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Vavrik et al.

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(54) **SYSTEM AND METHOD FOR MATCHING LIGHT OUTPUT FROM LED LUMINAIRES**

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See application file for complete search history.

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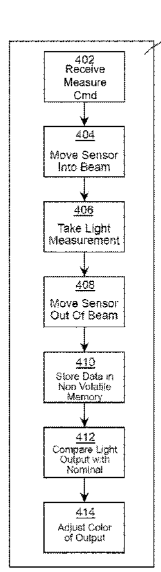
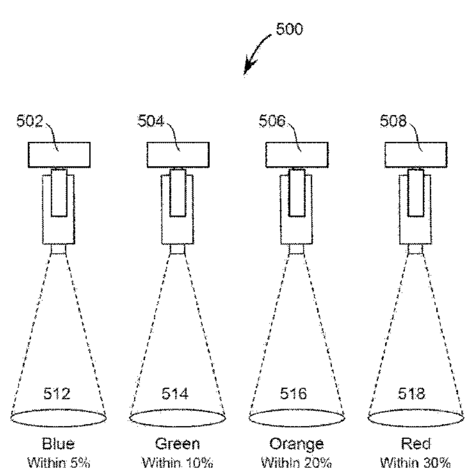
(57) **ABSTRACT**

A luminaire has a light-emitting diode (LED) light source, a light sensor, and a control system. The control system receives a Measure command measure the current intensity of the LED light source. The control system measures the intensity using the light sensor, stores current intensity data in non-volatile memory, obtains the LED light source's previous intensity, selects an indicator color representing how much the current intensity is reduced from the previous intensity, and causes the luminaire to emit a light beam having the indicator color. The control system also receives an Adjust command to reduce the LED light source to a total intensity reduction amount. The control system obtains the LED light source's current reduction amount, determines whether the total intensity reduction amount is more than the current reduction amount, and, if so, causes the LED light source to emit a reduced intensity light beam.

17 Claims, 7 Drawing Sheets





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F21Y 115/10	(2016.01)

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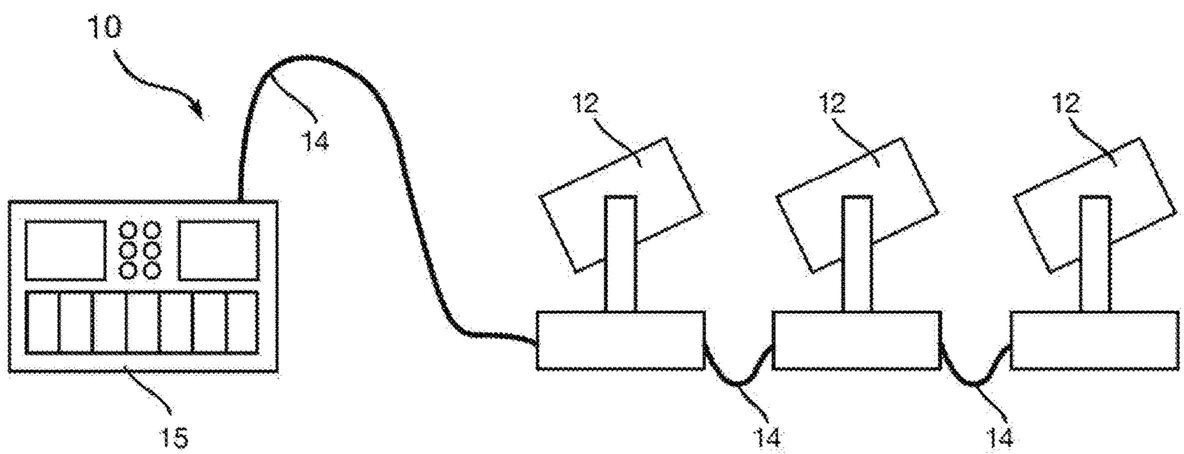

