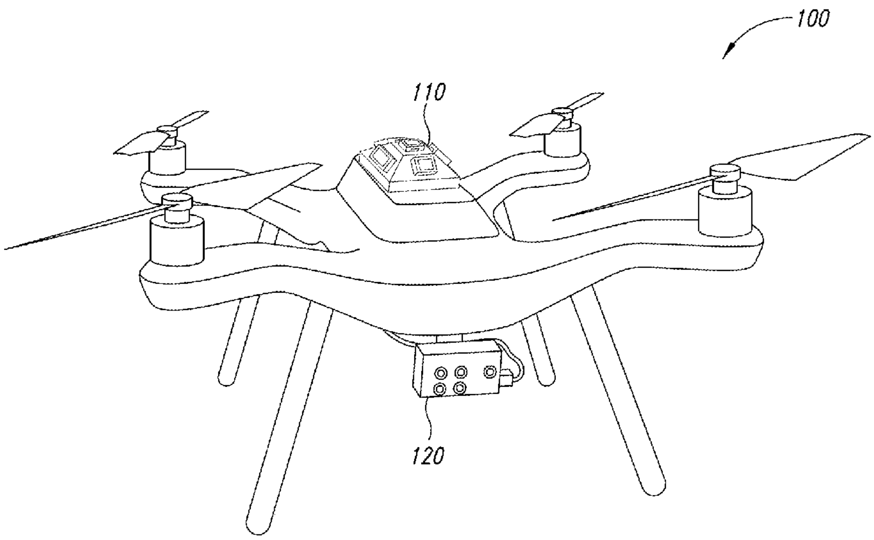

FIG. 2

(57) Abstract: The present disclosure is directed to devices and methods for simultaneously sensing irradiance with multiple photo sensors having different orientations, and determining direct and scattered components of the irradiance. One such device includes an aerial vehicle and an irradiance sensing device. The irradiance sensing device includes a base structure mounted to the aerial vehicle, and the base structure including a plurality of surfaces. A plurality of photo sensors are arranged on respective surfaces of the base structure, with each photo sensor having a different orientation.

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MULTI-SENSOR IRRADIANCE ESTIMATION

BACKGROUND

Technical Field

The present disclosure is directed to estimating or determining irradiance using an irradiance sensing device having a plurality of photo sensors having different orientations.

Description of the Related Art

A common problem in radiometric remote sensing is the estimation of incident irradiance from the sun on arbitrary surfaces from the scattered and direct component of the sunlight. Traditionally, these components of sunlight are measured on the ground, using a shaded pyranometer for the scattered component and a pyrheliometer for the direct component. Both of these devices track the position of the sun during measurement. The pyrheliometer has a long tube that only allows direct light in and the tracking shading of the pyranometer blocks direct light, so that the instruments measure only the direct and scattered light, respectively. Both instruments have significant cost and are unsuitable for mounting on a small, rapidly moving platform such as a drone.

A single conventional light sensor can be used to measure both components of sunlight, if the sensor attitude is well determined and the attitude is varied over time. However, while such a sensor can be mounted on a drone, the precise attitude estimates for a moving platform are difficult to obtain, or require costly sensors and are prone to significant errors, particularly under changing light conditions, e.g. due to partial cloud cover.

Accordingly, in conventional remote sensing applications, such as multispectral imaging applications for determining the health of vegetation, ground-based calibration systems are typically employed for normalizing the effects of a variable light source (e.g., the sun) on multispectral images of a target. Such calibration systems commonly rely on the use of target calibration or reflectance panels having a known spectral reflectance that are placed in the field of view of a multispectral imaging device and can be used to calibrate the acquired image of the target. There are several drawbacks to such techniques, including that the calibration or reflectance panels are costly, cumbersome and do not accurately measure irradiance levels simultaneously with the acquired images.

BRIEF SUMMARY

The present disclosure is directed to devices and methods for sensing irradiance from a light source, such as the sun, by an irradiance sensing device including a plurality of photo sensors arranged at differing orientations. By simultaneously sensing the irradiance with multiple photo sensors having different orientations, particular components of the irradiance, such as the direct and scattered components and the incidence angle, may be determined. These determined irradiance components may be used to compensate or normalize images of a target that are acquired at the same time by an imaging device. The irradiance sensing device and the imaging device may be carried on an aerial vehicle, such as a drone.

In one embodiment, the present disclosure provides a device that includes an aerial vehicle and an irradiance sensing device. The irradiance sensing device includes a base structure mounted to the aerial vehicle, and the base structure includes a plurality of surfaces. The irradiance sensing device further includes a plurality of photo sensors, with each of the photo sensors being arranged on a respective surface of the base structure and having different orientations.

In another embodiment, the present disclosure provides a method that includes: simultaneously sensing irradiance by a plurality of photo sensors, each of the photo sensors having a different sensing orientation; acquiring image information associated with a target object; determining, by a processor, direct and scattered components of the sensed irradiance; and determining a reflectance of the target object based on the determined direct and scattered components and the acquired image information.

In yet another embodiment, the present disclosure provides a method that includes: simultaneously sensing irradiance by a plurality of photo sensors positioned on an aerial vehicle, each of the photo sensors having a different sensing orientation; transmitting information indicative of the sensed irradiance from the plurality of photos sensors to a processor; and determining, by the processor, direct and scattered components of the irradiance.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

In the drawings, identical reference numbers identify similar elements. The sizes and relative positions of elements in the drawings are not necessarily drawn to scale.

Figure 1 is an illustration of an aerial vehicle for sensing irradiance and simultaneously obtaining an image of a target, in accordance with one or more embodiments of the present disclosure.

Figure 2 is an illustration showing further details of the aerial vehicle of Figure 1.

Figure 3 is an illustration of an irradiance sensing device, in accordance with one or more embodiments of the present disclosure.

