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(71) Applicant(s):
Ofil Ltd
Einstein 16, Nes Ziona 74140, Israel

(72) Inventor(s):
Eran Frisch
Odelya Koslovsky
Reuel Haavrahami

(74) Agent and/or Address for Service:
Shalom Lampert
Apt 1028, Chynoweth House, Trevissome Park, Truro,
Cornwall, TR4 8UN, United Kingdom

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G02B 5/20 (2006.01)

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US 6150652 A	**US 20110273560 A1**
US 20080233504 A1	

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INT CL **G01J, G01N, G01R, G02B, G06T**
Other: **EPODOC, WPI, TXTE**

(54) Title of the Invention: **Viewing device**
Abstract Title: **A UVB/visible hybrid viewing device where at least a portion of the visible-band imaging apparatus is in a field-of-view of the UV imaging apparatus**

(57) A UVB-visible hybrid system and method for visualizing a scene comprising one or more terrestrial corona discharge(s) and one or more objects is disclosed. A UVB image of the scene 200 is generated using UVB light which passes though a corona-peak tuned optical filter 410 configured to filter out sufficient non-terrestrial-corona light so that the generated UVB image is object-devoid. A visible-band imaging apparatus 500 comprises an array of photo-detectors 532 and is configured to generate a visible image of the scene. A derivative of the object-devoid UVB image is superposed with the visible-band image of the scene and displayed on a display device 580. The UVB imaging apparatus 400 and the visible-band imaging apparatus 500 share a common optical axis; the array of photo-detectors is disposed in the field of view of the UVB imaging apparatus. The object-devoid UVB image may be analyzed to classify pixels thereof as corona-discharge pixels or non-corona-discharge pixels. In some embodiments, the optical filter 410 has an average optical density over the [290 nm, 700 nm] spectrum of at least 4.

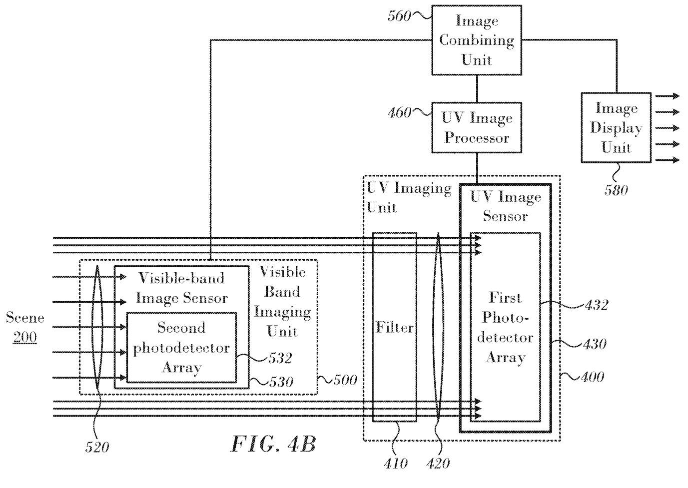


FIG. 4B

GB 2522095 A

At least some of the priority details shown above were added after the date of filing of the application.

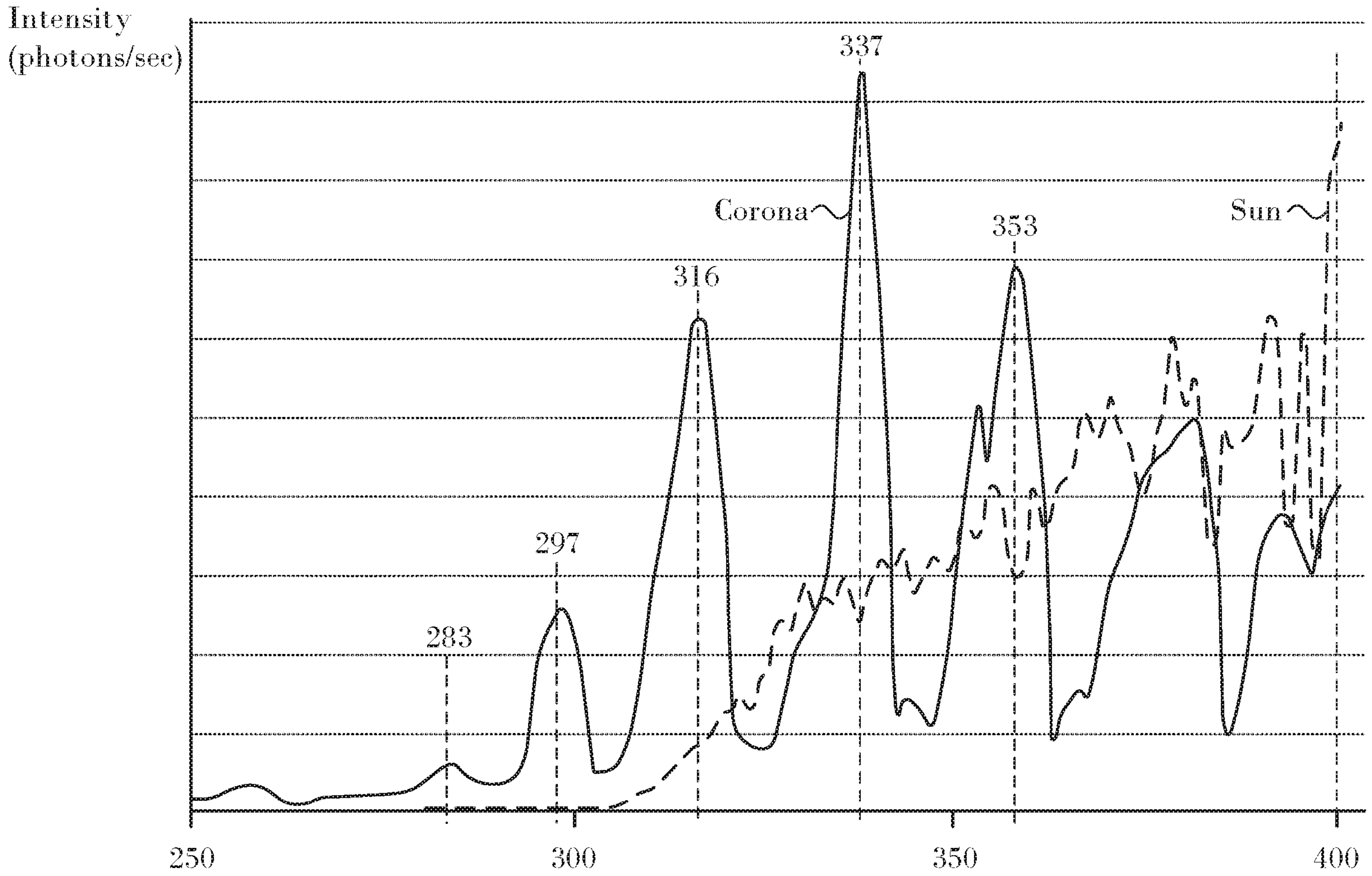


FIG. 1 (Prior Art)

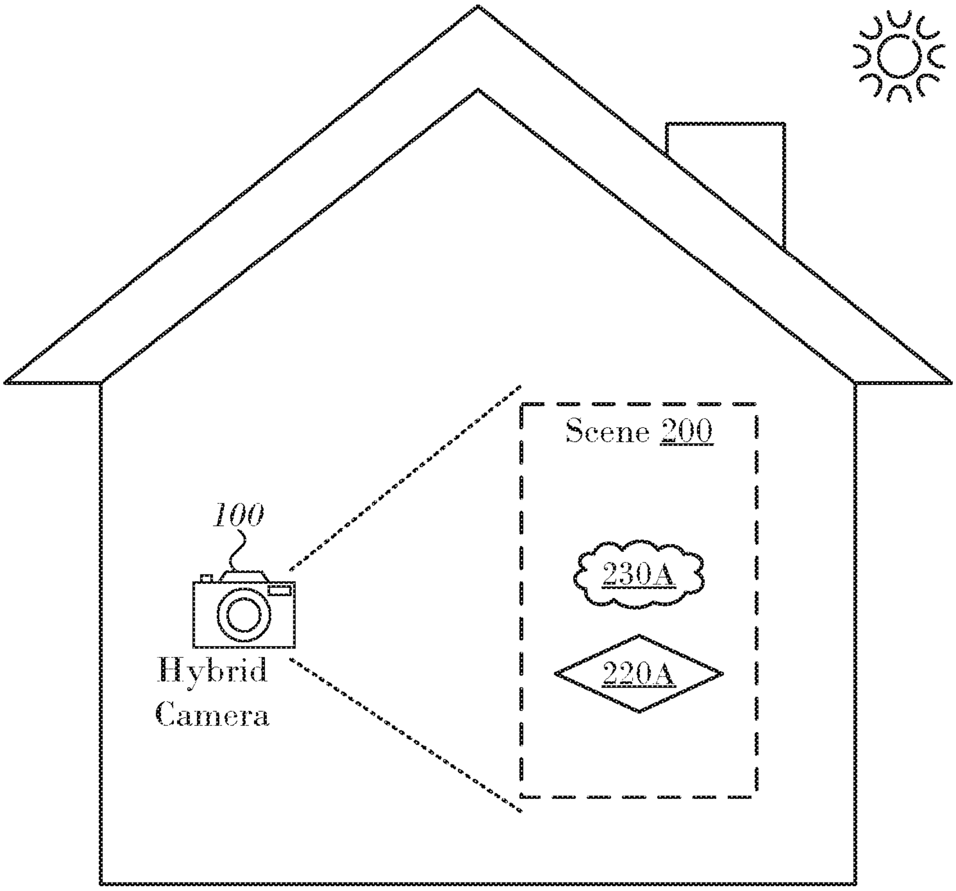

Scene 200
100
Hybrid Camera
230A
220A

FIG. 2

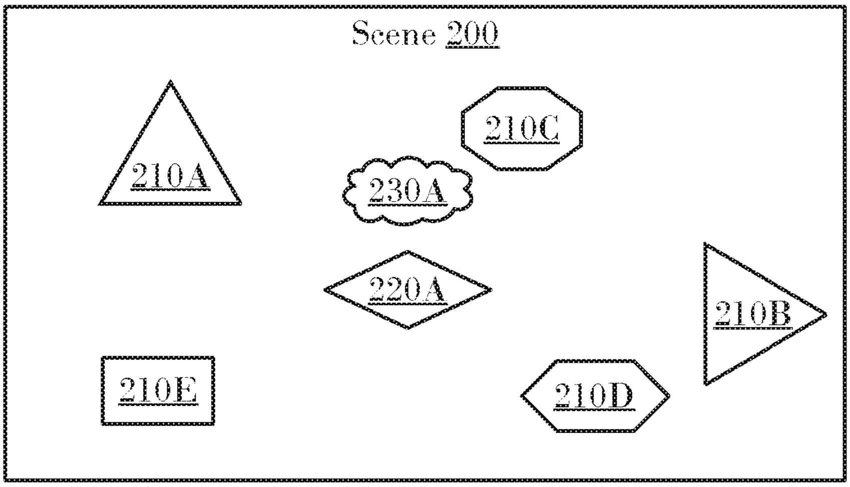

Scene 200
210A
210C
230A
220A
210B
210E
210D

FIG. 3

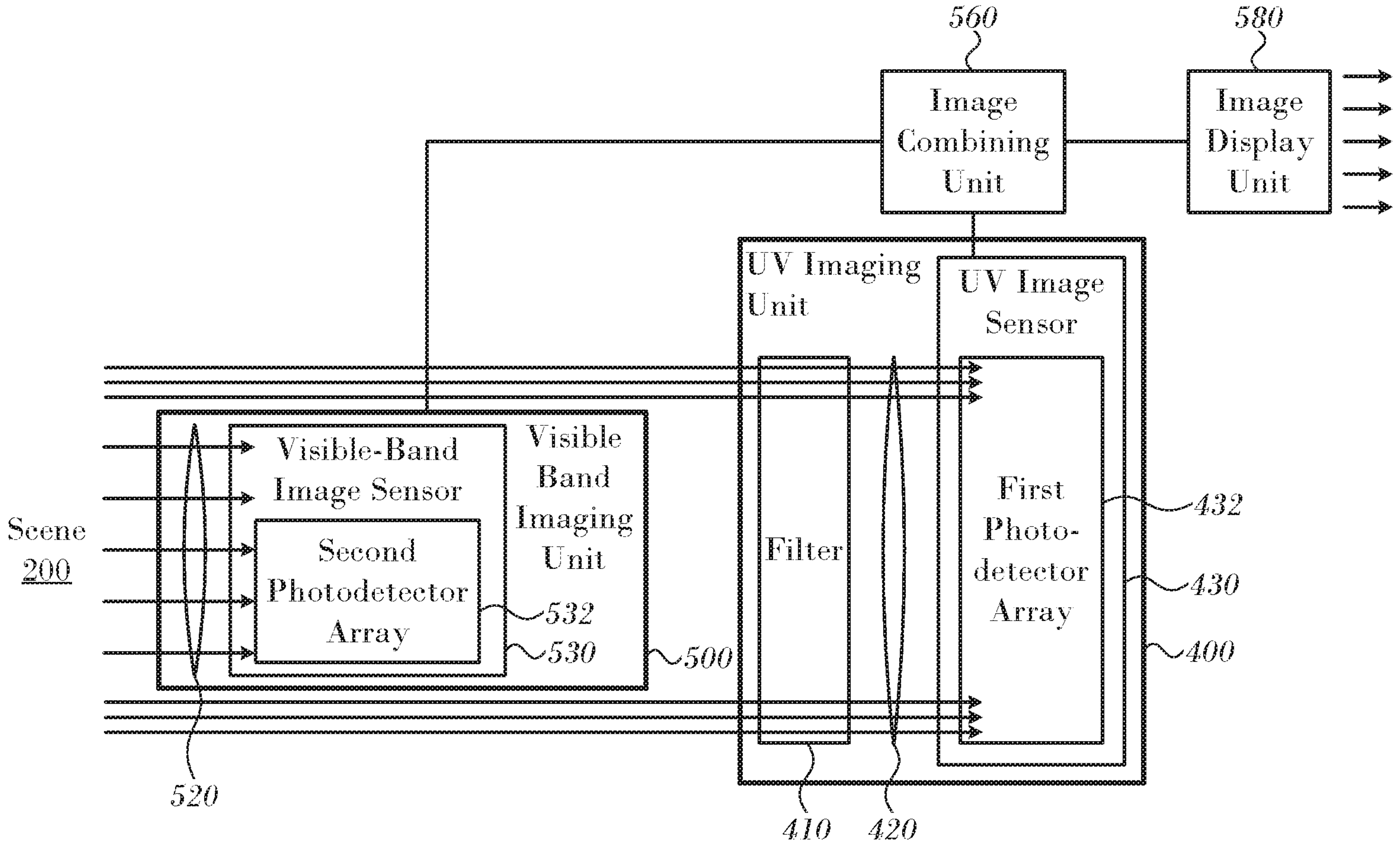

560
580
Image Combining Unit
Image Display Unit
UV Imaging Unit
UV Image Sensor
Visible-Band Image Sensor
Visible Band Imaging Unit
Scene
200
Second Photodetector Array
532
530
500
Filter
First Photo-detector Array
432
430
400
520
410
420

