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Bennette

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(54) **SYSTEMS, DEVICES, AND METHODS FOR IMPLEMENTING SPECTRAL REFLECTANCE IMAGING USING NARROW BAND EMITTERS**

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A01G 7/04 (2006.01)

(Continued)

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(58) **Field of Classification Search**

None

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

9,897,484 B1 2/2018 Gopalakrishnan et al.
2017/0124402 A1* 5/2017 Tanaka G06F 18/24

(Continued)

OTHER PUBLICATIONS

International Search Report and Written Opinion for Application No. PCT/US2020/025250 dated Jul. 29, 2020 (14 pages).

(Continued)

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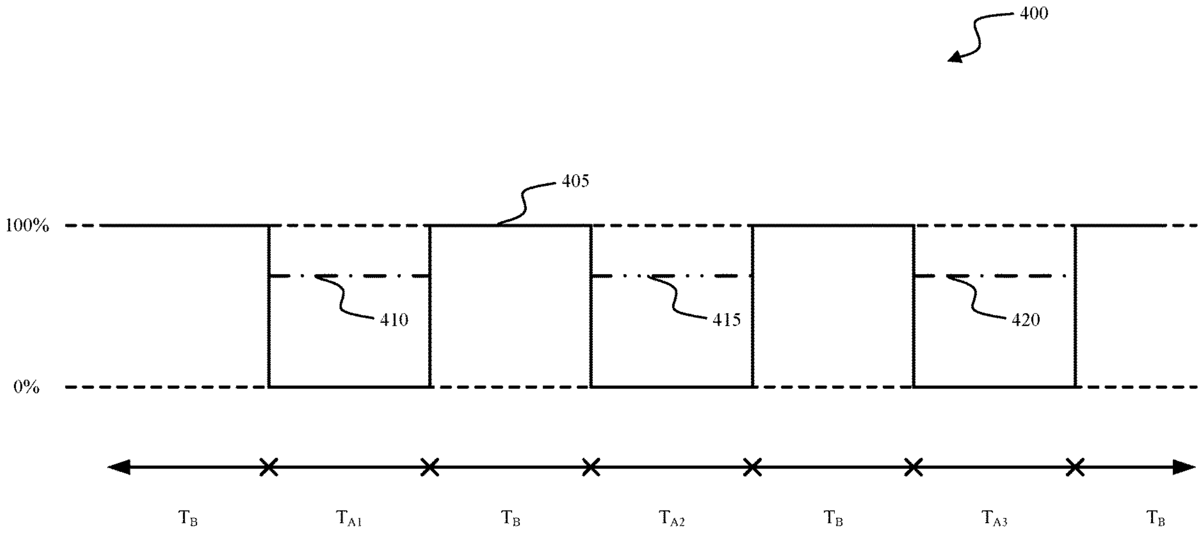
(57) **ABSTRACT**

A system for obtaining a multispectral image of a scene includes a first light source, a second light source, at least one imaging sensor, and a controller. The first light source emits light in a first wavelength range. The second light source emits light in a second wavelength range. The at least one imaging sensor senses light in the first wavelength range reflected off of the scene during a first illumination sensing period and senses light in the second wavelength range reflected off of the scene during a second illumination sensing period. The controller is electrically coupled to the at least one imaging sensor. The controller interprets signals received from the at least one imaging sensor as imaging data, stores the imaging data, and analyzes the imaging data with regard to multiple dimensions. The first illumination sensing period and the second illumination sensing period are discrete time periods.

20 Claims, 5 Drawing Sheets



Related U.S. Application Data

(60) Provisional application No. 62/829,859, filed on Apr. 5, 2019, provisional application No. 62/826,449, filed on Mar. 29, 2019, provisional application No. 62/826,434, filed on Mar. 29, 2019, provisional application No. 62/826,445, filed on Mar. 29, 2019.

(51) **Int. Cl.**

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G06F 3/14	(2006.01)
H04N 23/56	(2023.01)
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H04N 23/74	(2023.01)
H05B 45/10	(2020.01)
H05B 45/22	(2020.01)
H05B 45/325	(2020.01)
H05B 45/335	(2020.01)
H05B 47/16	(2020.01)
F21W 131/109	(2006.01)

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(56) **References Cited**

U.S. PATENT DOCUMENTS

2018/0313760	A1	11/2018	Kramer et al.	
2019/0109984	A1*	4/2019	Good	H04N 1/484
2020/0166646	A1*	5/2020	Van Der Sijde	G06T 5/50

OTHER PUBLICATIONS

Park et al., "Multispectral Imaging Using Multiplexed Illumination", downloaded Dec. 8, 2021, from IEEE Xplore, (8 Pages).