Figure 4 is a block diagram illustrating a system for estimating or determining irradiance, based on irradiance sensed from a plurality of photo sensors, and for determining the reflectance of an imaged object, in accordance with one or more embodiments of the present disclosure.

Figure 5 is a flowchart illustrating a method of determining direct and scattered components of sensed irradiance, and determining reflectance of an imaged target based on the determined direct and scattered components, in accordance with one or more embodiments of the present disclosure.

DETAILED DESCRIPTION

The present disclosure is directed to systems and methods for measuring solar irradiance in radiometric remote sensing applications. Irradiance from a light source, such as the sun, may be simultaneously sensed by a plurality of photo sensors arranged at differing orientations on an irradiance sensing device. Components of the irradiance, such as the direct and scattered components and the incidence angle, may thus be determined, and utilized to compensate or normalize images of a target that are acquired at the same time by an imaging device.

Figure 1 illustrates an aerial vehicle 100 for sensing irradiance and simultaneously obtaining an image, for example, of a ground-based target, in accordance with one or more embodiments, and Figure 2 illustrates further details of the aerial vehicle 100. Referring to Figures 1 and 2, the aerial vehicle 100 includes an irradiance sensing device 110 and an imaging device 120 for imaging a physical area or scene (i.e., a target). The irradiance sensing device 110 and the imaging device 120 may collect, store and/or output the obtained irradiance and image information.

The aerial vehicle 100 may be any type of aerial vehicle, including any rotary or fixed wing aerial vehicle, and may be an unmanned vehicle (as shown in Figure 1) or manned aerial vehicle, such as an airplane or a drone. Additionally, the aerial vehicle 100 may be an autonomous vehicle, capable of autonomous flight (and autonomous acquisition of irradiance and image information), or may be a piloted vehicle (e.g., flown by a pilot in a manned vehicle, or by a remote pilot of an unmanned vehicle).

The imaged target (e.g., trees 102, crops 104, 106, a field of grass, a body of water or the like) receives irradiance from a light source, such as the sun 108. The target may be one or more distinct objects (e.g., a single tree, a building, a pond, etc.), an area or scene (e.g., a portion of a forest, a portion of a field of crops, a portion of a lake, etc.) or any other target for which the acquisition of an image may be desired.

The imaging device 120 may be a multispectral imaging device capable of acquiring spectral images of a target, and may include multiple imagers, with each such imager being tuned for capturing particular wavelengths of light that is reflected by the target. The imaging device 120 may be configured to capture reflected light in one or more of the ultraviolet, visible, near-infrared, and/or infrared regions of the electromagnetic spectrum.

Images acquired by such multispectral imaging devices may be utilized to measure or determine different characteristics of the target, such as the chlorophyll content of a plant, an amount of leaf area per unit ground area, an amount or type of algae in a body of water, and the like. In one or more embodiments, the imaging device 120 may be used to determine the reflectance of the imaged target.

The imaging device 120 may be mounted to the aerial vehicle 100 and oriented in any manner as may be desired. For example, the imaging device 120 may be mounted to a lower surface of the aerial vehicle 100 and positioned such that images of ground-based targets may be obtained.

The irradiance sensing device 110 may be mounted to an upper surface of the aerial device 100, and includes a plurality of photo sensors configured to simultaneously sense irradiance from a light source, such as the sun 108, at various different orientations with respect to the light source.

By simultaneously sensing irradiance by multiple photo sensors having different orientations, it is possible to determine particular characteristics of the light source, such as the direct and scattered components of solar irradiance, as well as an angle of incidence α of the solar irradiance. Moreover, the irradiance sensing device 110 may sense irradiance at the same time as images are acquired by the imaging device 120, which enables normalization or compensation of the acquired images to account for variations in received irradiance by the imaged target. For example, an image of a target acquired by the imaging device 120 on a cloudy day can be correlated to an image acquired of the same target on a cloudless day, by accounting for the differences in the irradiance sensed by the irradiance sensing device 110 at the time of acquiring each image.

Figure 3 illustrates the irradiance sensing device 110 in further detail, in accordance with one or more embodiments of the present disclosure. The irradiance sensing device 110 includes a plurality of photo sensors 112 arranged on different surfaces of a base 115. The base 115 includes a lower surface 114 that may be mounted, for example, to an upper surface of the aerial vehicle 100. Extending from the lower surface 114 is a plurality of inclined surfaces 116 on which the photo sensors 112 may be mounted. As shown in Figure 3, in one or more embodiments, the base 115 may have a truncated square pyramid shape, with four inclined surfaces 116 extending between the lower surface 114 and a flat upper surface 118. One or more photo sensors 112 may be mounted on each of the inclined surfaces 116 and the upper surface 118. The photo sensors 112 may thus be oriented to receive and sense varying amounts or components (e.g., direct and scattered components) of irradiance from a light source such as the sun 108.

The base 115 may have any shape or form that includes a plurality of surfaces on which photo sensors 112 may be mounted and configured to sense irradiance from differing orientations. The irradiance sensing device 110 may preferably include at least four, and in one or more embodiments may include five, photo sensors 112. Accordingly, the base 115 may preferably include at least four, and in one or more embodiments may include five, surfaces having different orientations for mounting the photo sensors 112.

Each photo sensor 112 includes a housing 111 or some external packaging that houses electronic circuitry (such as one or more application specific integrated circuits, computer-readable memory and the like) for processing and/or storing received signals (e.g., signals indicative of the sensed irradiance), and a photo sensor surface 113 for sensing irradiance.

Each of the photo sensors 112 may include one or more ports 117 for communicating signals (e.g., one or more signals indicative of the sensed irradiance) to or from the photo sensors 112. In one or more embodiments, the photo sensors 112 may be coupled to a processor (e.g., by one or more electrical wires or cables coupled to the ports 117) that is included onboard the aerial vehicle 100. The processor may similarly be communicatively coupled to the imaging device 120. Accordingly, the processor may acquire the sensed irradiance by the photo sensors 112 at the same time as an image of a target is acquired by the imaging device 120. The irradiance sensed by the irradiance sensing device 110 may thus be correlated with the image that is simultaneously acquired by the imaging device 120.