FIG. 4A

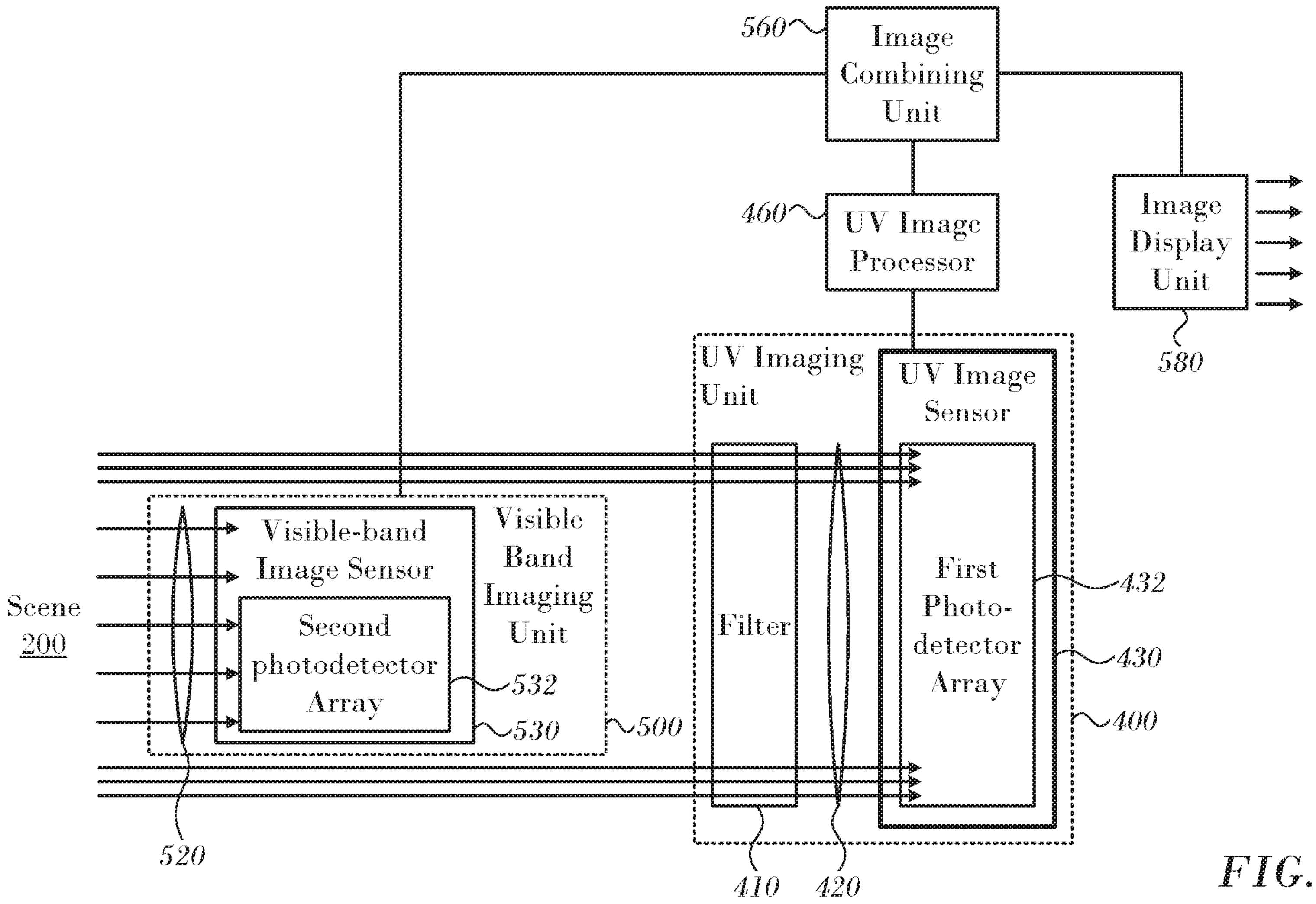

Scene
200
Visible-band Image Sensor
Second photodetector Array
Visible Band Imaging Unit
520
532
530
500
UV Imaging Unit
Filter
UV Image Sensor
First Photo-detector Array
432
430
400
410
420
Image Combining Unit
560
UV Image Processor
460
Image Display Unit
580

FIG. 4B

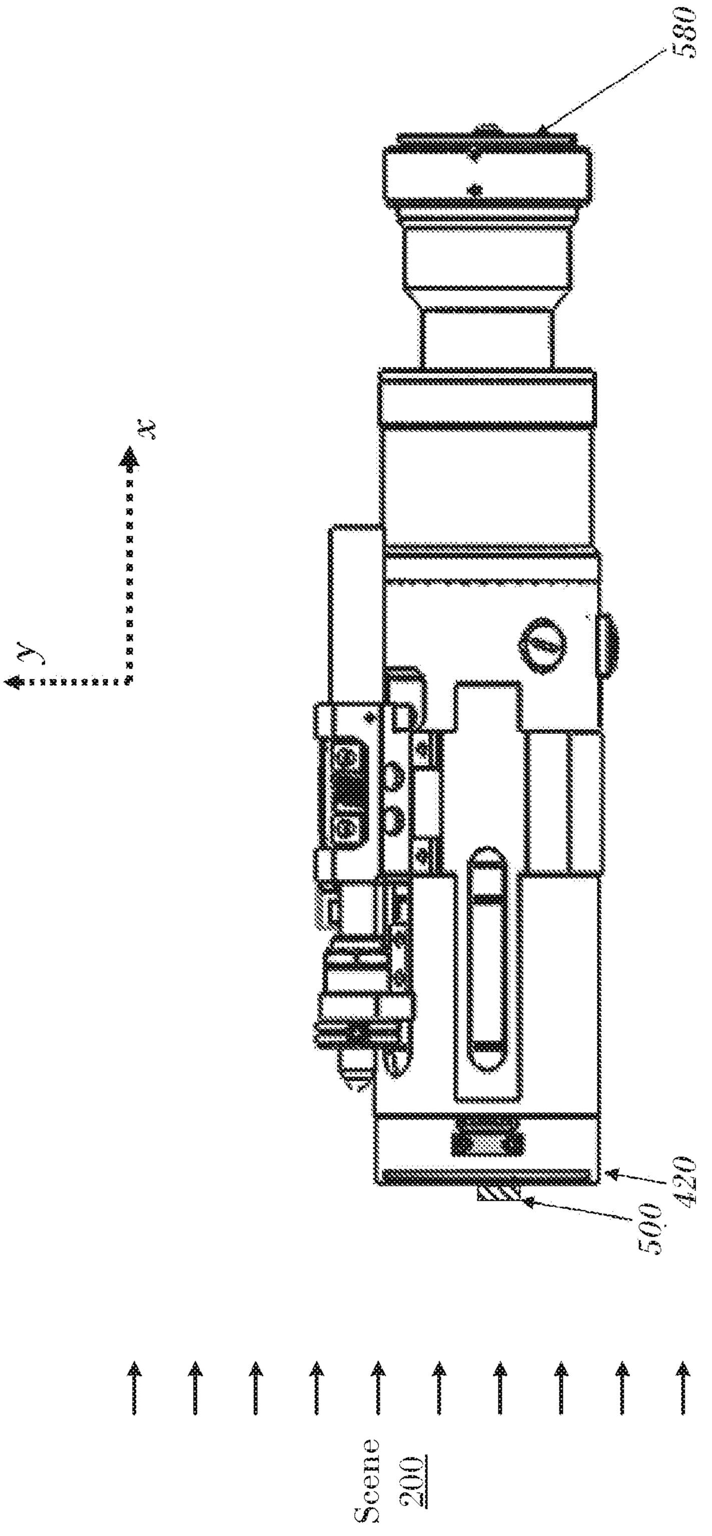


FIG. 4C

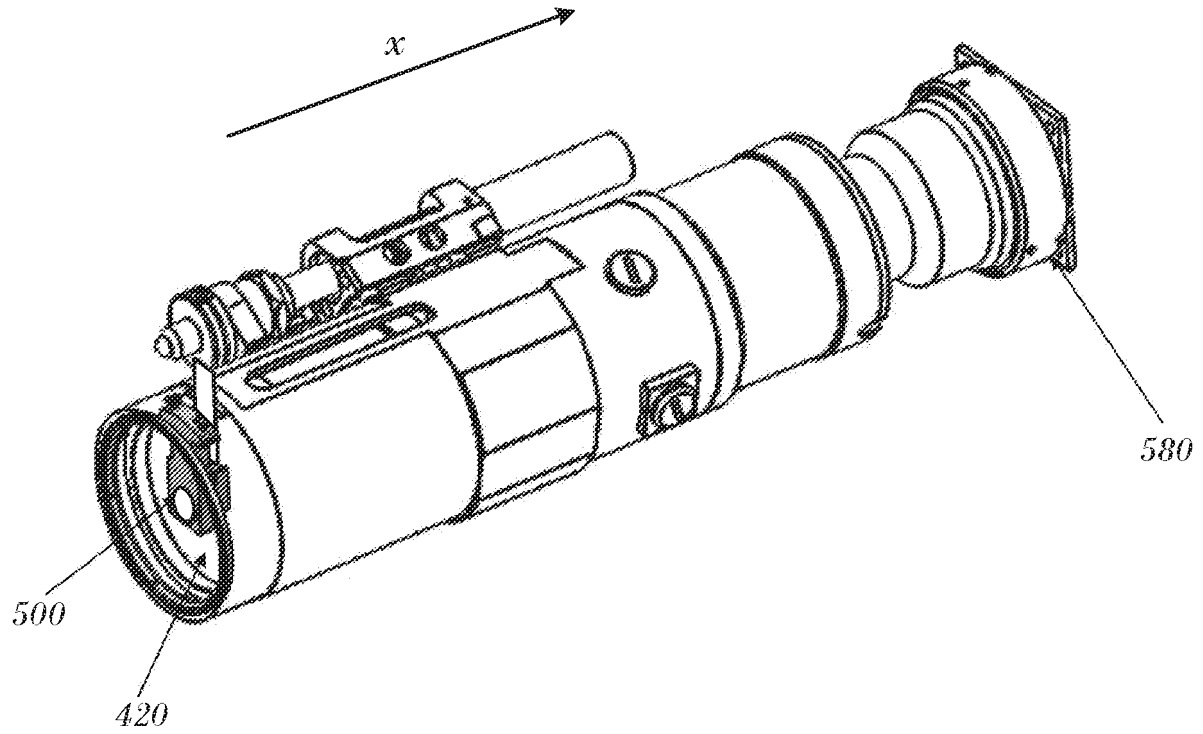


FIG. 4D

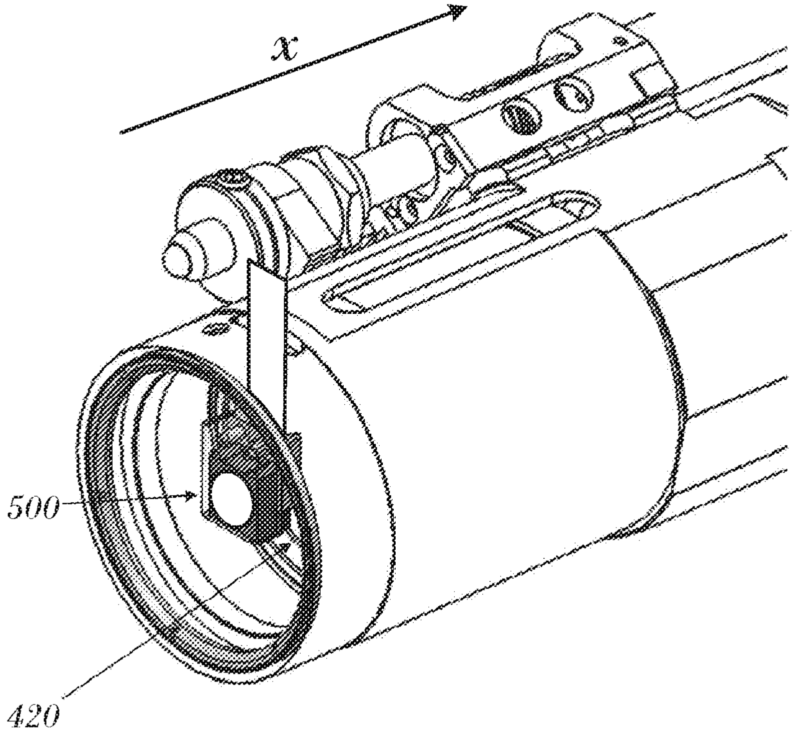


FIG. 4E

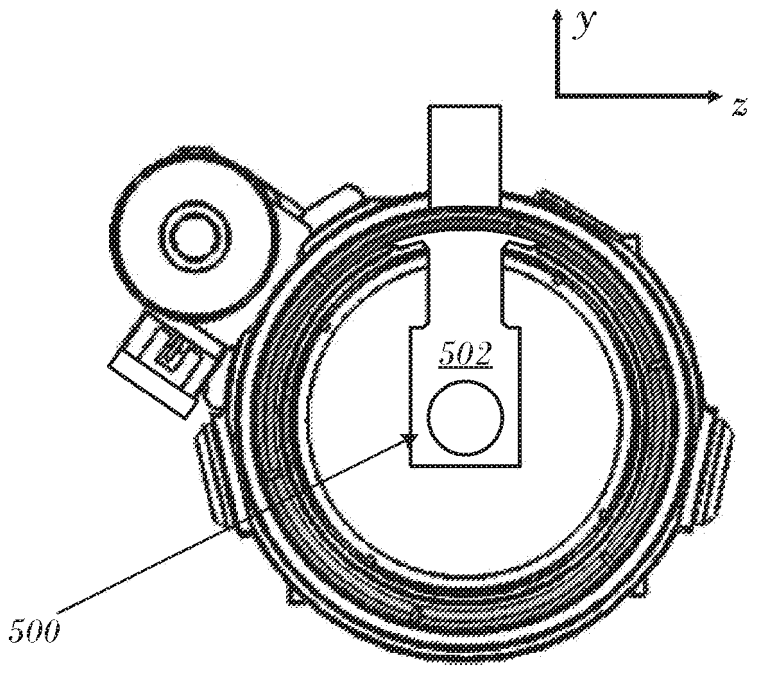


FIG. 4F

UVB Image (e.g. object-devoid) of Scene (SCHEMATIC)

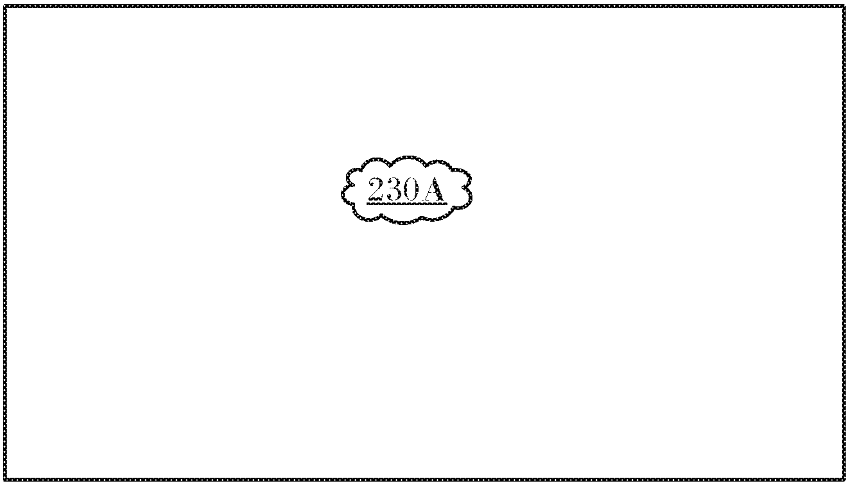


FIG. 5

Visible-Band Image of Scene (SCHEMATIC)