* cited by examiner

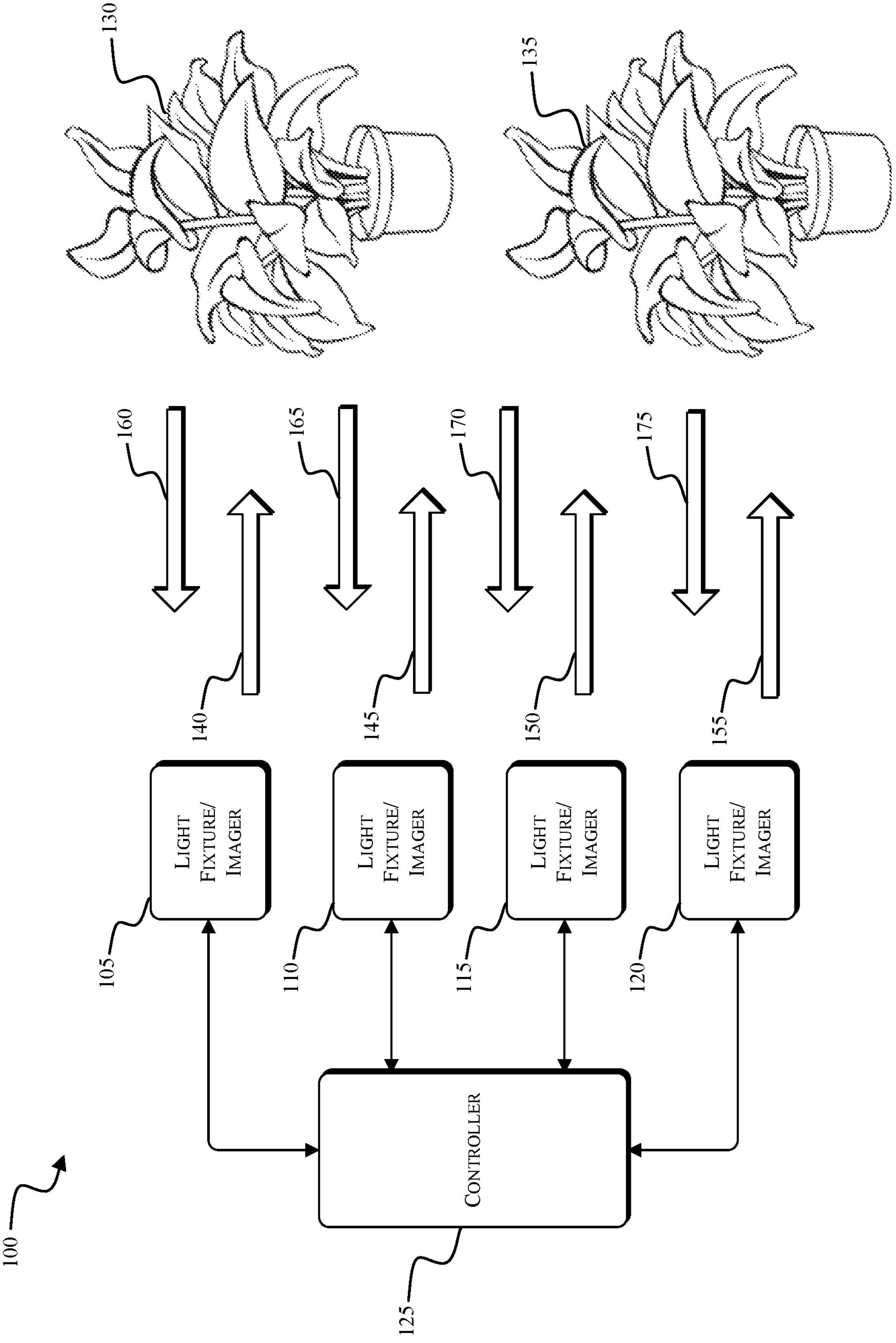

100
125
Controller
105
110
115
120
Light Fixture/ Imager
Light Fixture/ Imager
Light Fixture/ Imager