Additionally or alternatively, the photo sensors 112 may store the sensed irradiance information as it is acquired during a flight of the aerial vehicle 100. Similarly, the imaging device 120 may store images acquired during the flight. The image and irradiance information may later be uploaded to a computing system, which may correlate the stored irradiance and image information based on the time of acquisition of such information, which may be provided through a time stamp or similar information that may be included with the irradiance and image information.

The base 115 may be at least partially hollow or may otherwise include an inner cavity, which reduces the weight of the irradiance sensing device 110. Further, additional components of the aerial vehicle 100, such as any electrical or electronic components, may be housed within the inner cavity of the base 115. For example, a processor and/or any other circuitry may be included within the base 115 and may be communicatively coupled to the photo sensors 112 and/or the imaging device 120.

For irradiance sensing by an aerial vehicle, an irradiance sensing device should provide an instantaneous estimate of both the direct and scattered components, independent of sensor attitude estimates (e.g., which may be provided from an imprecise IMU) and large movements of the aerial vehicle itself. While a single sensor cannot provide such estimates, a multisensor array such as the irradiance sensing device 110 provided herein can.

As will be demonstrated below, the direct and scattered components of solar irradiance at any particular time may be determined based on the sensed irradiance simultaneously acquired by a plurality of photo sensors 112 having different orientations.

For simplicity sake and without loss of generality, a sensor body coordinate system may be assumed that has a Z-axis oriented towards the current sun position. In such a coordinate system, the incidence angle α between the sun and a sensor depends only on two angles (the azimuth angle and the zenith angle), since the irradiance is invariant under rotations around the Z-axis.

Rather than trying to directly measure these angles, the azimuth and zenith angles may be treated as unknowns to be estimated along with the direct and scattered solar irradiance. Thus in total, we aim to determine four unknowns from a set of five (or more) independent irradiance measurements, which will give us five (or more) non-linear equations. Such a system is readily solvable by standard means, such as Newton's method or least squares.

A system of five sensors (e.g., as shown in Figure 3) having the following configuration provides good results in simulation and allows a stable determination of all unknown quantities.

Note that the only inputs in this method are the known fixed photo sensor orientations and the measured irradiances. No assumptions about the time course of the direct and scattered irradiance are required and no attitudes need to be measured. The estimates of the components of the irradiance are instantaneous and as an added benefit, the photo sensor attitudes are provided in the special solar coordinate system.

It is noted that there are some special circumstances in which this method may not suitably determine the components of irradiance. One such circumstance exists in the absence of any direct light, in which the number of independent equations collapses to just one. However this is a special case that can easily be identified, as in this case all photo sensor readings should be the same, and equal to the scattered irradiance. Also, no meaningful results can be expected when the incidence angle becomes greater than 90 degrees for any photo sensor, a case which can be determined by use of an IMU. Note that in this case no particularly high accuracy from the IMU is required, as it is only needed to determine this special threshold.

In view of the above, the irradiance sensing device 110 may have a known coordinate system, and a transformation exists and may be determined between the device coordinate system and the global coordinate system, as the position of the sun at any given time is known.

Accordingly, irradiance sensed simultaneously by each of the photo sensors 112 of the irradiance sensing device 110 may be utilized to determine (e.g., by a processor) the direct and scattered components of solar irradiance (as well as the incidence angle α, the azimuth angle ϕ and the zenith angle θ) that is incident at a particular time on a target that may be imaged by the imaging device 120.

Figure 4 is a block diagram illustrating a system 200 for estimating or determining irradiance, based on the sensed irradiance from a plurality of photo sensors (e.g., as sensed by the irradiance sensing device 110), and for determining the reflectance of an imaged target or object. The system 200 may include a processor 230 that is communicatively coupled to the imaging device 120 and the irradiance sensing device 110 (including photo sensors 1 to N).

As noted previously herein, the processor 230 may be included onboard the aerial vehicle 100 (e.g., housed within a cavity in the base 115, or at any other location on the aerial vehicle 100). In other embodiments, the processor 230 may be included as part of a post-processing computer to which the irradiance sensing device 110 and/or the imaging device 120 may be coupled after an imaging session by the aerial vehicle 100. The post-processing computer may thus determine the components of the sensed irradiance based on the data collected and stored by the irradiance sensing device 110. Similarly, the imaging device 120 may capture and store data, which may later be provided to and processed by the processor 230.

Additionally, the processor 230 and/or instructions performed by the processor 230 (e.g., for determining irradiance components, reflectance values, etc.) may be located in the cloud, i.e., a remote distributed computing network that receives the collected data wirelessly from the imaging device 120 and the irradiance sensing device 110 or receives the data through a wired network once the imaging device 120 and irradiance sensing device 110 are coupled to a computer after the imaging session.

The processor 230 receives the sensed irradiance information from the irradiance sensing device 110 and the acquired image information from the imaging device 120. The processor 230 may access an irradiance determination module 234, which contains computer-readable instructions for determining the direct and scattered components of solar irradiance (and may further determine the incidence angle α, the azimuth angle ϕ and the zenith angle θ) based on the simultaneously sensed irradiance information from the plurality of photo sensors 112, as described herein.