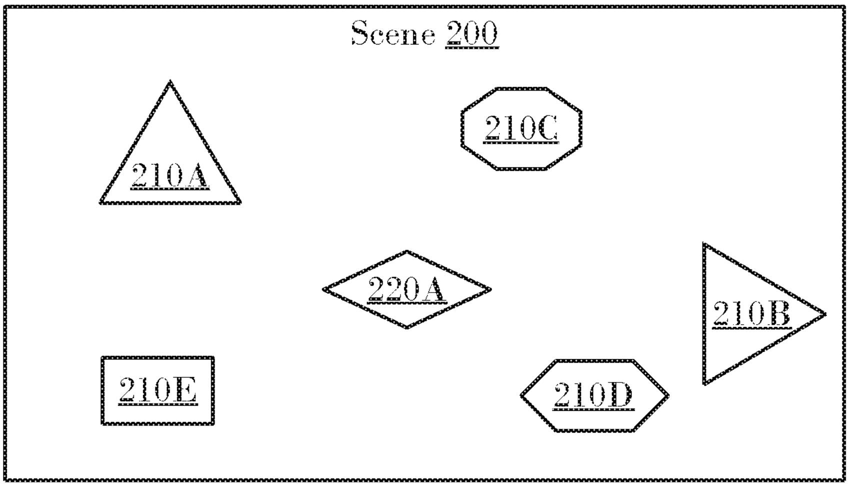


FIG. 6

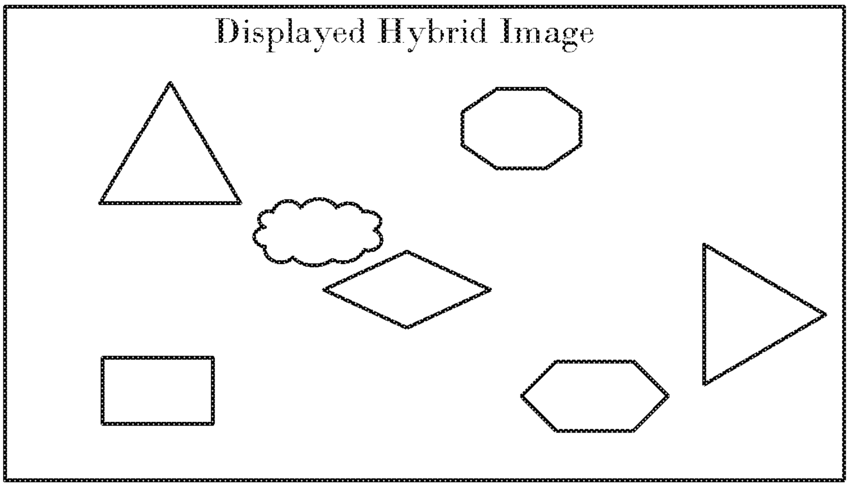


FIG. 7

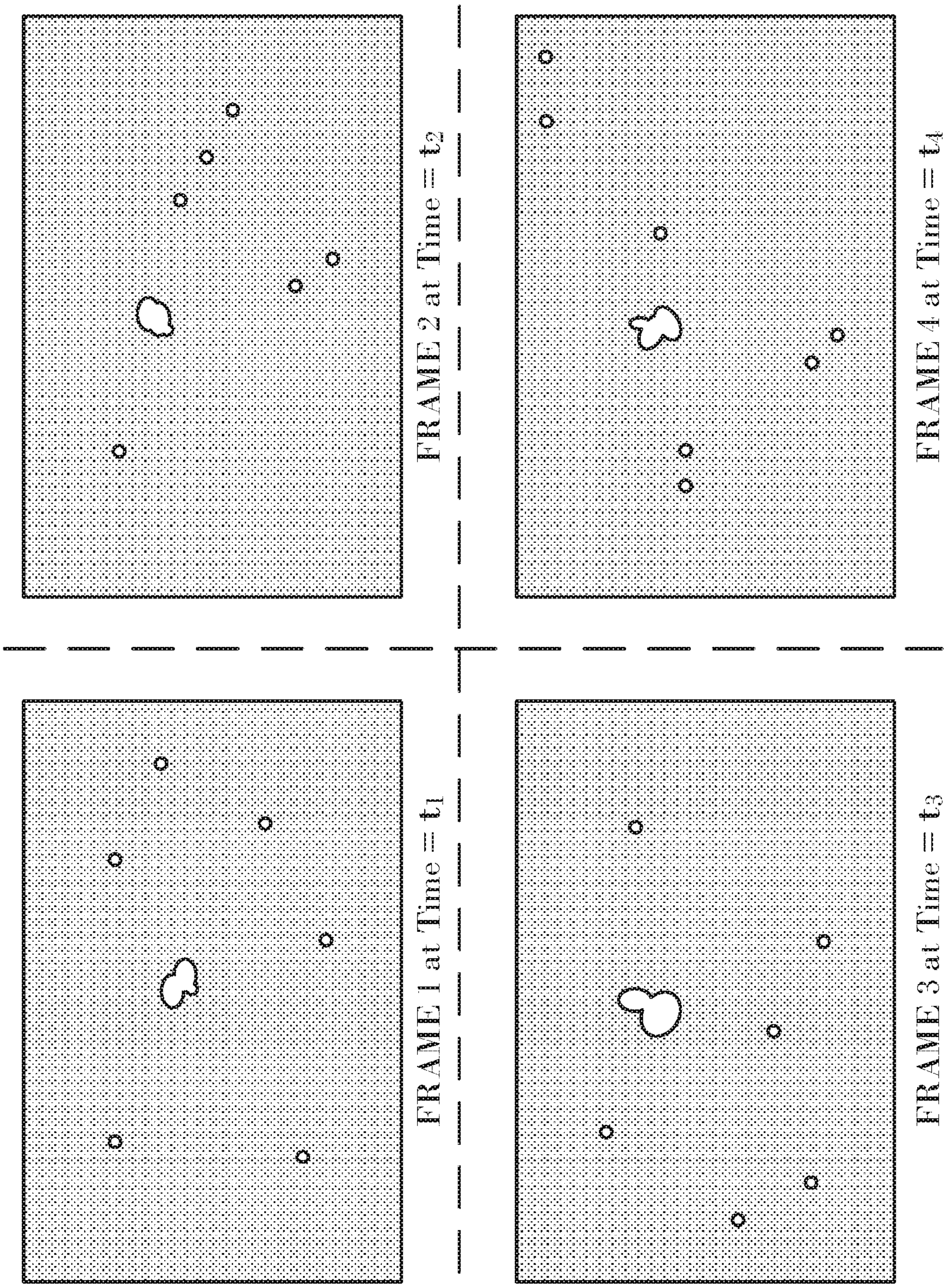

FRAME 1 at Time = t_1
FRAME 2 at Time = t_2
FRAME 3 at Time = t_3
FRAME 4 at Time = t_4

FIG. 8

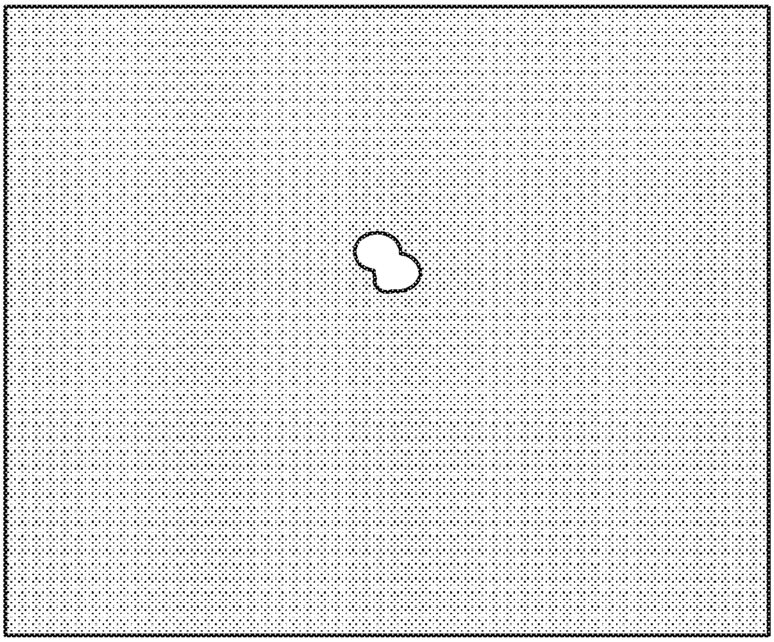
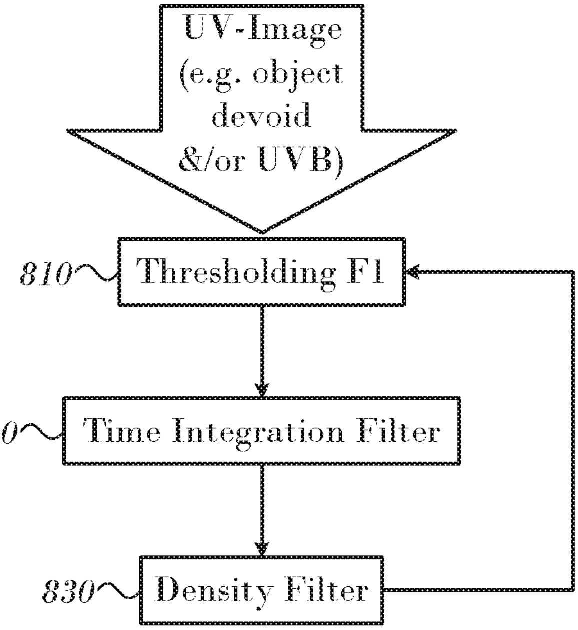


FIG. 9



UV-Image (e.g. object devoid &/or UVB)
810
Thresholding F1
820
Time Integration Filter
830
Density Filter