Light Fixture/ Imager
140
145
150
155
160
165
170
175
130
135

FIG. 1

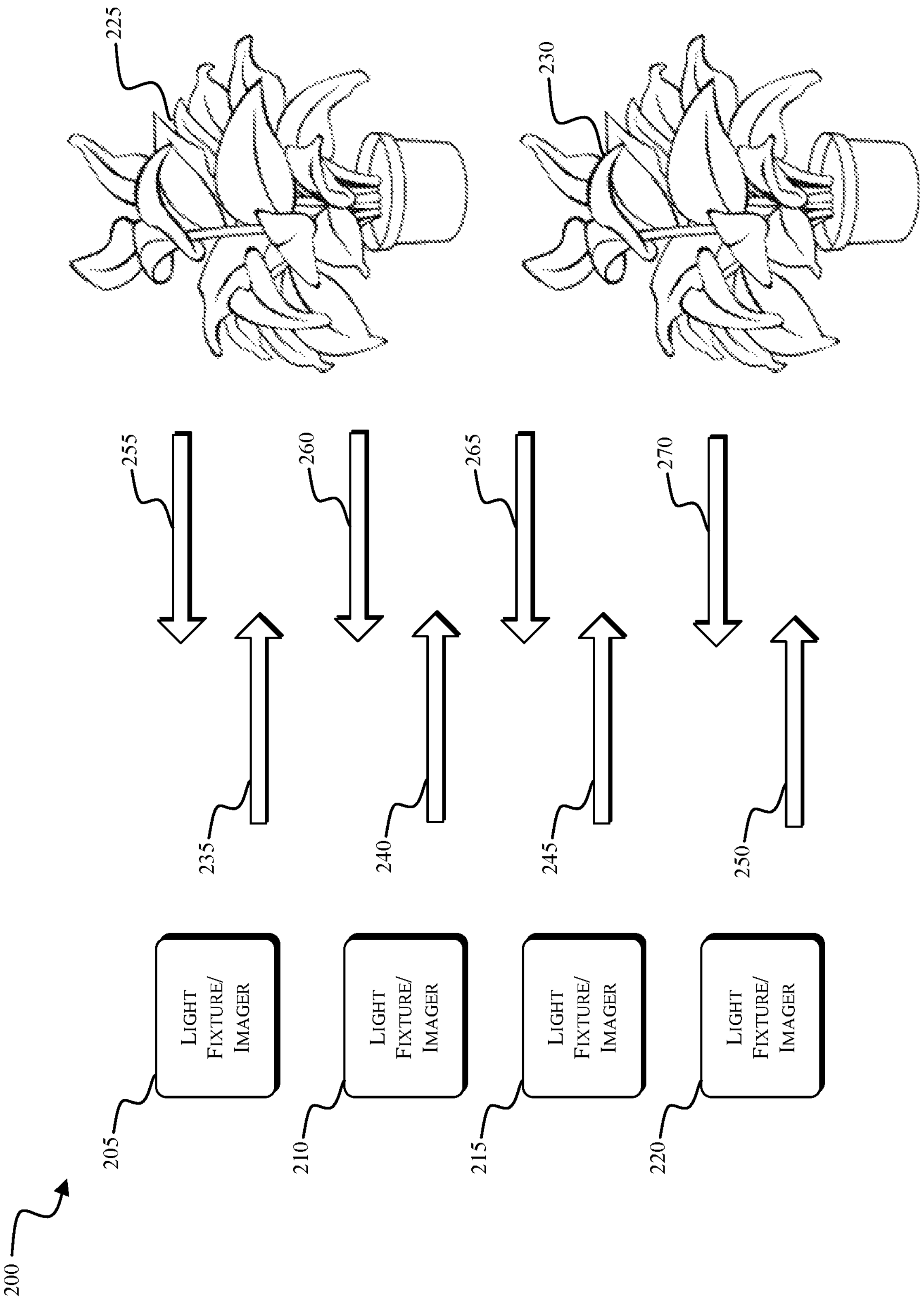
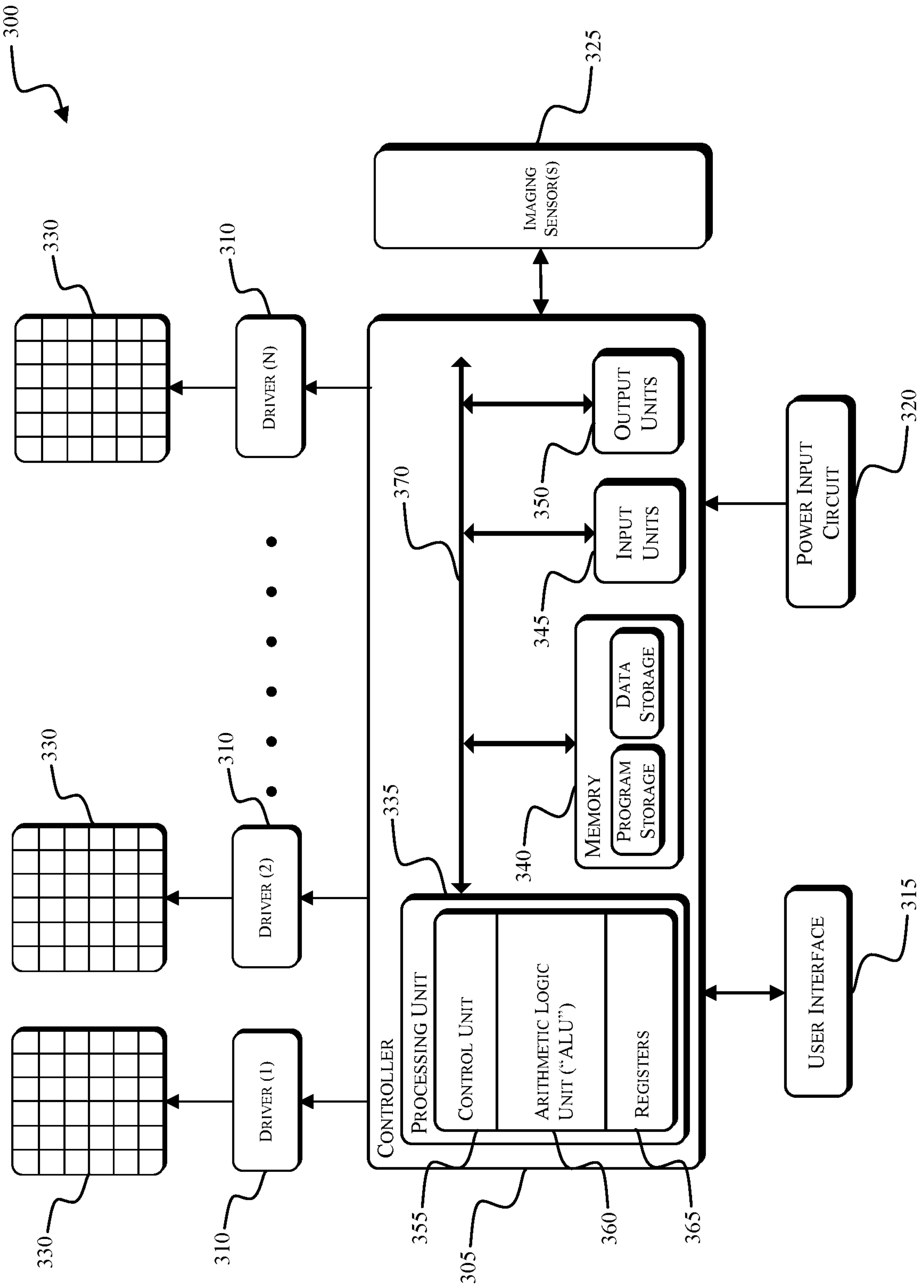