The processor 230 may provide the determined direct and scattered components of solar irradiance to a reflectance determination module 232, along with image information of a target that was acquired by the imaging device 120 at the same time that the irradiance information was acquired. The reflectance determination module 232 may include computer-readable instructions for determining the reflectance of the target based on the image information of the target (which may indicate, for example, an amount of light reflected by the target) and the determined components of irradiance at the time the image information was acquired. Accordingly, the determined reflectance of an imaged target may be normalized or compensated to account for different irradiance levels that may be present at the time of imaging a target. For example, a determined reflectance for a target based on an image of the target acquired on a cloudy day will be the same or substantially the same as the reflectance for that same target that is determined based on an image of the target that was acquired on a cloudless day.

A compensation factor may thus be determined by the processor 230 (based on the determined components of irradiance) and may be applied by the reflectance determination module 232 for every image that is acquired by the imaging device 120, in order to accurately determine the reflectance of the imaged target, regardless of the lighting conditions at the time the image was acquired.

Figure 5 is a flowchart 300 illustrating a method of the present disclosure. At 302, the method includes simultaneously sensing irradiance from a light source by an irradiance sensing device 110 including a plurality of photo sensors 112 having different orientations with respect to the light source. The photo sensors 112 may be arranged, for example, as shown in the irradiance sensing device 110 of Figure 3. The photo sensors 112 may be included onboard an aerial vehicle 100, and the irradiance may thus be sensed while the aerial vehicle 100 is in flight.

At 304, the method includes acquiring an image of a target object by an imaging device 120. The image may be acquired at the same time as the irradiance sensing device 110 senses irradiance, and the image and irradiance information may thus be correlated.

At 306, the method includes determining direct and scattered components of the sensed irradiance. And at 308, the method includes determining the reflectance of the target object based on the determined direct and scattered components of the sensed irradiance, and the acquired image of the target object. This method thus provides inherently compensated or normalized reflectance measurements of a target, such as vegetation, that are independent of changes in irradiance from a variable light source (e.g., the sun), and does not require an IMU or calibration of the imaging device. The method may be performed for each image acquired by the imaging device 120.

As is well known, different materials reflect and absorb incident irradiance differently at different wavelengths. Thus, targets can be differentiated based on their spectral reflectance signatures in remotely sensed images. Reflectance is a property of materials and is generally defined as the fraction of incident irradiance that is reflected by a target. The reflectance properties of a material depend on the particular material and its physical and chemical state (e.g., moisture), as well as other properties such as surface texture and other properties that may be known in the relevant field.

The various embodiments provided herein may be thus be utilized in a variety of applications in which determining reflectance of one or more imaged targets may be desirable. For example, by measuring or determining the reflectance of a plant at different wavelengths, areas of stress in a crop may be identified. Moreover, determined changes in reflectance of surface features such as vegetation, soil, water and the like can be utilized to determine the development of disease in crops, growth of algae in a body of water, changes in the chemical properties of ground or soil, and so on.

Various other applications are contemplated by the present disclosure. For example, embodiments provided herein may be utilized in navigational applications, since the orientation of the irradiance sensing device 110 is determined with respect to the position of the sun. That is, the orientation of the irradiance sensing device 110 may be mapped to the global or horizontal coordinate system, as described above, which may thus be used for navigational purposes by any vehicle including the irradiance sensing device 110. Additionally, it will be appreciated that flight parameters of the aerial vehicle 100, including pitch, heading and roll, may be determined based on the irradiance sensed by the photo sensors 112 of the irradiance sensing device 110, and the determined components of the irradiance. As noted previously herein, the estimates of the components of the irradiance are instantaneous and the photo sensor attitudes are provided in the special solar coordinate system. Moreover, the orientation of the irradiance sensing device 110 may be mapped to the global or horizontal coordinate system, as described herein. Accordingly, the determined photo sensor attitudes (including, pitch, heading and roll information) provided in the special solar coordinate system may be mapped to the global or horizontal coordinate system for an indication of the aerial vehicle's 100 attitude with respect to the Earth. Additionally, changes in the determined photo sensor pitch, heading and roll during flight may be utilized for navigational purposes.

In the description, certain specific details are set forth in order to provide a thorough understanding of various embodiments of the disclosure. However, one skilled in the art will understand that the disclosure may be practiced without these specific details. In other instances, well-known structures have not been described in detail to avoid unnecessarily obscuring the descriptions of the embodiments of the present disclosure.

Unless the context requires otherwise, throughout the specification and claims that follow, the word “comprise” and variations thereof, such as “comprises” and “comprising,” are to be construed in an open, inclusive sense, that is, as “including, but not limited to.”

Reference throughout this specification to “one embodiment” or “an embodiment” means that a particular feature, structure or characteristic described in connection with the embodiment is included in at least one embodiment. Thus, the appearances of the phrases “in one embodiment” or “in an embodiment” in various places throughout this specification are not necessarily all referring to the same embodiment. Furthermore, the particular features, structures, or characteristics may be combined in any suitable manner in one or more embodiments.

As used in this specification and the appended claims, the singular forms “a,” “an,” and “the” include plural referents unless the content clearly dictates otherwise. It should also be noted that the term “or” is generally employed in its sense including “and/or” unless the content clearly dictates otherwise.

The various embodiments described above can be combined to provide further embodiments. These and other changes can be made to the embodiments in light of the above-detailed description. In general, in the following claims, the terms used should not be construed to limit the claims to the specific embodiments disclosed in the specification and the claims, but should be construed to include all possible embodiments along with the full scope of equivalents to which such claims are entitled. Accordingly, the claims are not limited by the disclosure.

CLAIMS

1. A device, comprising:

an aerial vehicle; and

an irradiance sensing device including:

a base structure mounted to the aerial vehicle, the base structure including a plurality of surfaces, and

a plurality of photo sensors respectively arranged on the surfaces of the base structure and having different orientations with respect to each other.

2. The device of claim 1 wherein the plurality of photo sensors are configured to simultaneously sense irradiance from a light source, and to output signals indicative of the sensed irradiance.

3. The device of claim 2, further comprising a processor coupled to the plurality of photo sensors and configured to receive the output signals and to determine a direct component and a scattered component of the sensed irradiance.