FIG. 10

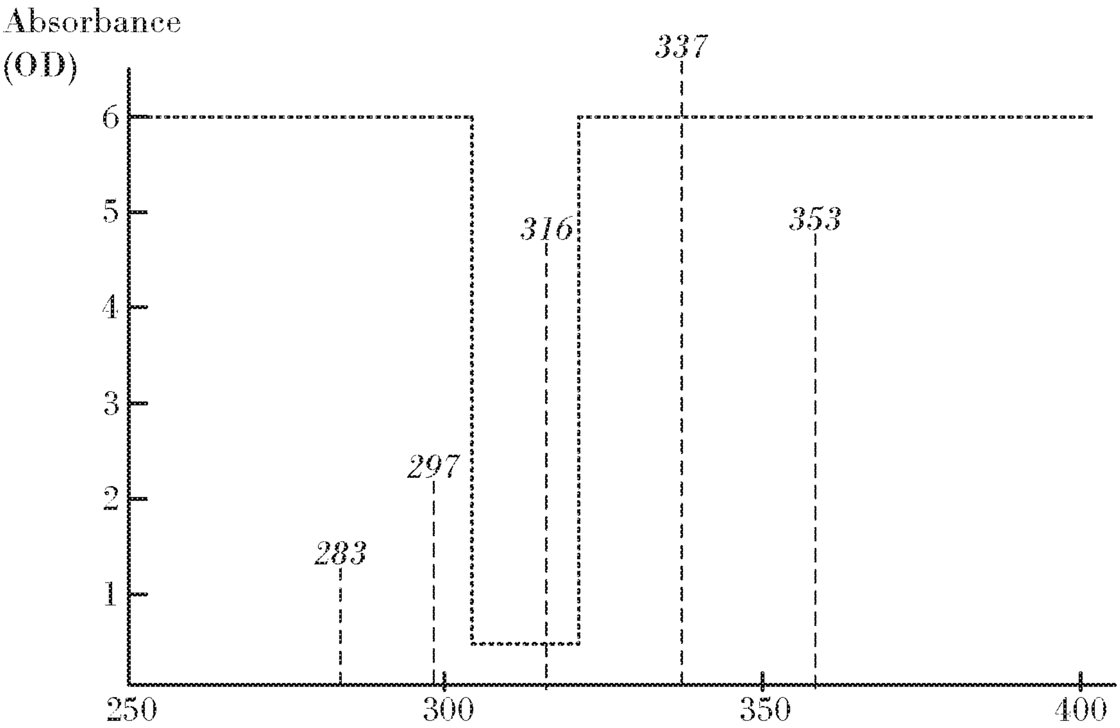


FIG. 11A

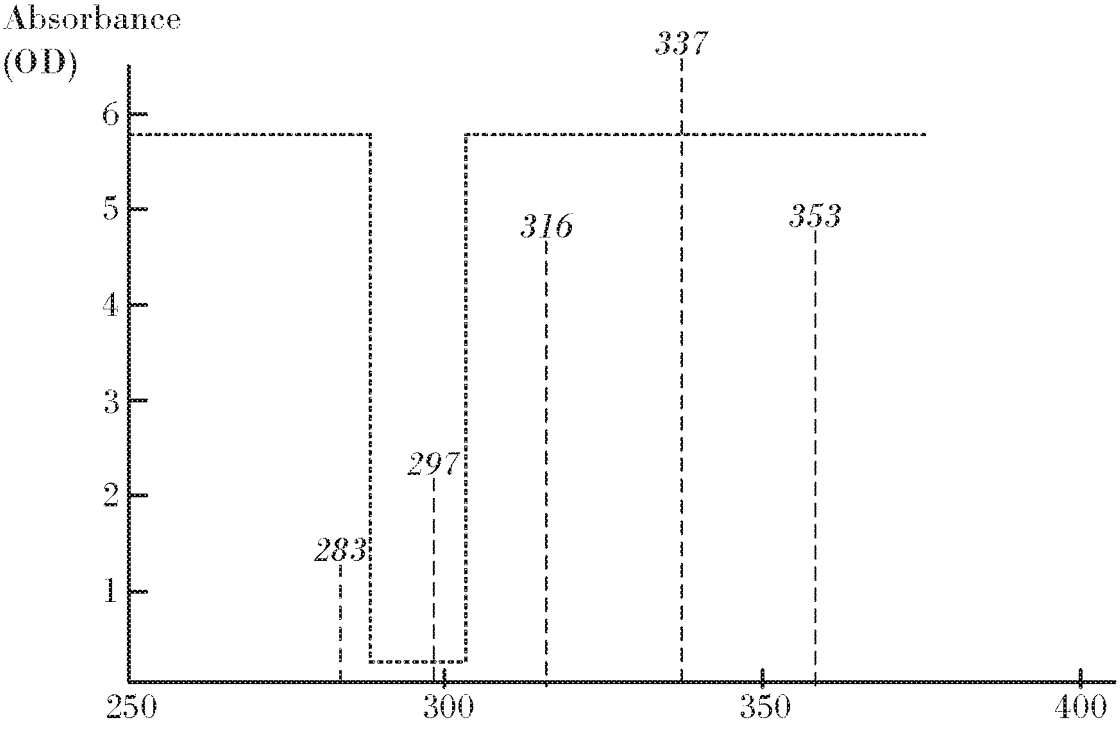


FIG. 11B

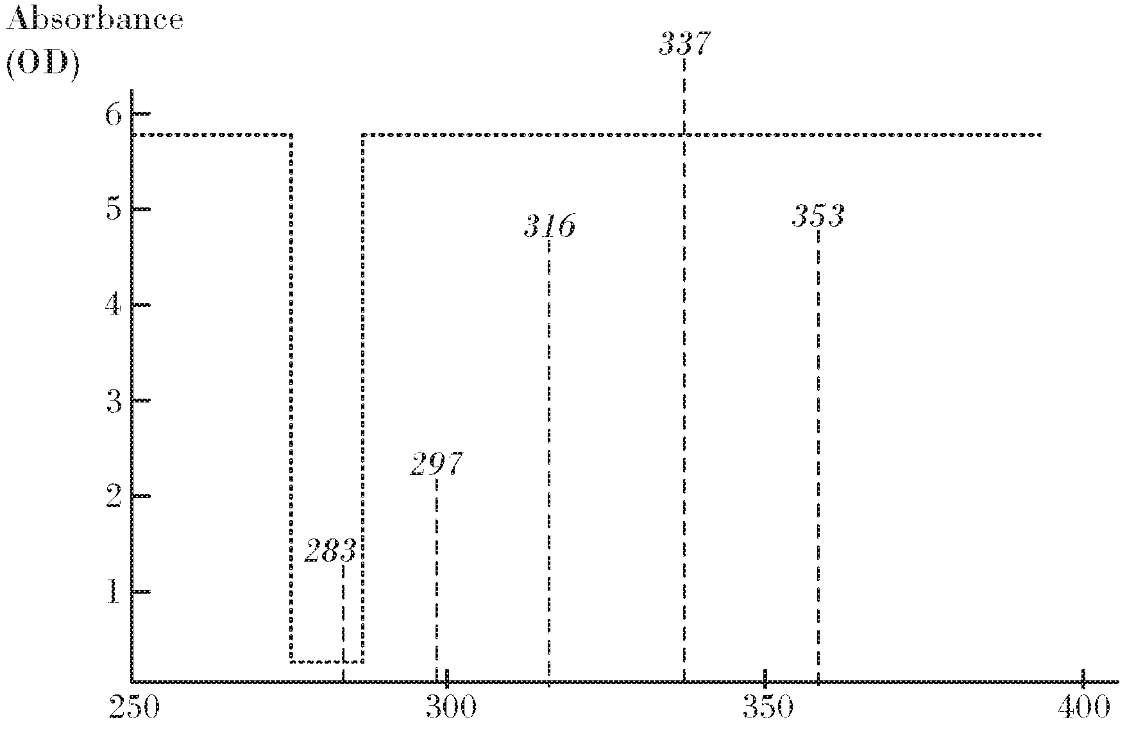


FIG. 11C

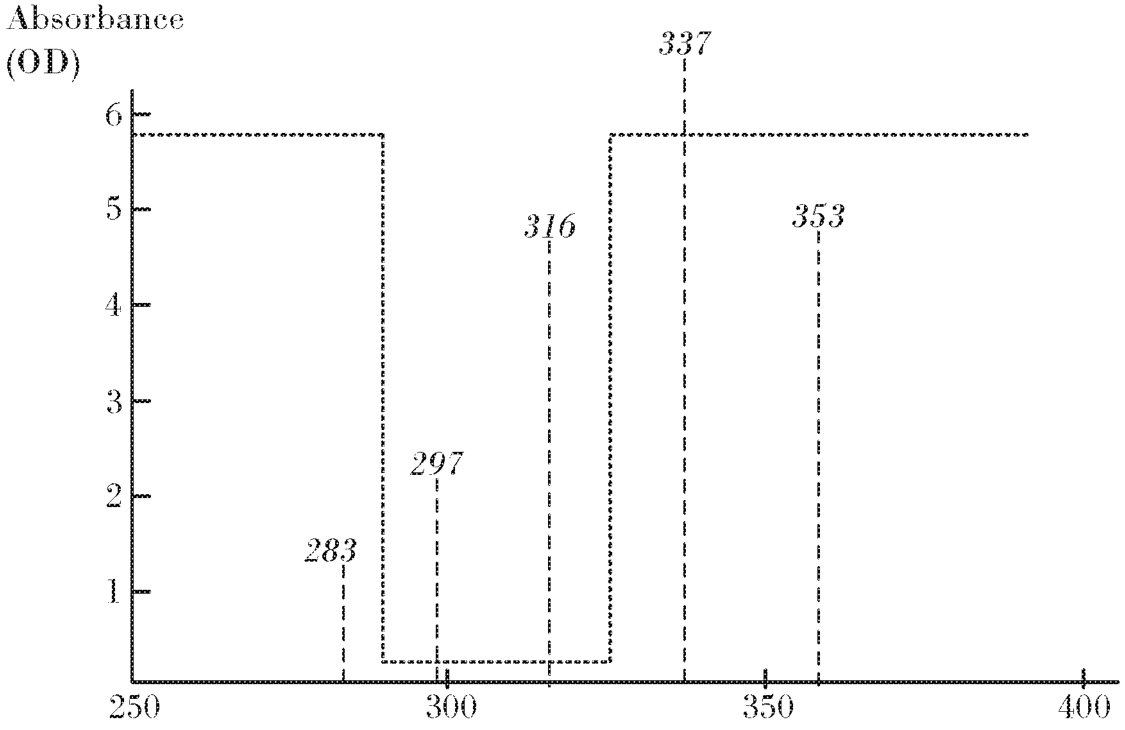


FIG. 11D

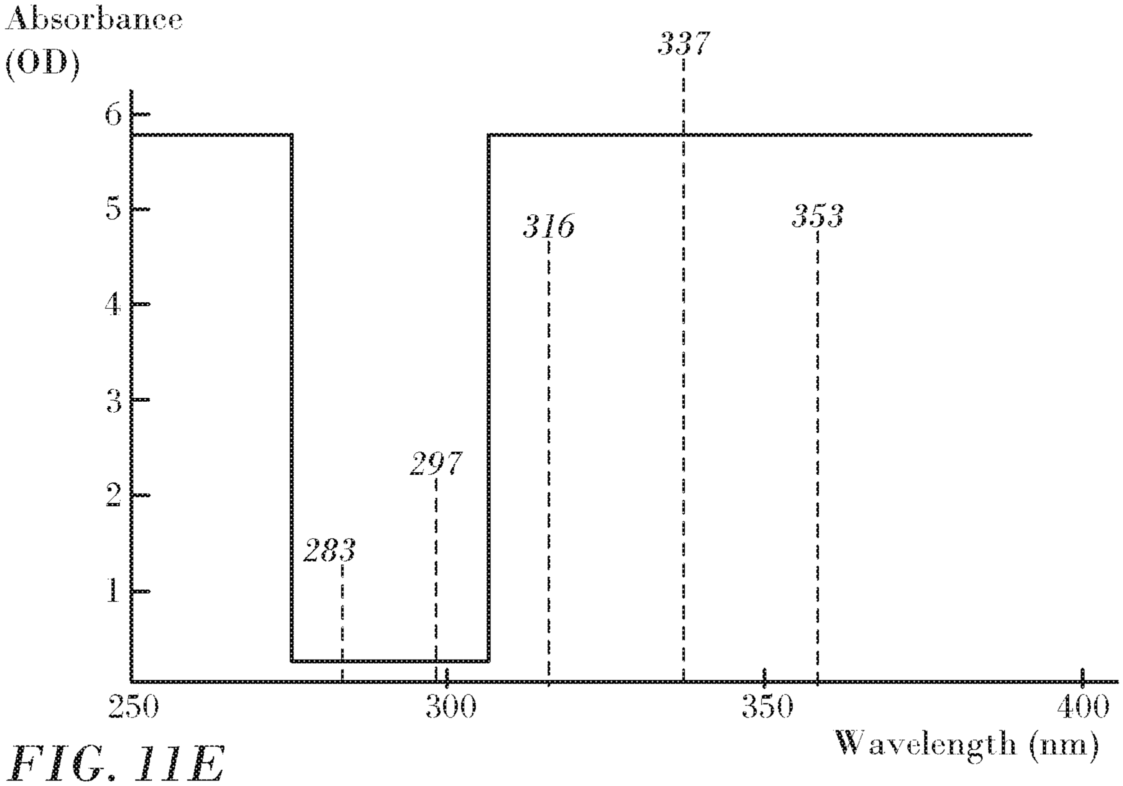


FIG. 11E

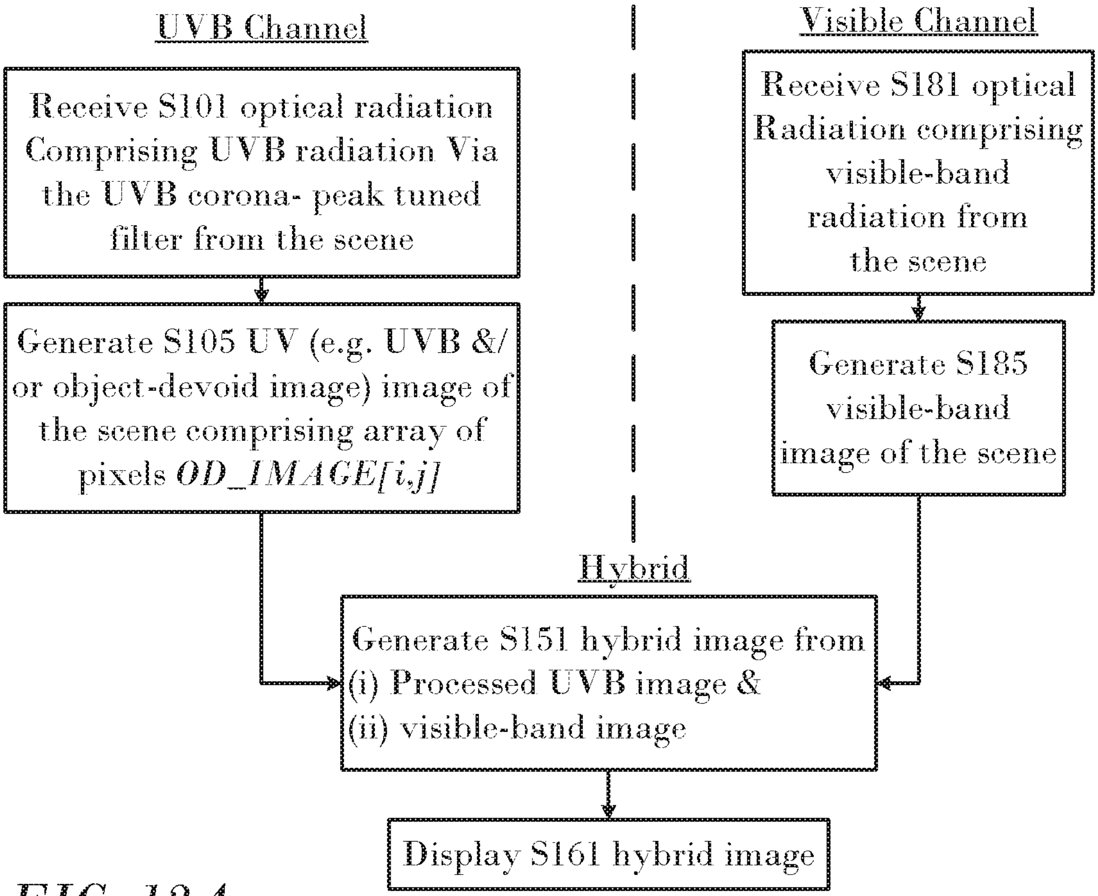


FIG. 12A

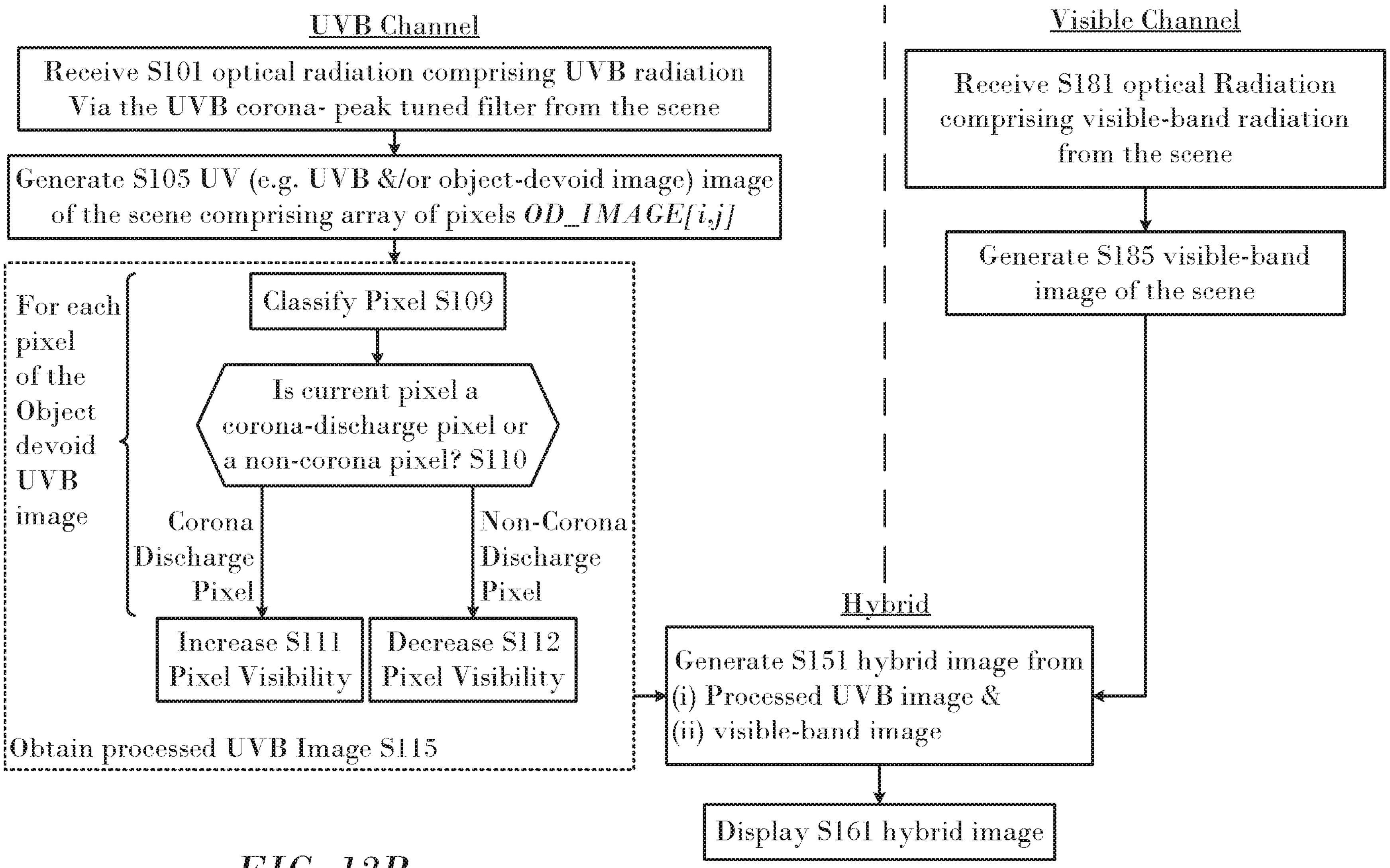

UVB Channel
Receive S101 optical radiation comprising UVB radiation Via the UVB corona- peak tuned filter from the scene
Generate S105 UV (e.g. UVB &/or object-devoid image) image of the scene comprising array of pixels *OD_IMAGE[i,j]*
For each pixel of the Object devoid UVB image
Classify Pixel S109
Is current pixel a corona-discharge pixel or a non-corona pixel? S110
Corona Discharge Pixel
Non-Corona Discharge Pixel
Increase S111 Pixel Visibility
Decrease S112 Pixel Visibility
Obtain processed UVB Image S115
Visible Channel
Receive S181 optical Radiation comprising visible-band radiation from the scene
Generate S185 visible-band image of the scene
Hybrid
Generate S151 hybrid image from (i) Processed UVB image & (ii) visible-band image
Display S161 hybrid image