200
205
210
215
220
LIGHT FIXTURE/ IMAGER
LIGHT FIXTURE/ IMAGER
LIGHT FIXTURE/ IMAGER
LIGHT FIXTURE/ IMAGER
235
240
245
250
255
260
265
270
225
230

FIG. 2

FIG. 3


300
Controller
Processing Unit
Control Unit
Arithmetic Logic Unit ("ALU")
Registers
Memory
Program Storage
Data Storage
Input Units
Output Units
Imaging Sensor(s)
Power Input Circuit
User Interface
Driver (1)
Driver (2)
Driver (N)
305
310
310
310
315
320
325
330
330
330
335
340
345
350
355
360
365
370

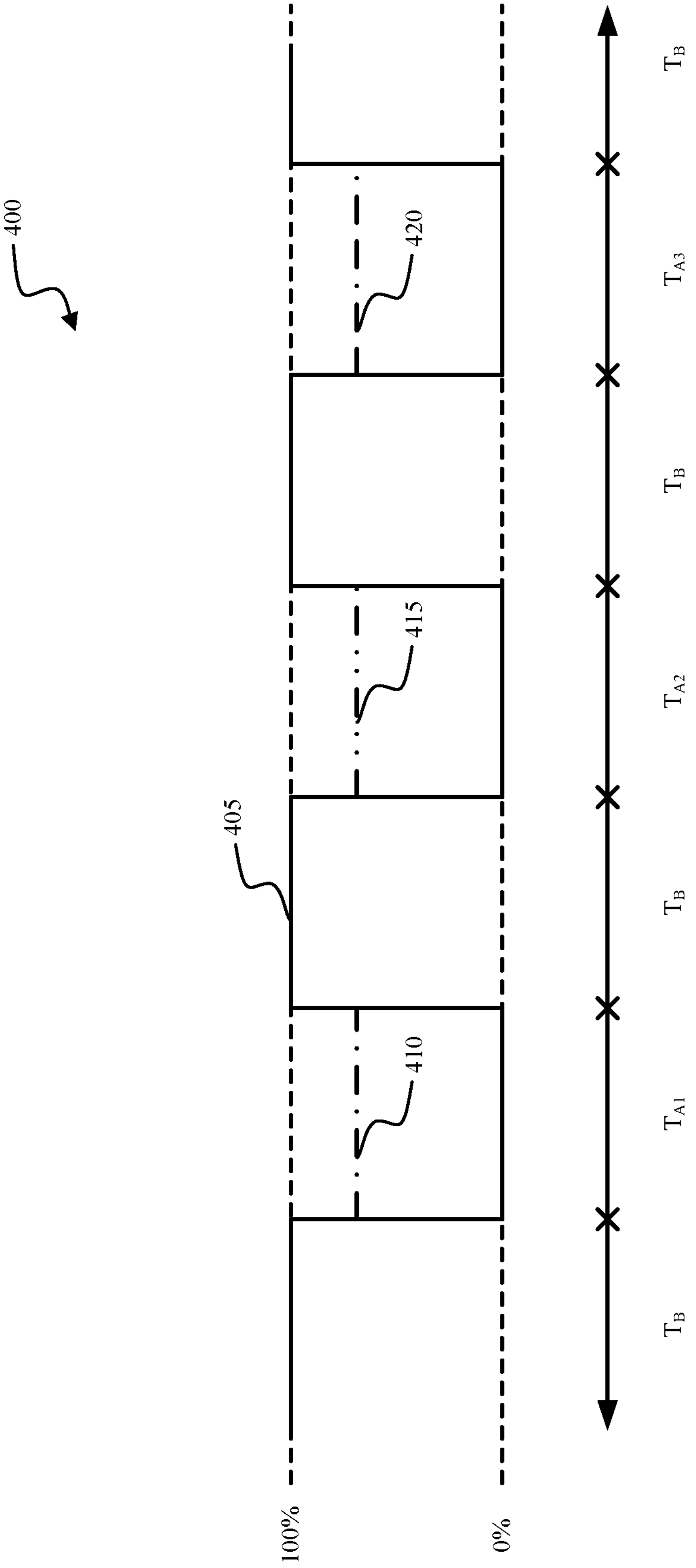
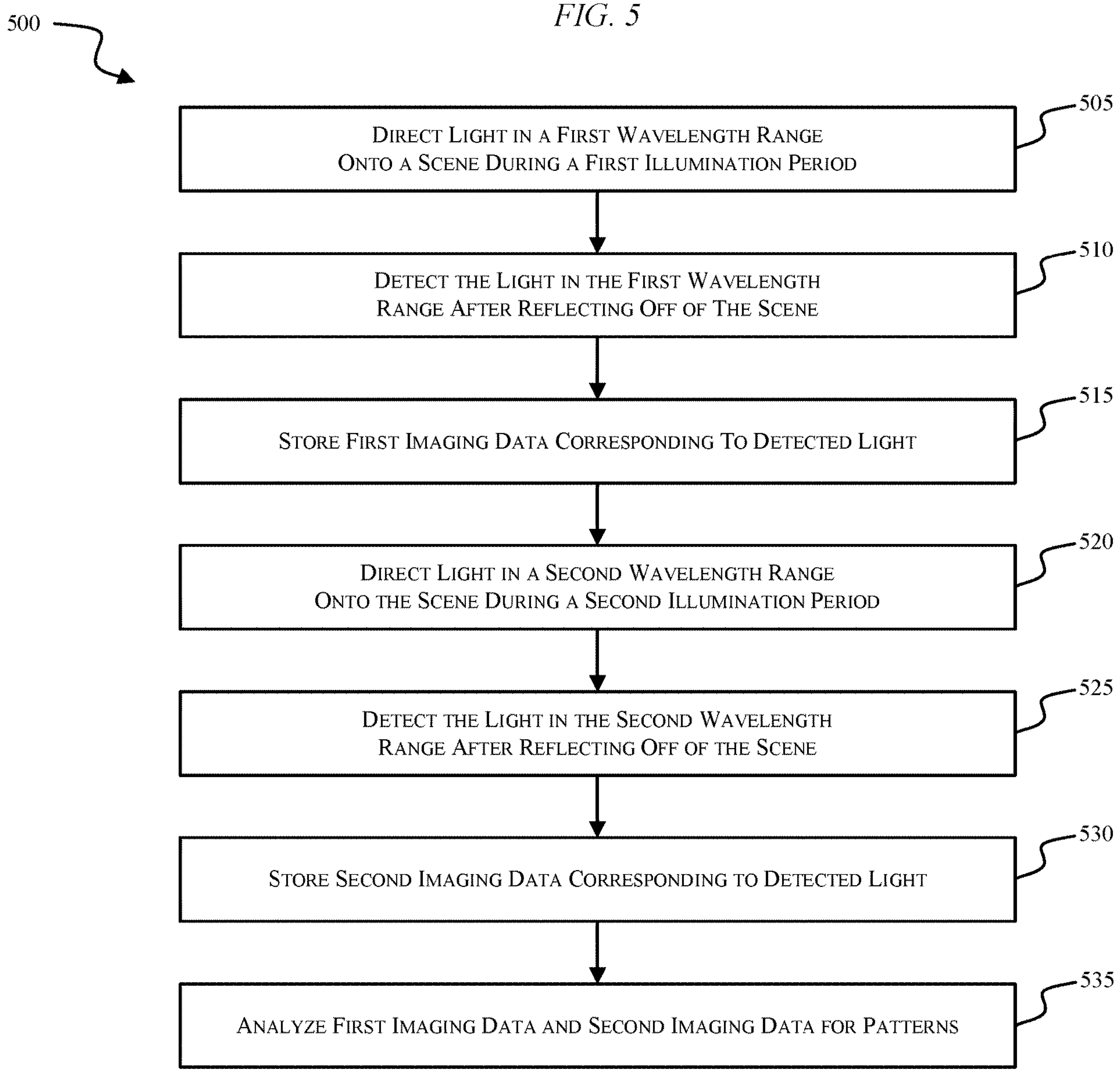


FIG. 4

FIG. 5


500
505
DIRECT LIGHT IN A FIRST WAVELENGTH RANGE ONTO A SCENE DURING A FIRST ILLUMINATION PERIOD
510
DETECT THE LIGHT IN THE FIRST WAVELENGTH RANGE AFTER REFLECTING OFF OF THE SCENE
515
STORE FIRST IMAGING DATA CORRESPONDING TO DETECTED LIGHT
520
DIRECT LIGHT IN A SECOND WAVELENGTH RANGE ONTO THE SCENE DURING A SECOND ILLUMINATION PERIOD
525
DETECT THE LIGHT IN THE SECOND WAVELENGTH RANGE AFTER REFLECTING OFF OF THE SCENE
530
STORE SECOND IMAGING DATA CORRESPONDING TO DETECTED LIGHT
535
ANALYZE FIRST IMAGING DATA AND SECOND IMAGING DATA FOR PATTERNS

SYSTEMS, DEVICES, AND METHODS FOR IMPLEMENTING SPECTRAL REFLECTANCE IMAGING USING NARROW BAND EMITTERS

RELATED APPLICATIONS

This application is a continuation application of U.S. patent application Ser. No. 16/832,475, filed Mar. 27, 2020, which claims the benefit of U.S. Provisional Patent Application No. 62/829,859, filed, Apr. 5, 2019, U.S. Provisional Patent Application No. 62/826,434, filed Mar. 29, 2019, U.S. Provisional Patent Application No. 62/826,445, filed Mar. 29, 2019, and U.S. Provisional Patent Application No. 62/826,449, filed Mar. 29, 2019, the entire contents of each of which is hereby incorporated by reference.