4. The device of claim 1 wherein the plurality of surfaces of the base structure includes a lower surface, an upper surface and a plurality of inclined surfaces extending between the lower and upper surfaces.

5. The device of claim 4 wherein the plurality of photo sensors are arranged on the upper and inclined surfaces of the base structure.

6. The device of claim 5 wherein the inclined surfaces of the base structure include four inclined surfaces, and the plurality of photo sensors are arranged on the four inclined surfaces and the upper surface.

7. The device of claim 1, further comprising an imaging device mounted to the aerial vehicle.

8. The device of claim 7 wherein the imaging device is a multispectral imaging device.

9. The device of claim 7, further comprising a processor coupled to the irradiance sensing device and the imaging device, the processor being configured to correlate irradiance information sensed by the plurality of photo sensors with image information acquired by the imaging device at a time the image information is acquired.

10. The device of claim 9 wherein the processor is further configured to determine to determine a direct component and a scattered component of the sensed irradiance.

11. The device of claim 1 wherein the aerial vehicle is an unmanned aerial vehicle.

12. The device of claim 1 wherein the base structure includes an inner cavity housing one or more electrical components of the device.

13. A method, comprising:

simultaneously sensing irradiance by a plurality of photo sensors, each of the photo sensors having a different sensing orientation;

acquiring image information associated with a target object;

determining, by a processor, direct and scattered components of the sensed irradiance; and determining a reflectance of the target object based on the determined direct and scattered components and the acquired image information.

14. The method of claim 13, further comprising correlating the sensed irradiance with the image information at a time the image information is acquired.

15. The method of claim 13, further comprising determining, by the processor, an incidence angle of the irradiance.

16. The method of claim 13 wherein the target object includes a plant, the method further comprising:

determining a state of health of the plant based on the determined reflectance of the plant.

17. The method of claim 13, further comprising:

determining, by the processor, at least one of pitch, heading and roll of the aerial vehicle based on the simultaneously sensed irradiance by the plurality of photo sensors having a different sensing orientation.

18. A method, comprising:

simultaneously sensing irradiance by a plurality of photo sensors positioned on an aerial vehicle, each of the photo sensors having a different sensing orientation;

transmitting information indicative of the sensed irradiance from the plurality of photos sensors to a processor; and

determining, by the processor, direct and scattered components of the irradiance.

19. The method of claim 17, further comprising:

determining, by the processor, at least one of pitch, heading and roll of the aerial vehicle based on the simultaneously sensed irradiance by the plurality of photo sensors having a different sensing orientation.

20. The method of claim 19, further comprising:

navigating a flight of the aerial vehicle based on the determined at least one of pitch, heading and roll.