FIG. 12B

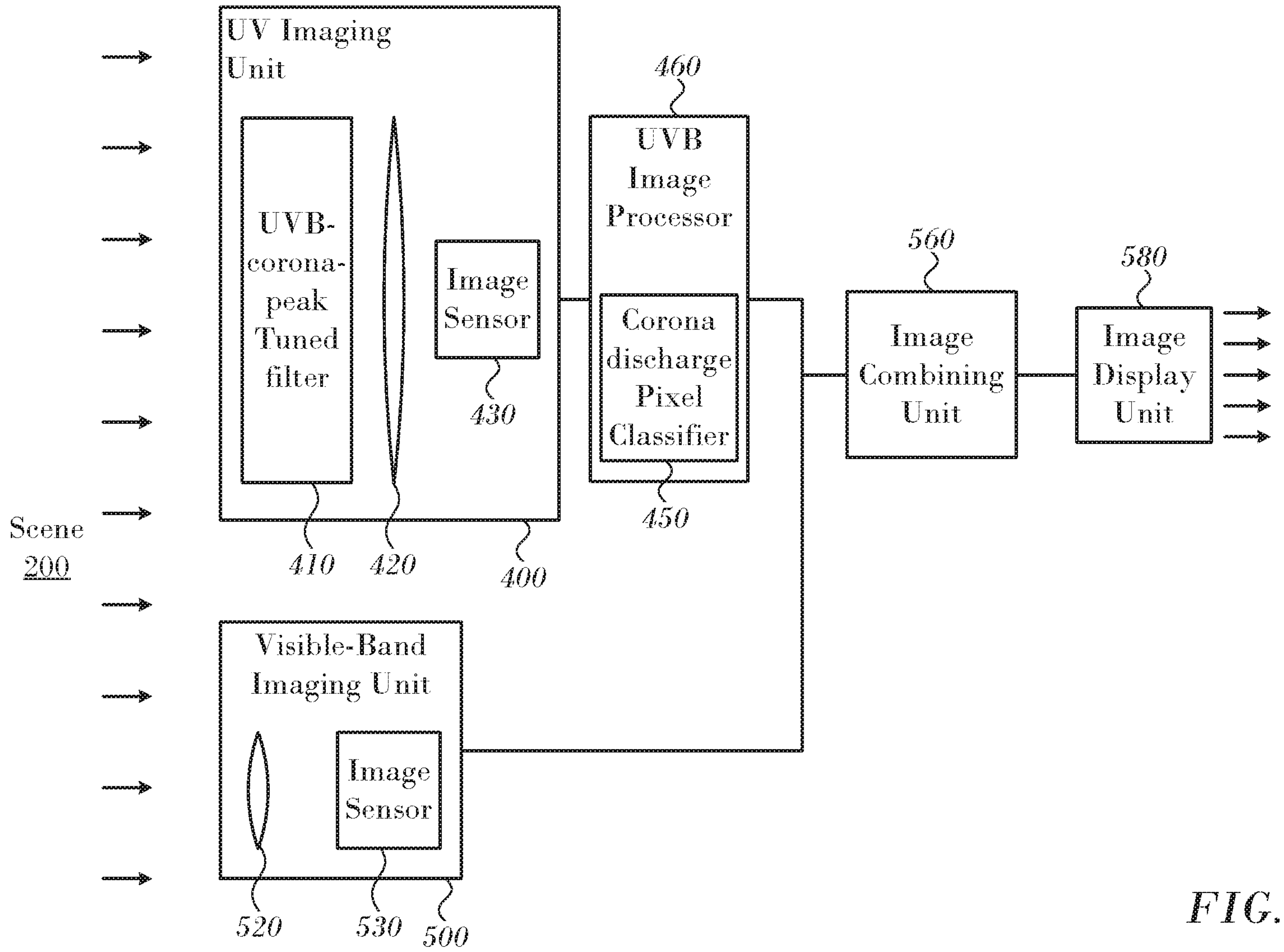

Scene
200
UV Imaging Unit
UVB-corona-peak Tuned filter
Image Sensor
410
420
430
400
UVB Image Processor
Corona discharge Pixel Classifier
460
450
Visible-Band Imaging Unit
Image Sensor
520
530
500
Image Combining Unit
560
Image Display Unit
580

FIG. 13

VIEWING DEVICE

FIELD

The present invention relates to methods and apparatus for generating a hybrid visible band-UV band image of a scene, for example, for viewing corona terrestrial discharge(s) in the context scene object(s).

BACKGROUND

FIG. 1 illustrates UVB corona absorption peaks, including peaks at 283 nm, 297nm, 316nm, 337nm, and 353nm.

SUMMARY OF EMBODIMENTS

Embodiments Relating to a Hybrid Viewing Device Where at Least a Portion of the Visible-Band Imaging Apparatus is in a Field-of View of the UV Imaging Apparatus

Some embodiments relate to a hybrid UV-visible-band viewing apparatus and method comprising visible-band and UV imaging apparatus. In some embodiments, (i) at least a portion of the visible-band imaging apparatus (e.g. an array of photodetectors thereof) is disposed in a field of view of a UV imaging apparatus; and/or (ii) both the visible-band and UV-band imaging apparatus share a common optical axis.

In order to generate a hybrid image, electrical output from each of the visible-band and the UV imaging-apparatus (or a derivative thereof) is received by an imaging-combining unit, for example, comprising electronic circuitry.

Although not a requirement, it is preferred for both the visible-band and UV imaging apparatus share a common optical axis in order to properly generate the hybrid image without being dependent on unwieldy and/or unreliable image-processing algorithms to properly superimpose the visible-band and UV scene-images.

One 'price' of placing the visible-band camera in the field of view of the UV imaging apparatus (instead of, for example, a beam-splitter) is that the visible-band camera can block light from the scene that would otherwise be useful for generating the

UV-image of the scene. This may be a particular challenge in situations whereby a subspectrum filter are employed, and only light of certain UV wavelength is incident upon photodetectors of the UV imaging apparatus. However, the present inventors are now disclosing that if a small-enough visible-band imaging apparatus is employed, it is possible to minimize the light-blocking so that the UV imaging apparatus still receives enough light to generate a proper and/or commercially usable UV-image of the scene.

By placing the visible-band imaging apparatus in front of the UV imaging apparatus (instead of relying on a beam-splitter or a mirror to direct visible-light to a location that is 'next to' the UV imaging apparatus), it is possible to provide a hybrid viewing device that is much more compact and/or narrow than prior art devices.

In one non-limiting application, it is possible to employ the hybrid viewing device to view corona-discharges - e.g. to identify defective electrical equipment emitting the corona-discharge. A more compact and/or more narrow hybrid viewing device that is more ergonomic may encourage greater use (e.g. by employees of an electrical company), and more diligent identification (and hence, repair) of defective environment-damaging defective electrical equipment.

In some embodiments, UV light is blocked from reaching the UV imaging apparatus by both (i) the visible-band imaging apparatus (or a portion thereof); (ii) a wired connection between the visible-band imaging apparatus and other parts of the hybrid viewing device -- e.g. a data-connection between the UV imaging apparatus and circuitry of the imaging-combining unit. In order to minimize the blocking of UV light from the scene, it is possible to employ a transfer visible-band-image data from the visible-band imaging unit to the imaging combining unit via a wireless connection. This may allow the visible-band imaging unit to be configured as a 'wire-connection island-located entirely in the field of view of the UV imaging apparatus, without any UV-light-diminishing wired connections.

A system for visualizing a scene comprises: a. UVB imaging apparatus comprising a first array of photodetectors and a wavelength-dependent light filter, the UVB imaging apparatus configured to generate an image of the scene from UVB-light of the scene incident upon the first array of photodetectors after passing through the light filter, an optical-density $OD(\lambda)$ profile of the light filter satisfying the following conditions: i. an average value of $\min[OD(\lambda),10]$ over the range [280 nm, 700 nm] is x, a value of x being at least 2;ii. for at least one wavelength in at least one range selected from the UVB corona-peak range set defined as {[281 nm,285 nm],[292 nm,302 nm],[308 nm,320 nm],[334 nm,340 nm],[351 nm,362 nm]}, an optical density *OD* of the filter is at most *y*, a value of *y* being at most 1; b. a visible-band imaging apparatus comprising a second array of photodetectors, the visible-band imaging apparatus configured to generate a visible-band image from visible light of the scene incident upon the second array of photodetectors; and c. video-display apparatus configured to display a visible band-UVB hybrid image that is a superposition of: (i) the visible-band image or a derivative thereof; and (ii) the UVB image or a derivative thereof, wherein: i. the UVB imaging apparatus and the visible-band imaging apparatus share a common optical axis; ii. the second array of photodetectors is disposed in a field of view of the UVB imaging apparatus; and iii. at most 50% of an intensity of UVB light from the scene is blocked by portion(s) of the visible-band imaging apparatus in a field of view of the UVB imaging apparatus.

In some embodiments, a value of x is at least 3 or at least 4 or at least 5 or at least 6.

In some embodiments, a value of y is at most 0.75 or at most 0.5 or at most 0.25 or at most 0.1

In some embodiments, at most 30% (or at most 20% or at most 10%) of an intensity of UVB light from the scene is blocked by portion(s) of the visible-band imaging apparatus in a field of view of the UVB imaging apparatus.

In some embodiments, the second array of photodetectors is part of a wire-connection island located entirely in the field of view of the UVB imaging apparatus and the video-display apparatus receives the visible-band image from the second array of photodetectors via a wireless connection.

In some embodiments, the system further comprises: b. UVB image-processing apparatus operative generate a UVB processed image from the UVB image so as to increase a visibility of corona-discharge pixels and/or to decrease a visibility of non-corona-discharge pixels, the video-display apparatus configured so the visible band-UVB hybrid image comprises the UVB processed image or a derivative thereof, the UVB image-processing apparatus configured to generate the UVB processed image.

In some embodiments, the system is configured to obtain the estimated intensity of ambient non-corona-discharge UVB radiation, and to generate the UVB processed image from the UVB image in accordance with the estimated non-corona-discharge UVB radiation intensity.

In some embodiments, the system obtains the estimated intensity of ambient non-corona-discharge UVB radiation in accordance with at least one of: (i) an auxiliary photodetector; (ii) location data; (iii) time-of-day; and (iv) weather data.

In some embodiments, the UVB image-processing apparatus is configured to respond to a change in an estimated ambient level of non-corona-discharge UVB radiation by modifying a thresholding function so as to increase a contrast between corona-discharge pixels and non-corona-discharge pixels in response to an increase in the estimated ambient level.

In some embodiments, the UVB image-processing apparatus is configured to respond to a change in an estimated ambient level of non-corona-discharge UVB radiation by modifying a corona-discharge-classification-threshold-function of the pixels to increase the threshold-function in response to an increase in the estimated ambient level and to decrease the threshold-function in response to an estimated decrease in the ambient level.

In some embodiments, the system is configured obtain the estimated intensity of ambient non-corona-discharge UVB radiation in accordance with at least one of: (i) an auxiliary photodetector; (ii) location data; (iii) time-of-day; and (iv) weather data.

A system for visualizing a scene comprises a. UV imaging apparatus comprising a first array of photodetectors and a wavelength-dependent light filter, the UV imaging apparatus configured to generate an image of the scene from UV-light of the scene incident upon the first array of photodetectors; b. a visible-band imaging apparatus comprising a second array of photodetectors disposed in a field of view of the UV imaging apparatus, the visible-band imaging apparatus configured to generate a visible-band image from visible light of the scene incident upon the second array of photodetectors,; and c. video-display apparatus configured to display a visible band-UV hybrid image that is a superposition of: (i) the visible-band image or a derivative thereof; and (ii) the UV processed image or a derivative thereof.

In some embodiments, the UV imaging apparatus and the visible-band imaging apparatus share a common optical axis.

In some embodiments, the UV imaging apparatus is a UVB imaging apparatus configured to generate an image of the scene from UVB-light of the scene incident upon the first array of photodetectors.

In some embodiments, the system further comprises a UVB-wavelength-dependent light filter disposed on an optical path between the scene and the first array of photodetectors.

In some embodiments, the UVB-wavelength-dependent light filter has a non-uniform filtering profile in the UVB spectrum such that an optical density of the UVB-wavelength-dependent light filter varies as a function of wavelength within the UVB spectrum.

In some embodiments, the system further comprises a UVB-wavelength-dependent light filter disposed on an optical path between the scene and the first array of photodetectors, an optical-density $OD(\lambda)$ profile of the UVB-wavelength-dependent-light filter satisfying the following conditions: i. an average value of $\min[OD(\lambda),10]$ over the range [280 nm, 700 nm] is at least x, a value of x being at least 2 or at least 3 or at least 4 or at least 5 or at least 6; ii. for at least one wavelength in at least one range selected from the UVB corona-peak range set defined as {[281 nm,285 nm],[292 nm,302 nm],[308 nm,320 nm],[334 nm,340 nm],[351 nm,362 nm]}, optical density OD of the filter is at most y, a value of y being at most 1 or at most 0.75 or at most 0.5 or at most 0.25 or at most 0.1.

In some embodiments, the UV imaging apparatus is a UVC imaging apparatus configured to generate an image of the scene from UVC-light of the scene incident upon the first array of photodetectors.

In some embodiments, the system further comprises a solar-blind filter disposed on an optical path between the scene and the first array of photodetectors, an optical-density $OD(\lambda)$ profile of the solar-blind light filter satisfying the following conditions:i. for at least one wavelength in the range [220 nm,280 nm], an optical density OD of the filter is at most 1 or at most 0.75 or at most 0.5 or at most 0.25 or at most 0.1; ii. an average value of $\min[OD(\lambda),10]$ over the range [280 nm, 70 0 nm] is at least x, a value of x being at least 2 (or at least 3 or at least 4 or at least 5 or at least 6).

In some embodiments, the system further comprises a solar-blind filter disposed on an optical path between the scene and the first array of photodetectors, an optical-density $OD(\lambda)$ profile of the solar-blind light filter satisfying the following conditions: i. for a majority of wavelengths of the range [220 nm,280 nm], an optical density OD of the filter is at most 1 or at most 0.75 or at most 0.5 or at most 0.25 or at most 0.1; ii. an average value of $\min[OD(\lambda),10]$ over the range [280 nm, 700 nm] is at least x, a value of x being at least 2 (or at least 3 or at least 4 or at least 5 or at least 6).