FIELD

Embodiments described herein relate to spectral reflectance imaging.

SUMMARY

Spectral reflectance imaging can be used to analyze plants or crops for development and disease detection. Spectral reflectance imaging can also be used to analyze paintings or other colored objects to determine the method of production, materials used, or to detect forgeries and repairs. Conventional spectral reflectance imaging uses a wideband illuminant (e.g., broadband white light, daylight, an electric light source of known spectral content, etc.) and a specialized camera (e.g., a multispectral or hyperspectral camera). Such cameras implement a series of precision band-pass filters, which typically include dichroic filters, diffraction gratings, etc. Such cameras are also bulky, complex, and prohibitively expensive.

Embodiments described herein provide systems, devices, and methods for obtaining a multispectral image using a comparatively less expensive imaging sensor (e.g., a monochrome camera) and by lighting a scene using a sequence of narrow band emitters. One narrow band emitter can be used for each waveband of interest. In some embodiments, such a technique is implemented in an obscured or low ambient light environment (e.g., not outdoors or in the presence of daylight). Illumination is provided by a collection of narrow band emitters (e.g., LEDs, tunable diffused laser, etc.). A controller collects and stores a set of images or image data sets obtained from the imaging sensor and analyzes the images in multiple dimensions. For example, a first and second dimension correspond to x-y spatial dimensions of an imaged object. A third dimension corresponds to the spectral dimension and the spectral content of an image is analyzed. In some embodiments, implementation of time-lapse imaging by the controller provides a fourth dimension of image analysis. The results of the image analysis can then be used to, for example, monitor plants or crops for distress or disease.

Systems described herein provide for obtaining a multispectral image of a scene. The systems include a first light source, a second light source, at least one imaging sensor, and a controller. The first light source emits light in a first wavelength range onto the scene. The second light source emits light in a second wavelength range onto the scene. The at least one imaging sensor senses light in the first wavelength range reflected off of the scene during a first illumination sensing period and senses light in the second wavelength range reflected off of the scene during a second illumination sensing period. The controller is connected to the at least one imaging sensor. The controller receives signals from the at least one imaging sensor as imaging data, stores the imaging data, and analyzes the imaging data with regard to multiple dimensions. The first illumination sensing period and the second illumination sensing period are discrete time periods.

Systems described herein provide for obtaining a multispectral image of a scene. The systems include a first light source, a second light source, a first imaging device, and a second imaging device. The first light source emits light in a first wavelength range onto the scene. The second light source emits light in a second wavelength range onto the scene. The first imaging device includes a first imaging sensor and a first controller. The first imaging sensor senses light in the first wavelength range reflected off of the scene during a first illumination sensing period. The first controller is connected to the first imaging sensor. The first controller receives signals from the first imaging sensor as first imaging data, stores the first imaging data, and analyzes the first imaging data with regard to a plurality of dimensions. The second imaging device includes a second imaging sensor and a second controller. The second imaging sensor senses light in the second wavelength range reflected off of the scene during a second illumination sensing period. The second controller is connected to the second imaging sensor. The second controller receives signals from the second imaging sensor as second imaging data, stores the second imaging data, and analyzes the second imaging data with regard to multiple dimensions. The first illumination sensing period and the second illumination sensing period are discrete time periods.

Methods described herein provide for obtaining a multispectral image of a scene. The methods include directing light in a first wavelength range onto the scene, detecting the light in the first wavelength range after the light has reflected off of the scene during a first illumination sensing period, storing first imaging data corresponding to the detected light in the first wavelength range, directing light in a second wavelength range onto the scene after the first illumination sensing period, detecting the light in the second wavelength range after the light has reflected off of the scene during a second illumination sensing period, storing second imaging data corresponding to the detected light in the second wavelength range, and analyzing the first imaging data and the second imaging data for one or more patterns.

Before any embodiments are explained in detail, it is to be understood that the embodiments are not limited in application to the details of the configuration and arrangement of components set forth in the following description or illustrated in the accompanying drawings. The embodiments are capable of being practiced or of being carried out in various ways. Also, it is to be understood that the phraseology and terminology used herein are for the purpose of description and should not be regarded as limiting. The use of "including," "comprising," or "having" and variations thereof are meant to encompass the items listed thereafter and equivalents thereof as well as additional items. Unless specified or limited otherwise, the terms "mounted," "connected," "supported," and "coupled" and variations thereof are used broadly and encompass both direct and indirect mountings, connections, supports, and couplings.

In addition, it should be understood that embodiments may include hardware, software, and electronic components or modules that, for purposes of discussion, may be illustrated and described as if the majority of the components were implemented solely in hardware. However, one of ordinary skill in the art, and based on a reading of this detailed description, would recognize that, in at least one embodiment, the electronic-based aspects may be implemented in software (e.g., stored on non-transitory computer-readable medium) executable by one or more processing units, such as a microprocessor and/or application specific integrated circuits ("ASICs"). As such, it should be noted that a plurality of hardware and software based devices, as well as a plurality of different structural components, may be utilized to implement the embodiments. For example, "servers" and "computing devices" described in the specification can include one or more processing units, one or more computer-readable medium modules, one or more input/output interfaces, and various connections (e.g., a system bus) connecting the components.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates a lighting system.

FIG. **2** illustrates a lighting system.

FIG. **3** illustrates a control system for implementing spectral reflectance imaging using narrow band emitters.

FIG. **4** illustrates a timing diagram for implementing spectral reflectance imaging.

FIG. **5** illustrates a method of obtaining a multispectral image.

DETAILED DESCRIPTION

FIG. **1** illustrates a lighting system **100** that includes four light fixtures **105**, **110**, **115**, and **120**. In the illustrated embodiment, the light fixtures **105-120** are combined light fixtures and imaging devices or imagers (e.g., including an imaging sensor, a camera, etc.). In other embodiments, imaging devices separate from the light fixtures **105-120** are used. Each of the fixtures/imagers **105-120** is connected to a controller **125** in a wired or wireless manner for receiving control signals that control respective light outputs **140**, **145**, **150**, and **155** of the fixtures/imagers **105-120**. The fixtures/imagers **105-120** are configured to be capable of sensing the light **160**, **165**, **170**, and **175** that is reflected off of the surfaces of an object, such as the plants **130**, **135**. In some embodiments, the fixtures/imagers **105-120** are configured to measure light in the range of approximately 1 micrometer (e.g., infrared light) to approximately 200 nanometers (e.g., ultraviolet light).