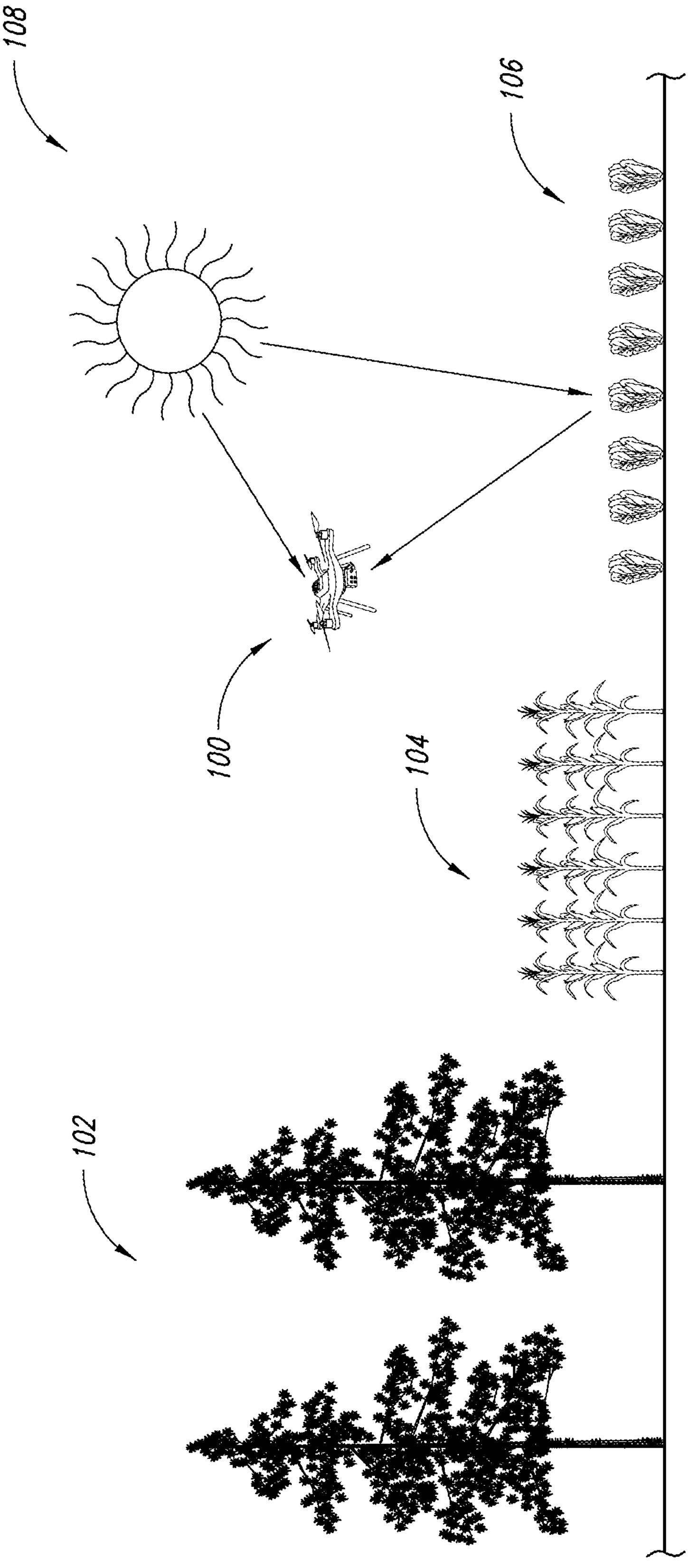


FIG. 1

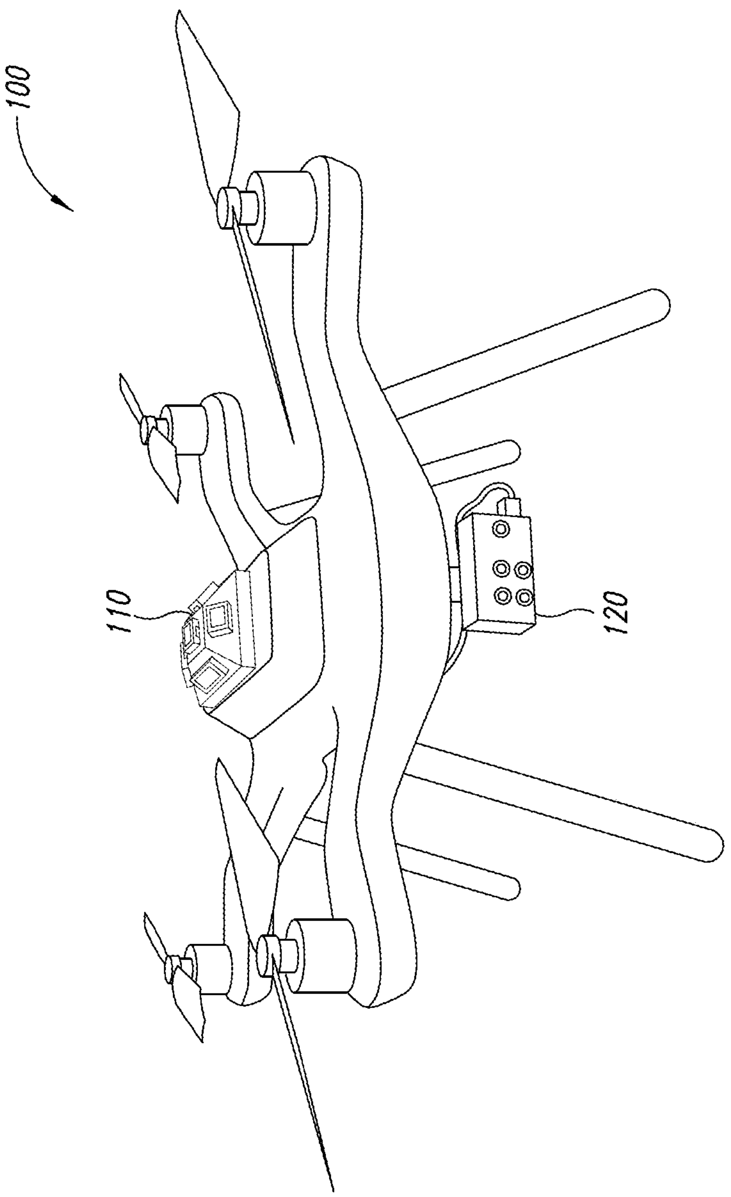


FIG. 2

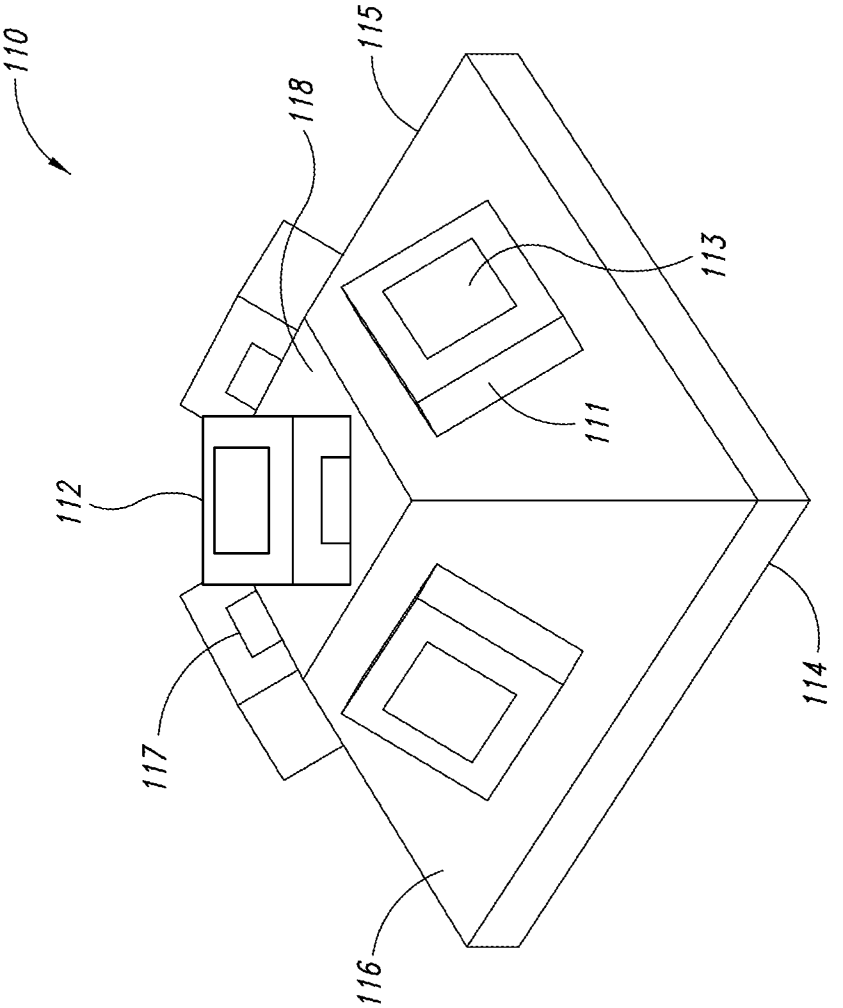
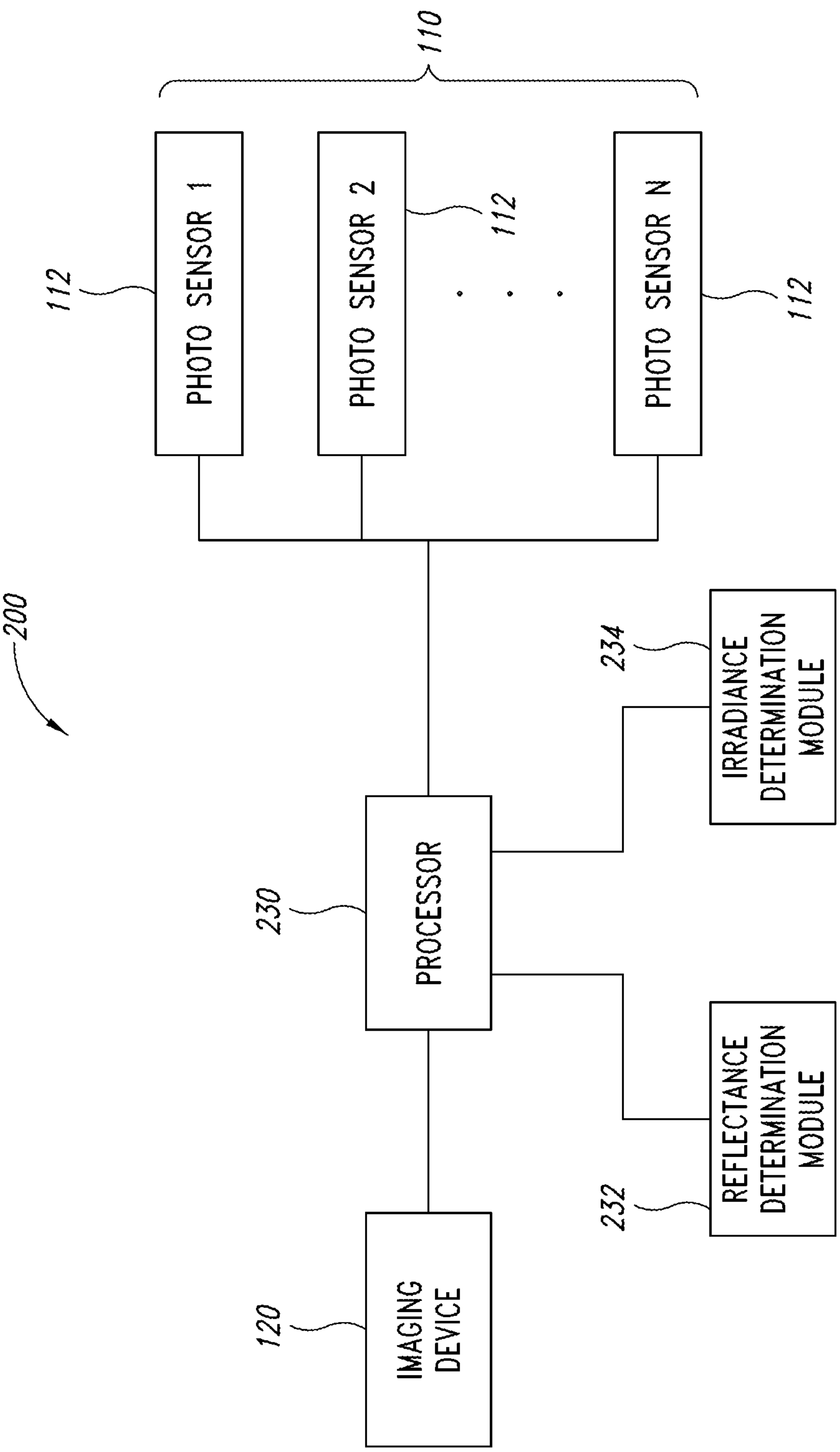


FIG. 3


110
112
PHOTO SENSOR 1
PHOTO SENSOR 2
112
PHOTO SENSOR N
112
200
234
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230
PROCESSOR
232
REFLECTANCE DETERMINATION MODULE
120
IMAGING DEVICE