Embodiments Relating to a UVB/Visible Hybrid Viewing Device -- for example, configured to Generate an Object-Devoid UVB Image

The present inventors are now disclosing a UVB/visible hybrid viewing device for viewing terrestrial corona discharges associated with one or more objects in scene. Within the scene are one or more corona-emitting objects (e.g. electrical equipment), one or more terrestrial corona discharges, and optionally one or more non-corona objects (e.g. tables, chairs, etc). The presently-disclosed optical and image-processing features make the device and method particularly useful for viewing corona-discharges in 'daytime/indoor' situations - i.e. in the presence of a relatively-low but not insignificant level of solar radiation.

A 'terrestrial corona' discharge is in contrast to solar corona discharges.

The presently-disclosed device and method are based upon the combination of several features: (i) the use of a specialized, highly-absorptive optical filter configured to generate an 'object-devoid' UVB image; (ii) analyses of this object-devoid UVB image to classify pixels thereof as either 'corona discharge pixels' or 'non-corona discharge pixels' and (iii) display to a user of a hybrid overlay/superposition display of both UVB and visible-band images in a manner which increases a visibility of the corona-discharge pixels and/or decreases a visibility of the non-corona-discharge pixels.

The present disclosure relates to imaging of a scene comprising objects and one or more terrestrial-corona discharges to produce an 'object-devoid' UVB image of the scene. For the present disclosure, an 'object-devoid' UVB image of this scene only includes a UVB image of the corona discharge, and optionally noise, with no image of any of the objects in the scene. Thus, by definition, none of the objects that are visible to the naked eye in the actual scene appear within the object-devoid UVB image. As discussed below, the object-devoid UVB image may be generated by employing a corona-tuned optical filter (i) having an extremely high optical density (e.g. OD of at least 4, or at least 6, or at least 8, or at least 10) for at least 95% or at least 97% of the [280 nm,700 nm] spectrum and (ii) having a low optical density (i.e. less than 1) for at least one wavelength within 10 nm of one or more of the UVB corona peaks.

The object-devoid UVB image in-and-of-itself may lack utility for viewing corona discharges in their proper context of the neighboring objects of the scene. Nevertheless, when the object-devoid UVB image (or a derivative thereof) superposed over a visible image of the scene, it is possible, for the first time, to view the corona discharge in its 'neighboring context' despite the fact that none of these 'neighboring objects' are present within the UVB image.

Because the UVB image generated with the intention to superpose with the visible image, it is possible to generate the UVB image in a manner that is extremely corona-specific to view weaker coronas. The 'price' of generating a UVB image devoid of objects is that the UVB image may no longer by used to provide context data, due to the lack of objects therein. The present inventors are now disclosing a hybrid device where this 'price' is irrelevant because the visible-band image now serves this function.

Because the UVB image is, in fact, object-devoid, it is possible to assume that the non-corona-discharge thereof pixels do not provide meaningful information -- i.e. are not required to display background objects to provide proper context to the image of the corona-discharge. Because the non-corona pixels of the UVB image represent noise rather than necessary object-background objects (i.e. required for providing context to the corona discharge), it is possible to (A) classify pixels of the UVB image as (i) corona-discharge pixels or (ii) non-corona-discharge pixels. The displaying of the hybrid UVB-visible image on the display device may be performed in a manner that increases a visibility of the terrestrial-corona pixels and decreases a visibility of the non-corona pixels. For example, the non-corona pixels may be effectively 'erased' from the hybrid UVB-visible image.

When the highly-absorptive optical filter filters out the light, it effectively eliminates all objects from the UVB image to generate an object-devoid image. However, the device does not need to rely on the UVB image/channel to display the objects to give 'visual context' to the corona discharge-- instead, the visible-band channel provides this functionality. By relying on the visible-channel to properly display the 'corona-discharge context' it is possible to employ the highly-absorptive specialized optical filter that eliminates objects from the UVB image in order to properly view even 'weak' corona discharges, to provide a greater sensitivity to coronas.

It is now disclosed a system for visualizing a scene comprising one or more terrestrial corona discharge(s) and one or more objects, the scene illuminated by non-terrestrial-corona-discharge radiation, the system comprising: a. UVB image-generating apparatus configured to generate, from UVB light of the non-terrestrial-corona-discharge-radiation-illuminated scene, an object-devoid UVB image of at least an object-containing portion of the scene, the object-devoid UVB image comprising an image of the corona discharge(s) of the scene and lacking images of all of the scene objects, the UVB image-generating apparatus comprising a wavelength-dependent light filter configured to filter out sufficient non-corona UVB radiation so that generated image is object-devoid, the wavelength-dependent light filter having an optical-density $OD(\lambda)$ profile that satisfies the following conditions: i. an average value of $\min[OD(\lambda),10]$ over the range [280 nm, 700 nm] is at least x, a value of x being at least 4 (or at least 5 or at least 6 or at least 7 or at least 8 or at least 9 or at least 10 or at least 12); ii. for at least one wavelength in at least one range selected from the UVB corona-peak range set defined as {[281 nm,285 nm],[292 nm,302 nm],[308 nm,320 nm],[334 nm,340 nm],[351 nm,362 nm]}, optical density OD of the filter is at most 1; b. UVB image-processing apparatus operative to classify each pixel of the object-devoid UVB image as either a corona-discharge pixel or as a non-corona-discharge pixel and to process the object-devoid image according to the results of the pixel-classifying to generate a UVB processed image; c. a visible-band image-generating apparatus configured to generate a visible-band image from visible light of the scene; d. video-display apparatus configured to display a visible band-UVB hybrid image that is a superposition of: (i) the visible-band image or a derivative thereof; and (ii) the UVB processed image or a derivative thereof, the UVB image-processing apparatus configured to perform the image processing so as to increase a visibility of the corona-discharge pixels and/or to decrease a visibility of the non-corona-discharge pixels.

In some embodiments, the UVB image-processing apparatus is configured to respond to a change in an estimated ambient level of non-corona-discharge UVB radiation by modifying a corona-discharge-classification-threshold-function of the pixels to increase the threshold-function in response to an increase in the estimated ambient level and to decrease the threshold-function in response to an estimated decrease in the ambient level.

In some embodiments, the system is configured to obtain the estimated intensity of ambient non-corona-discharge UVB radiation in accordance with at least one of: (i) an auxiliary photodetector; (ii) location data; (iii) time-of-day; and (iv) weather data.

In some embodiments, the system is configured to estimate the ambient level of non-corona-discharge UVB radiation by analyses of the object-devoid UVB image.

In some embodiments, the pixel classification is performed in accordance with detected temporal variations in the object-devoid UVB image.

Alternatively or additionally, the pixel classification of a target pixel is performed in accordance with analysis of neighboring pixels.

Alternatively or additionally, the pixel classification of a target pixel is performed in accordance with a brightness-thresholding algorithm.

In some embodiments, for at least 5 nm of wavelength over the UVB corona-peak range set, an optical density *OD* of the filter is at most 1.

In some embodiments an average value of $\min[OD(\lambda),10]$ over the range [400 nm, 700 nm] is at least y, a value of y being at least 4 or at least 6 or at least 8 or at least 10.

In some embodiments an average value of $\min[OD(\lambda),10]$ over the range [280 nm, 400 nm] is at least y, a value of y being at least 4 or at least 6 or at least 8 or at least 10.

In some embodiments, for at least one wavelength in at least one range selected from the UVB corona-peak range set defined as {[281 nm,285 nm],[292 nm,302 nm],[308 nm,320 nm],[334 nm,340 nm],[351 nm,362 nm]}, optical density *OD* of the filter is at most 0.75 or at most 0.5 or at most 0.25 or at most 0.1.

In some embodiments, (i) the UVB imaging apparatus comprises a first array of photodetectors, the visible-band imaging apparatus comprises a second array of photodetectors, and the second array of photodetectors is disposed in a field of view of the UVB imaging apparatus and/or (ii) the UVB imaging apparatus and the visible-band imaging apparatus share a common optical axis.

In some embodiments, (i) the UVB imaging apparatus comprises a first array of photodetectors, the visible-band imaging apparatus comprises a second array of photodetectors, and the second array of photodetectors is disposed in a field of view of the UVB imaging apparatus.

In some embodiments, the UVB imaging apparatus and the visible-band imaging apparatus share a common optical axis.

It is now disclosed a system for visualizing a scene, the system comprising: a. UVB imaging apparatus comprising a first array of photodetectors and a wavelength-dependent light filter, the UVB imaging apparatus configured to generate an image of the scene from UVB-light of the scene incident upon the first array of photodetectors after passing through the light filter, an optical-density $OD(\lambda)$ profile of the light filter satisfying the following conditions: i. an average value of $\min[OD(\lambda),10]$ over the range [280 nm, 700 nm] is at least 2 or at least 3 or at least 4 or at least 5 or at least 6 or at least 7 or at least 8 or at least 9 or at least 10; ii. for at least one wavelength in at least one range selected from the UVB corona-peak range set defined as {[281 nm,285 nm],[292 nm,302 nm],[308 nm,320 nm],[334 nm,340 nm],[351 nm,362 nm]}, an optical density *OD* of the filter is at most *y*, a value of *y* being at most 1 or at most 0.75 or at most 0.5 or at most 0.25 or at most 0.1; b. a visible-band imaging apparatus comprising a second array of photodetectors, the visible-band imaging apparatus configured to generate a visible-band image from visible light of the scene incident upon the second array of photodetectors; and c. video-display apparatus configured to display a visible band-UVB hybrid image that is a superposition of: (i) the visible-band image or a derivative thereof; and (ii) the UVB image or a derivative thereof.

In some embodiments, the UVB imaging apparatus and the visible-band imaging apparatus share a common optical axis.

In some embodiments, a second array of photodetectors is disposed in a field of view of the UVB imaging apparatus.

In some embodiments, the UVB imaging apparatus and the visible-band imaging apparatus are mechanically coupled to each other (e.g. directly or indirectly attached to each other).

In some embodiments, the second array of photodetectors is part of a wire-connection island located entirely in the field of view of the UVB imaging apparatus and/or the video-display apparatus receives the visible-band image from the second array of photodetectors via a wireless connection.

In some embodiments, at most 50% (or at most 40% or at most 30% or at most 20% at most 10%) of an intensity of UVB light from the scene is blocked by portion(s) of the visible-band imaging apparatus in a field of view of the UVB imaging apparatus.

In some embodiments, a distance between the first and second array of photodetectors is mechanically constrained to a maximum of at most 1 meter or at most 50 cm or at most 30 cm or at most 20 cm or at most 10 cm.

In some embodiments, the system further comprises: b. UVB image-processing apparatus operative generate a UVB processed image from the UVB image so as to increase a visibility of corona-discharge pixels and/or to decrease a visibility of non-corona-discharge pixels, the video-display apparatus configured so the visible band-UVB hybrid image comprises the UVB processed image or a derivative thereof, the UVB image-processing apparatus configured to generate the UVB processed image.

In some embodiments, the system is configured to obtain the estimated intensity of ambient non-corona-discharge UVB radiation, and to generate the UVB processed image from the UVB image in accordance with the estimated non-corona-discharge UVB radiation intensity.

In some embodiments, the device system obtains the estimated intensity of ambient non-corona-discharge UVB radiation in accordance with at least one of: (i) an auxiliary photodetector; (ii) location data; (iii) time-of-day; and (iv) weather data.

In some embodiments, the UVB image-processing apparatus is configured to respond to a change in an estimated ambient level of non-corona-discharge UVB radiation by modifying a thresholding function so as to increase a contrast between corona-discharge pixels and non-corona-discharge pixels in response to an increase in the estimated ambient level.

In some embodiments, the UVB image-processing apparatus is configured to respond to a change in an estimated ambient level of non-corona-discharge UVB radiation by modifying a corona-discharge-classification-threshold-function of the pixels to increase the threshold-function in response to an increase in the estimated ambient level and to decrease the threshold-function in response to an estimated decrease in the ambient level.

In some embodiments, configured obtain the estimated intensity of ambient non-corona-discharge UVB radiation in accordance with at least one of: (i) an auxiliary photodetector; (ii) location data; (iii) time-of-day; and (iv) weather data.\

It is now disclosed a system for visualizing a scene, the system comprising: a. UV imaging apparatus comprising a first array of photodetectors and a wavelength-dependent light filter, the UV imaging apparatus configured to generate an image of the scene from UV-light of the scene incident upon the first array of photodetectors; b. a visible-band imaging apparatus comprising a second array of photodetectors disposed in a field of view of the UV imaging apparatus, the visible-band imaging apparatus configured to generate a visible-band image from visible light of the scene incident upon the second array of photodetectors; and c. video-display apparatus configured to display a visible band-UV hybrid image that is a superposition of: (i) the visible-band image or a derivative thereof; and (ii) the UV processed image or a derivative thereof.

In some embodiments, the UV imaging apparatus and the visible-band imaging apparatus share a common optical axis.

In some embodiments, the UV imaging apparatus is a UVB imaging apparatus configured to generate an image of the scene from UVB-light of the scene incident upon the first array of photodetectors.

In some embodiments, further comprising a UVB-wavelength-dependent light filter disposed on an optical path between the scene and the first array of photodetectors - for example, a UVB-wavelength-dependent light filter having a non-uniform filtering profile in the UVB spectrum such that such that an optical density of the UVB-wavelength-dependent light filter varies as a function of wavelength within the UVB spectrum.

In some embodiments, further comprising a UVB-wavelength-dependent light filter disposed on an optical path between the scene and the first array of photodetectors, an optical-density $OD(\lambda)$ profile of the UVB-wavelength-dependent-light filter satisfying the following conditions: i. an average value of $\min[OD(\lambda),10]$ over the range [280 nm, 700 nm] is at least x, a value of x being at least 2 or at least 3 or at least 4 or at least 5 or at least 6 or at least 7 or at least 8; ii. for at least one wavelength in at least one range selected from the UVB corona-peak range set defined as {[281 nm,285 nm],[292 nm,302 nm],[308 nm,320 nm],[334 nm,340 nm],[351 nm,362 nm]}, optical density OD of the filter is at most y, a value of y being at most 1 or at most 0.75 or at most 0.5 or at most 0.25 or at most 0.1.

In some embodiments, the UV imaging apparatus is a UVC imaging apparatus configured to generate an image of the scene from UVC-light of the scene incident upon the first array of photodetectors.

In some embodiments, further comprising a solar-blind filter disposed on an optical path between the scene and the first array of photodetectors, an optical-density $OD(\lambda)$ profile of the solar-blind light filter satisfying the following conditions: i. for at least one wavelength in the range [220 nm,280 nm], an optical density OD of the filter is at most 1 or at most 0.75 or at most 0.5 or at most 0.25 or at most 0.1; and ii. an average value of $\min[OD(\lambda),10]$ over the range [280 nm, 700 nm] is at least x, a value of x being at least 2 or at least 3 or at least 4 or at least 5 or at least 6 or at least 7 or at least 8.