FIG. **2** illustrates a lighting system **200** that includes four light fixtures **205**, **210**, **215**, and **220**. In the illustrated embodiment, the light fixtures **205-220** are combined light fixtures and imaging devices or imagers (e.g., including an imaging sensor, a camera, etc.). In other embodiments, imaging devices separate from the light fixtures **205-220** are used. Each of the fixtures/imagers **205-220** includes its own internal controller for controlling respective light outputs **235**, **240**, **245**, and **250** of the fixtures/imagers **205-220**. The controllers internal to each of the fixtures/imagers **205-220** operate in a similar manner to the controller **125** in FIG. **1**. An exemplary controller for the system **100** or fixtures **205-220** is described with respect to FIG. **3**. The fixtures/imagers **205-220** are configured to be capable of sensing the light **255**, **260**, **265**, and **270** that is reflected off of the surfaces of an object, such as the plants **225**, **230**. In some embodiments, the fixtures/imagers **205-220** are configured to measure light in the range of approximately 1 micrometer (e.g., infrared light) to approximately 200 nanometers (e.g., ultraviolet light).

FIG. **3** illustrates a system **300** for implementing spectral reflectance imaging using narrow band emitters. A controller **305** for the system **300** is electrically and/or communicatively connected to a variety of modules or components of the system **300**. The controller **305** can correspond to, for example, the controller **125** of FIG. **1** or the internal controllers of the fixtures/imagers **205-220**. For illustrative purposes, the controller **305** is shown as providing drive signals independently and discretely to a plurality of drivers **310** (e.g., driver [1] to driver [N]). The controller **305** is also connected to a user interface **315**, a power input circuit **320**, and an imaging sensor **325** (e.g., a monochrome camera). The drivers **310** are each individually connected to an array of light sources **330** (e.g., LEDs). Each array of light sources **330** is configured to generate a narrow band light output (e.g., within a variance range of +/−10 nanometers of central emitter wavelength). Each array of light sources **330** is also configured to emit narrow band light outputs corresponding to different wavelengths of light. For example, a first array of light sources can produce light corresponding to infrared light (e.g., wavelengths in the range of approximately 800 nanometers to 1 micrometer). A final array of light sources can produce light corresponding to ultraviolet light (e.g., wavelengths in the range of approximately 200 nanometers to 400 nanometers). In some embodiments, the system **300** includes at least ten arrays of light sources **330** (e.g., between 10 and 35 arrays of light sources **330**). In other embodiments, the system **300** includes fewer than ten arrays of light sources **330**. The arrays of light sources **330** can, for example, be spectrally evenly spaced with respect to one another (e.g., consistent wavelength gaps between arrays along the electromagnetic spectrum) or the arrays of light sources **330** can be spectrally unevenly spaced such that some arrays are closer to spectrally adjacent arrays than others. Because the arrays of light sources **330** are spectrally spaced from each other, the corresponding wavelength range of each of the arrays of light sources **330** is discrete from the other wavelength ranges of the others of the arrays of light sources **330**.

Each of the arrays of light sources **330** can, for example, be housed in a separate light fixture (such as the fixtures/imagers **105-120** and/or the fixtures/imagers **205-220** described above). Alternatively, at least some of the arrays of light sources **330** can be housed in a common light fixture, with the corresponding drivers **310** still connected to each respective array of light sources **330** for individual control.

The controller **305** includes combinations of hardware and software that are operable to, among other things, control the operation of the system **300**, control the output of the arrays of light sources **330** (e.g., sequentially activating spectrally adjacent wavebands), control the operation of the imaging sensor(s) **325**, etc. The controller **305** includes a plurality of electrical and electronic components that provide power, operational control, and protection to the components and modules within the controller **305** and/or the system **300**. For example, the controller **305** includes, among other things, a processing unit **335** (e.g., a microprocessor, a microcontroller, an electronic processor, an electronic controller, or another suitable programmable device), a memory **340**, input units **345**, and output units **350**. The processing unit **335** includes, among other things, a control unit **355**, an arithmetic logic unit ("ALU") **360**, and a plurality of registers **365** (shown as a group of registers in FIG. **3**), and is implemented using a known computer architecture (e.g., a modified Harvard architecture, a von Neumann architecture, etc.). The processing unit **335**, the memory **340**, the input units **345**, and the output units **350**, as well as the various modules connected to the controller **305** are connected by one or more control and/or data buses (e.g., common bus **370**). The control and/or data buses are shown generally in FIG. **3** for illustrative purposes.

The memory **340** is a non-transitory computer readable medium and includes, for example, a program storage area and a data storage area. The program storage area and the data storage area can include combinations of different types of memory, such as a ROM, a RAM (e.g., DRAM, SDRAM, etc.), EEPROM, flash memory, a hard disk, an SD card, or other suitable magnetic, optical, physical, or electronic memory devices. The processing unit **335** is connected to the memory **340** and executes software instructions that are capable of being stored in a RAM of the memory **340** (e.g., during execution), a ROM of the memory **340** (e.g., on a generally permanent basis), or another non-transitory computer readable medium such as another memory or a disc. Software included in the implementation of the system **300** can be stored in the memory **340** of the controller **305**. The software includes, for example, firmware, one or more applications, program data, filters, rules, one or more program modules, and other executable instructions. The controller **305** is configured to retrieve from the memory **340** and execute, among other things, instructions related to the control processes and methods described herein. In other constructions, the controller **305** includes additional, fewer, or different components.

The user interface **315** is included to provide user input to the system **300** and controller **305**. The user interface **315** is operably coupled to the controller **305** to control, for example, the output of the arrays of light sources **330**, the imaging sensor **325**, etc. The user interface **315** can include any combination of digital and analog input devices required to achieve a desired level of control for the system **300**. For example, the user interface **315** can include a computer having a display and input devices, a touch-screen display, a plurality of knobs, dials, switches, buttons, faders, or the like.