FIG. 4

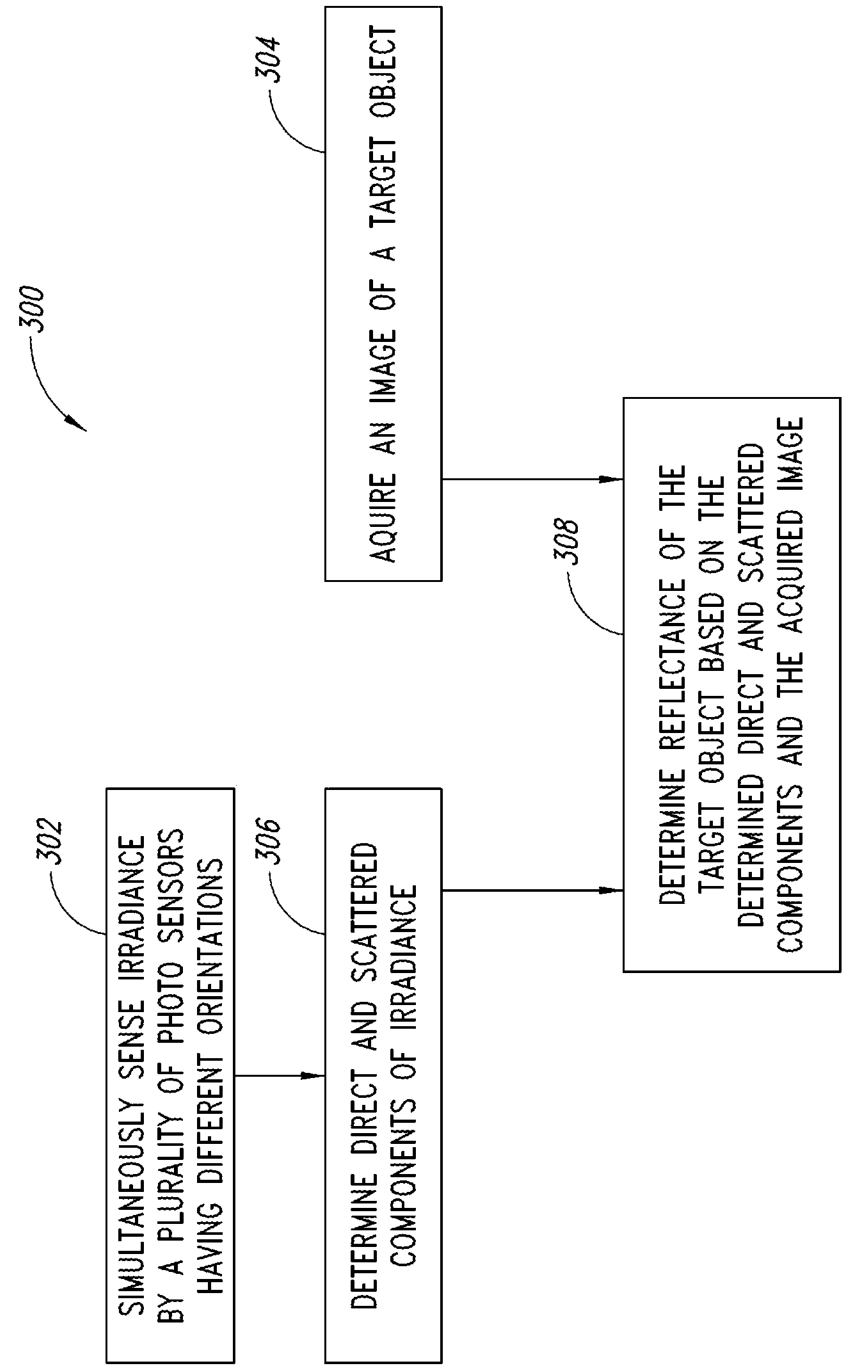
300
302
SIMULTANEOUSLY SENSE IRRADIANCE BY A PLURALITY OF PHOTO SENSORS HAVING DIFFERENT ORIENTATIONS
304
AQUIRE AN IMAGE OF A TARGET OBJECT
306
DETERMINE DIRECT AND SCATTERED COMPONENTS OF IRRADIANCE
308
DETERMINE REFLECTANCE OF THE TARGET OBJECT BASED ON THE DETERMINED DIRECT AND SCATTERED COMPONENTS AND THE ACQUIRED IMAGE

FIG. 5

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:
See extra sheet(s).

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-12

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/066524

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - G01J 3/28; G01J 3/00; G01J 3/02; H01L 27/00 (2018.01)
CPC - G01J 3/2823; G01J 3/00; G01J 3/0297; H01L 27/00 (2018.02)

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)
See Search History document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC - 250/208.1 (keyword delimited)

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2016/0069741 A1 (SLANTRANGE, INC.) 10 March 2016 (10.03.2016) entire document	1-12
Y	US 2014/0267596 A1 (GEERDS) 18 September 2014 (18.09.2014) entire document	1-12
Y	US 2013/0126706 A1 (LYNASS et al) 23 May 2013 (23.05.2013) entire document	3, 10
A	US 2015/0367957 A1 (AAI CORPORATION) 24 December 2015 (24.12.2015) entire document	5, 6
A	US 7,664,225 B2 (KLEIN) 16 February 2010 (16.02.2010) entire document	1-12
A	US 2012/0200703 A1 (NADIR et al) 09 August 2012 (09.08.2012) entire document	1-12

☐ 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
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
30 March 2018	17 APR 2018

Name and mailing address of the ISA/US	Authorized officer
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, VA 22313-1450 Facsimile No. 571-273-8300	Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Continued from Box No. III Observations where unity of invention is lacking

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees must be paid.

Group I, claims 1-12, are drawn to a device, comprising an irradiance sensing device including: a base structure mounted to the aerial vehicle, the base structure including a plurality of surfaces.

Group II, claims 13-20, are drawn to a method, comprising: simultaneously sensing irradiance by a plurality of photo sensors, each of the photo sensors having a different sensing orientation; and acquiring image information associated with a target object.

The inventions listed as Groups I-II do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons: the special technical feature of the Group I invention: an irradiance sensing device including: a base structure mounted to the aerial vehicle, the base structure including a plurality of surfaces as claimed therein is not present in the invention of Group II. The special technical feature of the Group II invention: simultaneously sensing irradiance by a plurality of photo sensors, each of the photo sensors having a different sensing orientation; acquiring image information associated with a target object; determining, by a processor, direct and scattered components of the sensed irradiance; and determining a reflectance of the target object based on the determined direct and scattered components and the acquired image information as claimed therein is not present in the invention of Group I.

Groups I and II lack unity of invention because even though the inventions of these groups require the technical feature of an aerial vehicle and a plurality of photo sensors, each of the photo sensors having a different sensing orientation, this technical feature is not a special technical feature as it does not make a contribution over the prior art.

Specifically, US 2016/0069741 to SlantRange, Inc. teaches an aerial vehicle and a plurality of photo sensors, each of the photo sensors having a different sensing orientation (Paras. [0056], [0087]).

Since none of the special technical features of the Group I or II inventions are found in more than one of the inventions, unity of invention is lacking.