In some embodiments, further comprising a solar-blind filter disposed on an optical path between the scene and the first array of photodetectors, an optical-density $OD(\lambda)$ profile of the solar-blind light filter satisfying the following conditions: i. for a majority of wavelengths of the range [220 nm,280 nm], an optical density OD of the filter is at most 1 or at most 0.75 or at most 0.5 or at most 0.25 or at most 0.1; ii. an average value of $\min[OD(\lambda),10]$ over the range [280 nm, 700 nm] is at least x, a value of x being at least 2 or at least 3 or at least 4 or at least 5 or at least 6 or at least 7 or at least 8.

In some embodiments, the UVB imaging apparatus and the visible-band imaging apparatus are mechanically coupled to each other (e.g. directly or indirectly attached to each other).

It is now disclosed a system for visualizing a scene, the system comprising: a. UVB imaging apparatus comprising a first array of photodetectors and a UVB-wavelength-dependent light filter, the UVB imaging apparatus configured to generate an image of the scene from UVB-light of the scene incident upon the first array of photodetectors after passing through the light filter, the UVB-wavelength-dependent light filter having a non-uniform filtering profile in the UVB spectrum; b. a visible-band imaging apparatus comprising a second array of photodetectors, the visible-band imaging apparatus configured to generate a visible-band image from visible light of the scene incident upon the second array of photodetectors; and c. video-display apparatus configured to display a visible band-UVB hybrid image that is a superposition of: (i) the visible-band image or a derivative thereof; and (ii) the UVB processed image or a derivative thereof.

In some embodiments, UVB image-processing apparatus is operative generate a UVB processed image from the UVB image so as to increase a visibility of corona-discharge pixels and/or to decrease a visibility of non-corona-discharge pixels, the video-display apparatus configured so the visible band-UVB hybrid image comprises the UVB processed image or a derivative thereof, the UVB image-processing apparatus configured to generate the UVB processed image.

In some embodiments, the system is configured to obtain the estimated intensity of ambient non-corona-discharge UVB radiation, and to generate the UVB processed image from the UVB image in accordance with the estimated non-corona-discharge UVB radiation intensity.

In some embodiments, the device system obtains the estimated intensity of ambient non-corona-discharge UVB radiation in accordance with at least one of: (i) an auxiliary photodetector; (ii) location data; (iii) time-of-day; and (iv) weather data.

In some embodiments, the UVB image-processing apparatus is configured to respond to a change in an estimated ambient level of non-corona-discharge UVB radiation by modifying a thresholding function so as to increase a contrast between corona-discharge pixels and non-corona-discharge pixels in response to an increase in the estimated ambient level.

In some embodiments, the UVB image-processing apparatus is configured to respond to a change in an estimated ambient level of non-corona-discharge UVB radiation by modifying a corona-discharge-classification-threshold-function of the pixels to increase the threshold-function in response to an increase in the estimated ambient level and to decrease the threshold-function in response to an estimated decrease in the ambient level.

In some embodiments, the system is configured to obtain the estimated intensity of ambient non-corona-discharge UVB radiation in accordance with at least one of: (i) an auxiliary photodetector; (ii) location data; (iii) time-of-day; and (iv) weather data.

In some embodiments, the UVB imaging apparatus and the visible-band imaging apparatus are mechanically coupled to each other (e.g. directly or indirectly attached to each other).

A UVB-visible hybrid system and method for visualizing a scene comprising one or more terrestrial corona discharge(s) and one or more objects is disclosed. On the UVB channel, an object-devoid UVB image of at least a portion of the scene is generated using UVB light which passes though a corona-peak tuned optical filter configured to filter out sufficient non-terrestrial-corona light so that the generated UVB image is object-devoid. The object-devoid UVB image is analyzed to classify pixels thereof as corona-discharge pixels or non-corona-discharge pixels. When a derivative of the object-devoid UVB image superposed with a visible-band image of the scene is displayed on a display device, the pixels classified as corona-discharge are displayed at increased visibility, while the pixels classified as corona-discharge are displayed at decreased visibility. In some embodiments, the optical filter has an average optical density over the [290 nm, 700 nm] spectrum of at least 4.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates UVB corona peaks (prior art).

FIG. 2 illustrates the imaging of a scene including terrestrial corona by a UVB-visible band hybrid imaging device under daytime-indoors conditions.

FIG. 3 is a schematic illustration of a scene including visible objects and a terrestrial corona discharge.

FIG. 4A-4E and 13 are diagrams of exemplary UV-visible band hybrid imaging devices of portions thereof.

FIG. 5 is a schematic illustration of an object-devoid UVB image of the scene of FIG. 3.

FIG. 6 is a schematic illustration of a visible-band image of the scene of FIG. 3.

FIG. 7 is a schematic illustration of UVB-visible hybrid image of the scene of FIG. 3.

FIGS. 8-10 relate to image processing algorithm to a classification of pixels of the object-devoid UVB image.

FIGS. 11A-11E illustrate example optical-density profiles in the UVB range for a UVB-corona-peak tuned filter.

FIGS. 12A-12B are block diagrams of an exemplary UVB-visible band hybrid imaging method configured to handle terrestrial-corona discharges.

FIG. 13 is a block diagram of an exemplary UVB-visible band hybrid imaging device.

DESCRIPTION OF EMBODIMENTS

The invention is herein described, by way of example only, with reference to the accompanying drawings. With specific reference now to the drawings in detail, it is stressed that the particulars shown are by way of example and for purposes of illustrative discussion of the preferred embodiments of the exemplary system only and are presented in the cause of providing what is believed to be a useful and readily understood description of the principles and conceptual aspects of the invention. In this regard, no attempt is made to show structural details of the invention in more detail than is necessary for a fundamental understanding of the invention, the description taken with the drawings making apparent to those skilled in the art how several forms of the invention may be embodied in practice and how to make and use the embodiments.

For brevity, some explicit combinations of various features are not explicitly illustrated in the figures and/or described. It is now disclosed that any combination of the method or device features disclosed herein can be combined in any manner – including any combination of features – any combination of features can be included in any embodiment and/or omitted from any embodiments.

FIG. 2 is a side-view illustration (i) a scene **200** including a corona-emitting object **220A** that is visible to the naked eye and a corona-discharge **230A** that is invisible to the naked eye and (ii) a UVB-visible band hybrid device **100** for imaging the scene **200**. FIG. 3 is a view of the scene from the perspective of hybrid device **100.** The scene includes both non-corona objects **210A-210E** (e.g. tables, chairs, etc) as well as the corona-emitting object **220A**, all of which are visible to the naked eye. For simplicity, the non-corona objects **210A-210E** are not illustrated in FIG. 2.

FIG. 4A is a schematic block diagram of a hybrid device **100** for viewing a scene - e.g. scene **200.** The hybrid-device comprises: (i) visible-band imaging unit **500** and (ii) a UV imaging unit **400.**

UV imaging unit **400** comprises: (i) lens **420** which is transparent to at least some UV light and (ii) UV image sensor **430** comprising a first array **432** of photodetectors (e.g. which employ CMOS or CCD technology or any other technology known in the art). For example, lens **420** is configured to focus light from scene **200** upon the first array **432** of photodetectors. UV image sensor **430** generates an electronic image of scene **100 --** this may be a multi-frame image (e.g. a video stream). Optionally, UV imaging unit **400** includes filter **410** which may be positioned either before lens **420** (as shown in FIG. 3) or thereafter.

Visible-band imaging unit **500** comprises: (i) lens **520** which is transparent to at least some visible-band light and (ii) visible-band image sensor **530** comprising a second array **532** of photodetectors (e.g. which employ CMOS or CCD technology or any other technology known in the art). For example, lens **520** is configured to focus light from scene **200** upon the second array **532** of photodetectors. Visible image sensor **530** generates an electronic image of scene **100** -- this may be a multi-frame image (e.g. a video stream).

One salient feature of the system of FIG. 4A is that at least a portion of visible-band imaging unit **500** is disposed in a field of view of the UV imaging unit **400.** For example, at least a portion of visible-band imaging unit **500** may be mounted to a device housing and/or otherwise configured so that least a portion of visible-band imaging unit **500** is disposed in a field of view of the UV imaging unit **400.**

Thus, as shown in FIG. 4A, at least some light from scene **200** is blocked from reaching the first photodetector array **432** by a presence of at least a portion of visible-band imaging unit **500** - e.g. by a presence of second photodetector array **532.** Thus, in some embodiments, it is preferred to employ a relatively-small imaging unit **500** and/or relatively-small second photodetector array **532** to minimize the aforementioned light-blocking. In one example, visible-band imaging unit **500** may be a 'very small camera' such as that employed within many mobile telephones.

In different embodiments, at most 50% (or at most 40% or at most 30% or at most 20% at most 10%) of an intensity of UV light from the scene is blocked by portion(s) (e.g. blocked by second photodetector array **532)** of the visible-band imaging apparatus **500** in a field of view of the UV imaging apparatus **400.** This may be true either for the UV spectrum as a whole or for portions thereof. Thus, in one embodiment, at most 50% (or at most 40% or at most 30% or at most 20% at most 10%) of an intensity of UVB light from the scene is blocked by portion(s) (e.g. blocked by second photodetector array **532)** of the visible-band imaging apparatus **500** in a field of view of the UV imaging apparatus **400.** Alternatively or additionally, at most 50% (or at most 40% or at most 30% or at most 20% at most 10%) of an intensity of UVC light from the scene is blocked by portion(s) (e.g. blocked by second photodetector array **532)** of the visible-band imaging apparatus **500** in a field of view of the UV imaging apparatus **400.**

Respective electrical signals (e.g. analog and/or digital electrical signal) respectively representing visible and UV images of the scene **200** are respectively output from visible-imaging unit **500** and UV imaging unit **400** and received by image combining unit **560.** Image combining unit **560** forms a visible-band UV hybrid image from (i) the visible-band image (i.e. output by imaging unit **500**) or a derivative thereof and (ii) the UV image (i.e. output by UV imaging unit **400**) or a derivative thereof. The hybrid image may be formed electronically or optically or in any other manner.

One example of a 'derivative' of the UV image is a UV processed image. Thus, as illustrated in FIG. 4B, output of UV imaging unit is received by UV image processor **460.** UV image processor **460** generates the UV processed image, which is received as input for generating a UV-visible band hybrid image by image combining unit **560.**

Preferably, visible-band **500** imaging unit and UV imaging unit **400** share a common optical axis. It visible-band **500** imaging unit is small enough, this may, in some embodiments, careful mounting of visible-band imaging unit **500** to ensure the correct orientation angle so that visible-band **500** imaging unit and UV imaging unit **400** share the common optical axis.

In some embodiments, visible-band imaging unit **500** is located outside of the field-aperture of UV imaging unit **400.**

In some embodiments, a field of view of the UV imaging apparatus and/or the visible-band imaging apparatus is at least 5 degrees or at least 7.5 degrees or at least 10 degrees or at least 12.5 degrees or at least 15 degrees or at least 20 degrees.

It is noted that no attempt is made in any figures, including FIGS. 4A-4B to illustrate all components -- for example, an image-intensifier (NOT SHOWN) may also be used -- see, for example, PCT/IL1999/000381 which published as WO/2000/005536 - SOLAR BLIND UV VIEWING APPARATUS AND CAMERA.

FIG. 4C-4E illustrates a device comprising visible-band imaging apparatus **500** and UV imaging apparatus **400** -- in FIG. 6 both have an optical axis along the 'x' axis and a lens **420** of UV imaging apparatus **400** is illustrated.

As illustrated in FIG. 4F, an electrical connection between visible-band imaging apparatus **500** and other portions of the device is via a wire-connection **502,** which unfortunately, blocks UV light from reaching UV-imaging apparatus. In order to obviate this difficulty, it is possible to replace wire-connection **502** with a wireless connection within the single device.

UV Filter **410** -- UVB Embodiments

Optionally, UV imaging unit **400** includes filter **410**.

In some embodiments, an optical-density $OD(\lambda)$ profile of the light filter **410** any one of the following conditions, or both of the following conditions:

i. an average value of $\min[OD(\lambda),10]$ over the range [280 nm, 700 nm] is at least 2, or at least 3 or at least 4 or at least 5 or at least 6 or at least 7 or at least 8 or at least 9 or at least 10.

ii. for at least one wavelength in at least one range selected from the UVB corona-peak range set defined as {[281 nm,285 nm],[292 nm,302 nm],[308 nm,320 nm],[334 nm,340 nm],[351 nm,362 nm]}, an optical density *OD* of the filter is at most y, a value of y being at most 1, or at most 0.75, or at most 0.5, or at most 0.25, or at most 0.1.

In some embodiments, for at least one range selected from the UVB corona-peak range set defined as {[281 nm,285 nm],[292 nm,302 nm],[308 nm,320 nm],[334 nm,340 nm],[351 nm,362 nm]}, for a majority of wavelengths within the 'selected range,' an optical density *OD* of the filter **410** is at most 1, or at most 0.75, or at most 0.5, or at most 0.25, or at most 0.1.

In some embodiments, an average value of $\min[OD(\lambda),6]$ over the range [280 nm, 700 nm] is at least 2, or at least 3 or at least 4 or at least 5 or at least 6.

Some embodiments relate to the *A*-*B* statement "an average value of $\min[OD(\lambda),10]$ over the range [*A* nm, *B* nm] is at least 2, or at least 3 or at least 4 or at least 5 or at least 6 or at least 7 or at least 8 or at least 9 or at least 10." In some embodiments, this is true for A=290 nm, B=700 nm. Alternatively or additionally, this is true for A=280 nm, B=400 nm. Alternatively or additionally, this is true for A=280 nm, B=500 nm. Alternatively or additionally, this is true for A=280 nm, B=600 nm. Alternatively or additionally, this is true for A=400 nm, B=450 nm.

UV Filter **410** -- UVC Embodiments

Optionally, UV imaging unit **400** includes filter **410**.

In some embodiments, filter **410** is so-called 'solar-blind.'

According to a first example, a solar-blind filer satisfies both of the following properties:

i. for at least one wavelength in the range [220 nm,280 nm], an optical density *OD* of the filter **410** is at most 1 or at most 0.75, or at most 0.5, or at most 0.25, or at most 0.1.

ii. an average value of $\min[OD(\lambda),6]$ over the range [280 nm, 700 nm] is at least x, a value of x being at least 4 or at least 5, or at least 5.5 or at least 6.

In some embodiments, for a majority of the range [220 nm,280 nm], an optical density *OD* of the filter **410** is at most 1 or at most 0.75, or at most 0.5, or at most 0.25, or at most 0.1.

According to a second example, a solar-blind filer satisfies both of the following properties:

i. for at least one wavelength in the range [220 nm,280 nm], an optical density *OD* of the filter **410** is at most 1 or at most 0.75, or at most 0.5, or at most 0.25, or at most 0.1.

ii. an average value of $\min[OD(\lambda),10]$ over the range [280 nm, 700 nm] is at least x, a value of x being at least 4 or at least 5, or at least 5.5 or at least 6, or at least 7, or at least 8, or at least 9, or at least 10.

In some embodiments, for a majority of the range [220 nm,280 nm], an optical density *OD* of the filter **410** is at most 1 or at most 0.75, or at most 0.5, or at most 0.25, or at most 0.1.

For example, as discussed below, the optical filter **410** may have an average optical density over the [290 nm, 700 nm] spectrum of at least 4.