The power input circuit **320** supplies a nominal AC or DC voltage to the system **300** and components within the system **300**. The power input circuit **320** can be powered by mains power having nominal line voltages between, for example, 100V and 240V AC and frequencies of approximately 50-60 Hz. The power input circuit **320** is also configured to supply lower voltages to operate circuits and components within the system **300** (e.g., controller **305**). Additionally or alternatively, the system **300** can receive power from one or more batteries or battery packs.

The system **300** of FIG. **3** is used to illuminate a scene or object using the discretely controllable narrow band arrays of light sources **330**. The imaging sensor **325** is positioned to observe and capture images of the scene being illuminated by the individual arrays of light sources **330** (e.g., one array of light sources **330** is used for illumination and image capture at a time). Each pixel of the imaging sensor **325** is also configured to respond to a range of wavelengths between approximately 200 nanometers (e.g., ultraviolet) to 1 micrometer (e.g., infrared) and has a known response curve. In some embodiments, the controller **305** or the imaging sensor **325** normalizes captured images for dynamic range to minimize noise and prevent saturation of the imaging sensor **325**. Such a normalization can be performed for each waveband of light produced by the individual arrays of light sources **330**. Least common denominator values from the normalization can then be used for image capture to preserve relative ratios of reflectance for each waveband. Each image captured by the imaging sensor **325** can be stored to the memory **340** of the controller **305**. The images related to the same imaged object or the same portion of an imaged scene can then be used to reconstruct or generate a full-spectrum color image capable of human viewing.

In some embodiments, the imaging sensor **325** is included within a light fixture (see FIG. **2**). In other embodiments, the imaging sensor **325** is separate from a light fixture (see FIG. **1**) and provides captured images to the controller **305** in a wired or wireless manner (e.g., using Bluetooth, ZigBee, WiFi, etc.). The imaging sensor **325** is, for example, a monochrome camera that includes only a luminance channel (e.g., no Bayer filter, no color mask, no IR blocking filter, etc.). In some embodiments, such a technique is implemented in a low ambient light environment (e.g., an environment having an approximate 20:1 ratio of light source intensity to ambient light). Additionally, if the imaging sensor **325** implements auto-white balance, such a feature should be disabled or a set of reference images should be captured using a target object (e.g., an object nominally white in appearance, having known spectral reflectance) and post-image compensation should be applied. In some embodiments, the response curve of the imaging sensor **325** to different wavelengths of light is compensated to produce a nominally flat reflectance spectrum for the reference target (e.g., a white reference surface). Additional compensation can be implemented as needed for a particular application of the system **300**, such as temperature compensation (e.g., using a temperature sensor), humidity compensation (e.g., using a hygrometer), compensation for chromatic aberration of the camera optics, and other similar compensation techniques employed for image capture and luminance measurement.

The controller **305** is configured to analyze images or image data sets collected from the imaging sensor **325** using pattern detection techniques on the image data sets, such as by implementing specialized machine learning algorithms, Fourier analysis, and other known methods for detecting patterns in images. After the controller **305** has detected patterns in the image data sets, the controller **305** can monitor or track the development of an object (e.g., a plant or crop) in the scene or determine whether the object is experiencing distress or disease. By using a wide range of wavelengths of light produced by the arrays of light sources **330**, the controller **305** is able to detect such properties or characteristics of the object that are not viewable from direct observation (e.g., using the human eye).

In embodiments where the system **300** is implemented to analyze plants or crops, the photobiological processes of the plants or crops can be directly affected by the light to which they are exposed. As a result, the controller **305** is configured to expose the plants or crops to the light from the arrays of light sources **330** for the minimum amount of time required for the imaging sensor **325** to capture an image. FIG. **4** illustrates a timing diagram **400** according to embodiments described herein. When the controller **305** is not controlling the arrays of light sources **330** and imaging sensor **325** to capture images, the plants or crops should receive only the spectrum of light and radiant power normally required to assure growth in a particular environment or under particular conditions (e.g., indoors). The nominal flux for normal growing or illumination is at **405** in FIG. **4**. The time between images, T_B, includes the normal growing light source(s) being ON. The time, T_{A1}, corresponds to the time when an image is being captured using a flux from a first of the arrays of light sources **330**. The intensity of the first array of light sources **330** is at **410** in FIG. **4**. The time, T_{A2}, corresponds to the time when an image is being captured using a flux from a second of the arrays of light sources **330**. The intensity of the second array of light sources **330** is at **415** in FIG. **4**. The time, T_{A3}, corresponds to the time when an image is being captured using a flux from a third of the arrays of light sources **330**. The intensity of the third array of light sources **330** is at **415** in FIG. **4**. This sequence is continued for each of the arrays of light sources **330** during a particular imaging cycle. In some embodiments, the time for image capture is between two and three times the frame rate of the imaging sensor **325**. As a result, at least one and no more than two whole frames would be captured for a single waveband of light produced by one of the arrays of light sources **330**. In some embodiments, an imaging cycle lasts approximately 5-10 seconds. Therefore, the implementation of spectral reflectance imaging by the system **300** interferes as little as possible with the plant or crop being analyzed.

Although FIG. **4** illustrates embodiments including discrete (e.g., separate) time periods for each of the light source **330** activations **410**, **415**, **420**, some embodiments may include overlap of the activations **410**, **415**, **420**. With regard to such embodiments, the imaging sensor(s) **325** activate to sense reflected light only while one of the light source **330** activations **410**, **415**, **420** is ongoing. Stated another way, the illumination sensing periods in which the imaging sensor(s) **325** senses reflected light at respective wavelength ranges are discrete time periods in that they do not overlap temporally. For example, the first array of light sources **330** activates to illuminate the scene with light (such as light **140** or light **235**) in a first wavelength range. Then, the imaging sensor(s) **325** activates during a first illumination sensing period to detect reflected light (such as light **160** or light **255**) in the first wavelength range. Next, the imaging sensor(s) **325** deactivates to end the first illumination sensing period. Now that the first illumination sensing period has ended, the first array of light sources **330** may be extinguished contemporaneously or may be extinguished at a later time. Further, the second array of light sources **330** activates to illuminate the scene with light (such as light **145** or light **240**) in a second wavelength range. This activation of the second array of light sources **330** may occur before the first array of light sources **330** have been extinguished or may happen after the first array of light sources **330** have been extinguished, but the activation of the second array of light sources **330** does not happen until after the end of the first illumination sensing period. Once the first array of light sources **330** have been extinguished and the second array of light sources **330** have been activated, the imaging sensor(s) **325** activate to begin a second illumination sensing period. The process continues in such a manner until all the different arrays of light sources **330** corresponding to respective light wavelength ranges have operated.

A method **500** of obtaining a multispectral image of a scene is shown in FIG. **5**. The method **500** may be performed using, for instance, the system **300** described above. The method **500** includes a first step **505** of directing light (such as light **140** or light **235**) in a first wavelength range (such as 800 nanometers to 1 micrometer) onto a scene or an object (such as plants **130**, **135** or plants **225**, **230**) during a first illumination period (such as time T_{A1}). Next, the method **500** includes a second step **510** of detecting light (such as light **160** or light **255**) in the first wavelength range (by, for instance, the imaging sensor **325**) reflected off of the scene during a first illumination sensing period. First imaging data corresponding to the detected light is then stored (by, for instance, the controller **305**) in a third step **515**. Then, the method **500** includes a fourth step **520** of directing light (such as light **145** or light **240**) in a second wavelength range onto the scene during a second illumination period (such as time T_{A2}). Light (such as light **165** or light **260**) in the second wavelength range reflected off of the scene is detected during a second illumination sensing period in a fifth step **525** of the method **500**. Second imaging data corresponding to the detected light is then stored (by, for instance, the controller **305**) in a sixth step **530**. During a seventh step **535**, the first imaging data and the second imaging data are then analyzed for patterns as described above (by, for instance, the controller **305**). The method **500** can include further steps of directing light, detecting reflected light, and storing imaging data corresponding to additional wavelength ranges of light emitted by additional light sources. These further steps can occur prior to the analysis step, such that the analysis is performed only once during the analysis step. Alternatively, the analysis may occur continually or continuously during the method **500**.

Thus, embodiments described herein provide, among other things, systems, devices, and methods for implementing spectral reflectance imaging using narrow band emitters.

What is claimed is:

1. A system for obtaining a multispectral image of a scene, the system comprising:
- a nominal light source configured to emit a nominal flux onto the scene;
- a first light source configured to emit first light onto the scene during a first sensing period;
- a second light source configured to emit second light onto the scene during a second sensing period;
- an imaging device including a monochromatic imaging sensor and a controller connected to the monochromatic imaging sensor,
- the monochromatic imaging sensor configured to:
  - sense the first light that is reflected off of the scene during the first sensing period; and
  - sense the second light that is reflected off of the scene during the second sensing period; and
- the controller configured to:
  - receive signals from the monochromatic imaging sensor as imaging data, the signals corresponding to the first and the second light sensed during the first and the second sensing periods, respectively;
  - store the imaging data; and
  - analyze pattern data of the imaging data;
- wherein the nominal light source is off during the first sensing period and the second sensing period; and wherein the multispectral image of the scene is generated using the imaging data.

2. The system of claim **1**, wherein the first light source emits the first light in a first wavelength range, the second light source emits the second light in a second wavelength range, and the first wavelength range and the second wavelength range are discrete ranges.

3. The system of claim **2**, wherein the first wavelength range is 800 nanometers to 1 micrometer, and wherein the second wavelength range is 200 nanometers to 400 nanometers.

4. The system of claim **3**, further comprising a plurality of light sources, the plurality of light sources including the first light source, the second light source, and a third light source configured to emit third light in a third wavelength range onto the scene.

5. The system of claim **4**, wherein:
- the plurality of light sources includes ten light sources; and

each of the ten light sources is configured to emit light in a discrete wavelength range.

6. The system of claim **2**, wherein the first and the second wavelength ranges are evenly spaced along a spectrum.

7. The system of claim **2**, wherein the first and the second wavelength ranges are unevenly spaced along a spectrum.

8. The system of claim **2**, wherein the monochromatic imaging sensor is a first monochromatic imaging sensor, and the imaging device includes a second monochromatic imaging sensor connected to the controller,

wherein the first monochromatic imaging sensor is configured to sense the first light in the first wavelength range reflected off of the scene during the first sensing period, and

wherein the second monochromatic imaging sensor is configured to sense the second light in the second wavelength range reflected off of the scene during the second sensing period.

9. The system of claim **8**, further comprising:

a first fixture including:
  the first light source, and
  the first monochromatic imaging sensor; and
a second fixture including:
  the second light source, and
  the second monochromatic imaging sensor;

wherein the controller is further connected to the first light source and the second light source.

10. The system of claim **1**, wherein the controller is configured to analyze the imaging data with respect to a plurality of dimensions, and wherein the plurality of dimensions includes first and second dimensions corresponding to x-y spatial dimensions of an imaged object, and wherein the plurality of dimensions includes a third dimension corresponding to a spectral dimension of the imaged object.

11. The system of claim **10**, wherein the plurality of dimensions includes a fourth dimension corresponding to a time of capture of the imaged object.

12. The system of claim **1**, wherein

the first light source includes a first array of light-emitting diodes, and

the second light source includes a second array of light-emitting diodes.

13. A method of obtaining a multispectral image of a scene, the method comprising:

directing a nominal light onto the scene;

directing other light onto the scene during a first illumination sensing period and during a second illumination sensing period;

detecting the other light after the other light has reflected off of the scene during the first illumination sensing period and during the second illumination sensing period, wherein the nominal light is off during the first illumination sensing period and the second illumination sensing period;

storing imaging data corresponding to the detected light;

analyzing the imaging data to identify a pattern in the imaging data; and

generating a multispectral image of the scene.

14. The method of claim **13**, wherein the other light comprises first light and second light, and wherein a first light source emits the first light in a first wavelength range, a second light source emits the second light in a second wavelength range, and the first wavelength range and the second wavelength range are discrete ranges.

15. The method of claim **14**, wherein the first wavelength range is 800 nanometers to 1 micrometer.

16. The method of claim **15**, wherein the second wavelength range is 200 nanometers to 400 nanometers.

17. The method of claim **13**, further comprising:

using a monochrome camera to detect the other light after the other light has reflected off of the scene during the first illumination sensing period and during the second illumination sensing period.

18. The method of claim **13**, wherein analyzing the imaging data to identify a pattern in the imaging data includes analyzing the imaging data with respect to a plurality of dimensions, and wherein the plurality of dimensions includes first and second dimensions corresponding to x-y spatial dimensions of an imaged object.

19. The method of claim **18**, wherein the plurality of dimensions includes a third dimension corresponding to a spectral dimension of the imaged object.

20. The method of claim **19**, wherein the plurality of dimensions includes a fourth dimension corresponding to a time of capture of the imaged object.

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