Although not a limitation, in some embodiments, a presence of filter **410** within image unit **400** means that the UV image formed by lens **420** and image sensor **430** is object-devoid -- i.e. is devoid of all images within scene **200.** This may be accomplished, for example, by use of a solar blind filter or by use of a UVB filter tuned to one or more corona-peaks in the UVB spectrum.

For 'object devoid' UV images, instead of UV-images of scene-objects, the UV image includes only an image of the corona **230** and optionally noise. In the hypothetical absence of filter **410**, the image generated by imaging unit **400** would, in fact, images of the objects **210, 220** of the scene. For the specific case of UVB, the skilled artisan is referred to the discussion below with reference to FIGS. 11A-11E about the physical properties of UVB-corona-peak tuned filter **410** that enable generation of the object-devoid filter. For example, as discussed below, the optical filter **410** may have an average optical density over the [290 nm, 700 nm] spectrum of at least 4.

Certain embodiments that are now explained with reference to FIGS. 5-12 refer to an 'object-devoid UV image.' Although this may indeed be generated (e.g. be imaging unit **400**), this is not a requirement. Also, in some embodiments, UV imaging unit **400** is a UVB imaging unit **400,** although this is not a limitation for all embodiments.

FIG. 5 is a schematic of an object-devoid UVB image of the scene **200** of FIG. 2 generated by UVB imaging unit **400**. Thus, none of objects **210A-210E, 220A** are present within the object-devoid UVB image of FIG. 5. However, corona **230A** discharge is present in this UVB image.

In contrast, FIG. 6 illustrates a schematic of the visible-band image of scene **200** of FIG. 2 as generated by visible-band imaging unit **500.**

Also illustrated in FIG. 3 are: (i) lens **420** which is transparent to UVB light; (ii) UVB sensitive image sensor **430** (for example, CMOS or CCD or including any other appropriate technology); (iii) lens **520** which is transparent to visible light; and (iv) visible-band image sensor **530** (for example, CMOS or CCD image intensifier or including any other appropriate technology).

Once the object-devoid UVB image (see FIG. 5) is combined with the visible-band image (see FIG. 6) by image combining unit **560**, it is possible to view both objects as well as corona on display unit **580**. This allows for viewing the corona-discharge in its proper context of neighboring objects **210, 220 -** for example, see FIG. 7.

In order to obtain the result of FIG. 7, the presently-disclosed UVB-visible band hybrid viewing device **100** employs a combination of the following features (i) wavelength-dependent features of UVB filter **410** (see the discussion below with reference to FIGS. 11A-11E); and (ii) corona-specific image processing **460** based on classification of pixels of the object-devoid UVB image as either corona-discharge pixels or as non-corona-discharge pixels **450.**

This image processing will now be discussed with reference to FIGS. 8-10. In particular, FIG. 8 illustrates an example of object-devoid images of scene **200** generated by imaging unit **400** for four points in time -- t1, t2, t3, and t4. Towards the center of each image is an image of corona. Clearly, there is no image of any object in any of the four images. However, in addition to the image of the corona there may be noise present within the object-devoid UVB image -- see the slightly darker grey dots. Although the specific shape of the corona-discharge does vary as a function of time, its location and general shape are relatively constant compared to the noise. In contrast, location of the noise dots clearly varies in time.

With further reference to FIG. 8, it is noted that because of the optical properties of filter **410,** it may be assumed that non-corona-discharge pixels are in fact noise and are not 'object pixels' of objects **210, 220** that must be preserved in order to provide 'image context' for hybrid-image displayed by unit **280** (e.g. see FIG. 7). There is no need to preserve these non-corona images - the context information is provided by the visible-band image generated by unit **500.**

As such, it is possible to (i) classify each pixel as either a corona-discharge pixel or as a non-corona-discharge pixel and (ii) a non-corona discharge pixel. For example, this may be performed by classifier **450.** Image processing unit **460** may modify the contents of the object-devoid UVB image so that once the hybrid image is displayed by unit **580,** (i) a visibility of the corona-discharge pixels is increased and/or to (ii) a visibility of the non-corona-discharge pixels is decreased.

A schematic of the results of such a corona-discharge-classification-based UVB-image-processing routine is illustrated in FIG. 9 where the 'noise pixels' are removed or modified to blend with their surrounding pixels to make them less visible. The Corona image in FIG. 9 relates to a some sort of average shape over [t1,t4] time interval.

Comparing FIG. 8 to FIG. 9, it is clear that the grey non-corona-discharge pixels are less visible (in this case, substantially erased) in FIG. 9 compared to FIG. 8 - in this case, the pixels classified as 'non-corona-discharge pixels' may have 'null data' so as to be invisible in the hybrid pixel. Alternatively or additionally, it is possible to brighten the corona-discharge pixels. In another example, a color of the corona-discharge pixels may be modified in the hybrid image to make them more visible. In another example, a boundary may be drawn around the corona-discharge pixels to make them more visible in the hybrid image. These measures may be performed according to the results of the pixel classifying.

FIG. 10 illustrates one example of a UVB-pixel classification routine in accordance with terrestrial corona-discharges. In this non-limiting example, the image from unit **400** is first subjected to a threshold algorithm **810** according to a threshold level that is selected according to experimental data about what is an image of a terrestrial corona discharge and what is not (i.e. and thus is noise). Pixels of a first category are brighter than those of the second category - pixels of the first category are made even brighter, while those of the second category are made darker. By judicious selection of a criteria to distinguish between the first and second categories (e.g. based upon experimental data from scenes of or images of terrestrial corona-discharges), the threshold algorithm **810** effectively classifies between corona-discharge pixels and non-corona discharge pixels.

Similarly, the shape or brightness of the pixel may vary in time, and the time-integration filter may select between those pixels matching the experimentally-determined pattern, and those which do not -- this is algorithm **820.**

Similarly, it may be possible to determine if a pixel is a corona-discharge pixel or not from its neighbors - for example, using density filter **830**.

In some embodiments, the criteria for determining if a given pixel is a terrestrial-corona pixel or a non-corona-discharge pixel may be adaptive according to an ambient level of non-corona-discharge UVB radiation in the scene **200.** For example, on a brighter day, a given pixel is more likely to be noise than corona-discharge, and more rigorous criteria for designating a pixel as discharge may be used. Similarly, in mid-day this may also be the case, compared to early morning or late afternoon. In some embodiment, the pixel classification (and hence the image processing) may change in response to a detected change in an estimate level of ambient non-corona-discharge UVB radiation. For example, at 8 AM a first threshold may be used, and this may automatically be adjusted towards mid-day.

The level of ambient non-corona-discharge UVB radiation may also be determined by analyzing the object-devoid UVB image - for example, according to a density algorithm.

FIGS. 11A-11E illustrate example optical-density profiles in the UVB range for a UVB-corona-peak tuned filter **410.** Some or all of the filters of FIGS. 11A-11E may have the property that an average of $\min[OD(\lambda),10]$ over the [280 nm, 700 nm] range is at least 4 or at least 6 or at least 8 or at least 10. For any wavelength, the value of the function $\min[OD(\lambda),10]$ is the minimum of (i) the actual OD value of the filter at the wavelength lambda, and (ii) the number 10.

FIG. 12 illustrates a routine performed by the device of FIG. 4A, and includes steps **S101, S105, S109, S110, S111, S112, S115, S181, S185, S151,** and **S161.**

FIG. 13 is a block diagram of an exemplary UVB-visible band hybrid imaging device according to some embodiments.

Definitions

For convenience, in the context of the description herein, various terms are presented here. To the extent that definitions are provided, explicitly or implicitly, here or elsewhere in this application, such definitions are understood to be consistent with the usage of the defined terms by those of skill in the pertinent art(s). Furthermore, such definitions are to be construed in the broadest possible sense consistent with such usage

As discussed above, there is a distinction between an 'object' (e.g. **210** or **220**) and a corona-discharge **230A** - the former is visible to the naked eye, and the latter is not.

A 'terrestrial corona discharge' is in contrast to solar radiation - i.e. the sun also has corona. Non-terrestrial-corona radiation is any UVB radiation other than a terrestrial corona discharge - i.e. solar radiation or superficial sources of UVB radiation such as light bulbs or fire or welding.

Unless otherwise noted, a non-terrestrial-corona discharge is other than a source with 'flashover' such as lightening.

When a scene is 'illuminated' by non-terrestrial-corona radiation, a non-trivial (i.e. other than a trace amount) of non-terrestrial-corona radiation is present - for example, similar to a dark night with a few stars.

A 'corona-discharge pixel' is a pixel that is an image of a terrestrial corona discharge. Every other pixel of a UVB image is a 'non-corona-discharge pixel.'

In the present disclosure 'electronic circuitry' is intended broadly to describe any combination of hardware, software and/or firmware.

Any element disclosed herein may include or be implemented as 'electronic circuitry.' Electronic circuitry may include any executable code module (i.e. stored on a computer-readable medium) and/or firmware and/or hardware element(s) including but not limited to field programmable logic array (FPLA) element(s), hard-wired logic element(s), field programmable gate array (FPGA) element(s), and application-specific integrated circuit (ASIC) element(s). Any instruction set architecture may be used including but not limited to reduced instruction set computer (RISC) architecture and/or complex instruction set computer (CISC) architecture. Electronic circuitry may be located in a single location or distributed among a plurality of locations where various circuitry elements may be in wired or wireless electronic communication with each other.

It is further noted that any of the embodiments described above may further include receiving, sending or storing instructions and/or data that implement the operations described above in conjunction with the figures upon a computer readable medium. Generally speaking, a computer readable medium may include storage media or memory media such as magnetic or flash or optical media, e.g. disk or CD-ROM, volatile or non- volatile media such as RAM, ROM, etc. as well as transmission media or signals such as electrical, electromagnetic or digital signals conveyed via a communication medium such as network and/or wireless links.

Having thus described the foregoing exemplary embodiments it will be apparent to those skilled in the art that various equivalents, alterations, modifications, and improvements thereof are possible without departing from the scope and spirit of the claims as hereafter recited. In particular, different embodiments may include combinations of features other than those described herein. Accordingly, the claims are not limited to the foregoing discussion.

WHAT IS CLAIMED

1. A system for visualizing a scene, the system comprising:

a. UVB imaging apparatus comprising a first array of photodetectors and a wavelength-dependent light filter, the UVB imaging apparatus configured to generate an image of the scene from UVB-light of the scene incident upon the first array of photodetectors after passing through the light filter, an optical-density $OD(\lambda)$ profile of the light filter satisfying the following conditions:

i. an average value of $\min[OD(\lambda),10]$ over the range [280 nm, 700 nm] is x, a value of x being at least 2;

ii. for at least one wavelength in at least one range selected from the UVB corona-peak range set defined as {[281 nm,285 nm],[292 nm,302 nm],[308 nm,320 nm],[334 nm,340 nm],[351 nm,362 nm]}, an optical density OD of the filter is at most y, a value of y being at most 1;

b. a visible-band imaging apparatus comprising a second array of photodetectors, the visible-band imaging apparatus configured to generate a visible-band image from visible light of the scene incident upon the second array of photodetectors; and

c. video-display apparatus configured to display a visible band-UVB hybrid image that is a superposition of: (i) the visible-band image or a derivative thereof; and (ii) the UVB image or a derivative thereof,

wherein:

i. the UVB imaging apparatus and the visible-band imaging apparatus share a common optical axis;

ii. the second array of photodetectors is disposed in a field of view of the UVB imaging apparatus; and

iii. at most 50% of an intensity of UVB light from the scene is blocked by portion(s) of the visible-band imaging apparatus in a field of view of the UVB imaging apparatus.

2. The system of any preceding claim wherein a value of x is at least 3.

3. The system of any preceding claim wherein a value of x is at least 4.

4. The system of any preceding claim wherein a value of x is at least 5.

5. The system of any preceding claim wherein a value of x is at least 6.

6. The system of any preceding claim wherein a value of y is at most 0.75.

7. The system of any preceding claim wherein a value of y is at most 0.5.

8. The system of any preceding claim wherein a value of y is at most 0.25.

9. The system of any preceding claim wherein a value of y is at most 0.1.

10. The system of any preceding claim wherein at most 30% of an intensity of UVB light from the scene is blocked by portion(s) of the visible-band imaging apparatus in a field of view of the UVB imaging apparatus.

11. The system of any preceding claim wherein at most 20% of an intensity of UVB light from the scene is blocked by portion(s) of the visible-band imaging apparatus in a field of view of the UVB imaging apparatus.

12. The system of any preceding claim wherein at most 10% of an intensity of UVB light from the scene is blocked by portion(s) of the visible-band imaging apparatus in a field of view of the UVB imaging apparatus.

13. The system of any preceding claim wherein the second array of photodetectors is part of a wire-connection island located entirely in the field of view of the UVB imaging apparatus and the video-display apparatus receives the visible-band image from the second array of photodetectors via a wireless connection.

14. The system of any preceding further comprising:

> b. UVB image-processing apparatus operative generate a UVB processed image from the UVB image so as to increase a visibility of corona-discharge pixels and/or to decrease a visibility of non-corona-discharge pixels, the video-display apparatus configured so the visible band-UVB hybrid image comprises the UVB processed image or a derivative thereof, the UVB i mage-processing apparatus configured to generate the UVB processed image.

15. The system of claim 14, wherein the system is configured to obtain the estimated intensity of ambient non-corona-discharge UVB radiation, and to generate the UVB

processed image from the UVB image in accordance with the estimated non-corona-discharge UVB radiation intensity.

16. The system of claim 15 wherein the device system obtains the estimated intensity of ambient non-corona-discharge UVB radiation in accordance with at least one of: (i) an auxiliary photodetector; (ii) location data; (iii) time-of-day; and (iv) weather data.

17. The system of claim 16 wherein the UVB image-processing apparatus is configured to respond to a change in an estimated ambient level of non-corona-discharge UVB radiation by modifying a thresholding function so as to increase a contrast between corona-discharge pixels and non-corona-discharge pixels in response to an increase in the estimated ambient level.

18. The system of claim 16 wherein the UVB image-processing apparatus is configured to respond to a change in an estimated ambient level of non-corona-discharge UVB radiation by modifying a corona-discharge-classification-threshold-function of the pixels to increase the threshold-function in response to an increase in the estimated ambient level and to decrease the threshold-function in response to an estimated decrease in the ambient level.

19. The system of any of claims 16-17, configured obtain the estimated intensity of ambient non-corona-discharge UVB radiation in accordance with at least one of: (i) an auxiliary photodetector; (ii) location data; (iii) time-of-day; and (iv) weather data.

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Application No:	GB1417301.7	**Examiner:**	Dr Susan Dewar
Claims searched:	1-19	**Date of search:**	17 November 2014

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
A	-	US 8781158 B1 (FRISCH et al)
A	-	US 2011/0273560 A1 (SHONG et al)
A	-	US 6150652 A (FORSYTH)
A	-	JP 2005241624 A (JFE STEEL KK)
A	-	US 2008/0233504 A1 (THORSTED)

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

Worldwide search of patent documents classified in the following areas of the IPC

G01J; G01N; G01R; G02B; G06T

The following online and other databases have been used in the preparation of this search report

EPODOC, WPI, TXTE

International Classification:

Subclass	**Subgroup**	**Valid From**
G01J	0001/42	01/01/2006
G01J	0001/04	01/01/2006
G02B	0005/20	01/01/2006