FIGURE 1

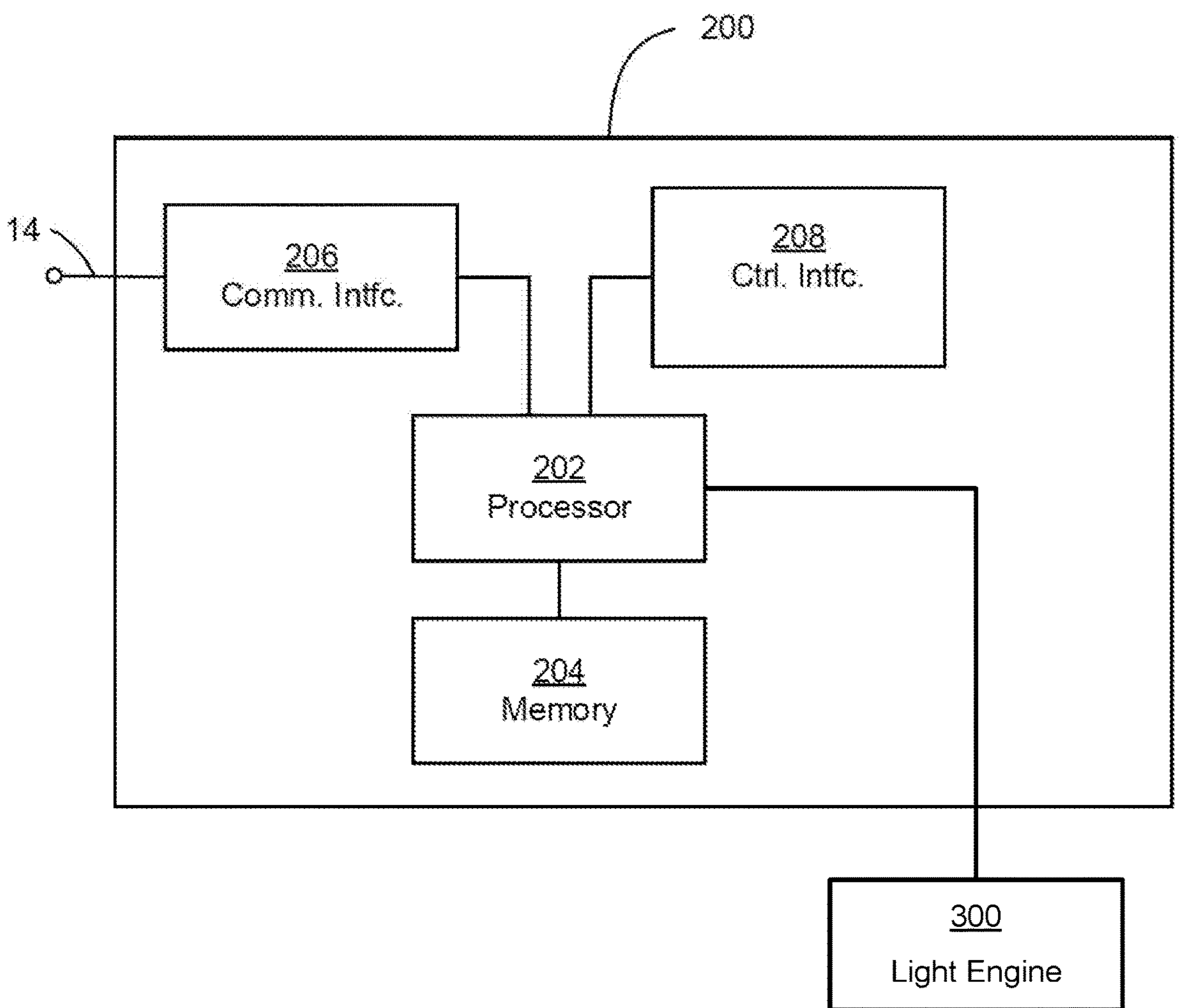
200
14
206
Comm. Intfc.
208
Ctrl. Intfc.
202
Processor
204
Memory
300
Light Engine

FIGURE 2

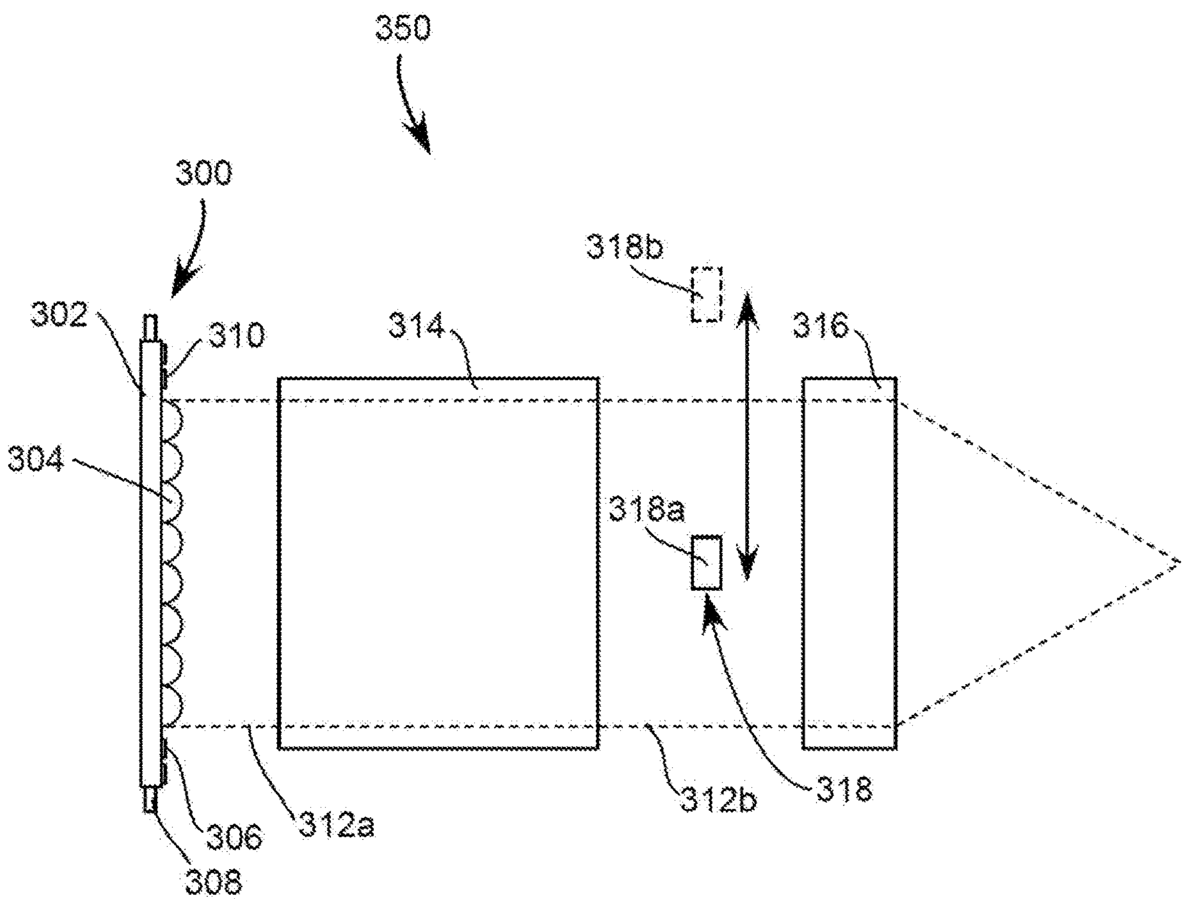

FIGURE 3

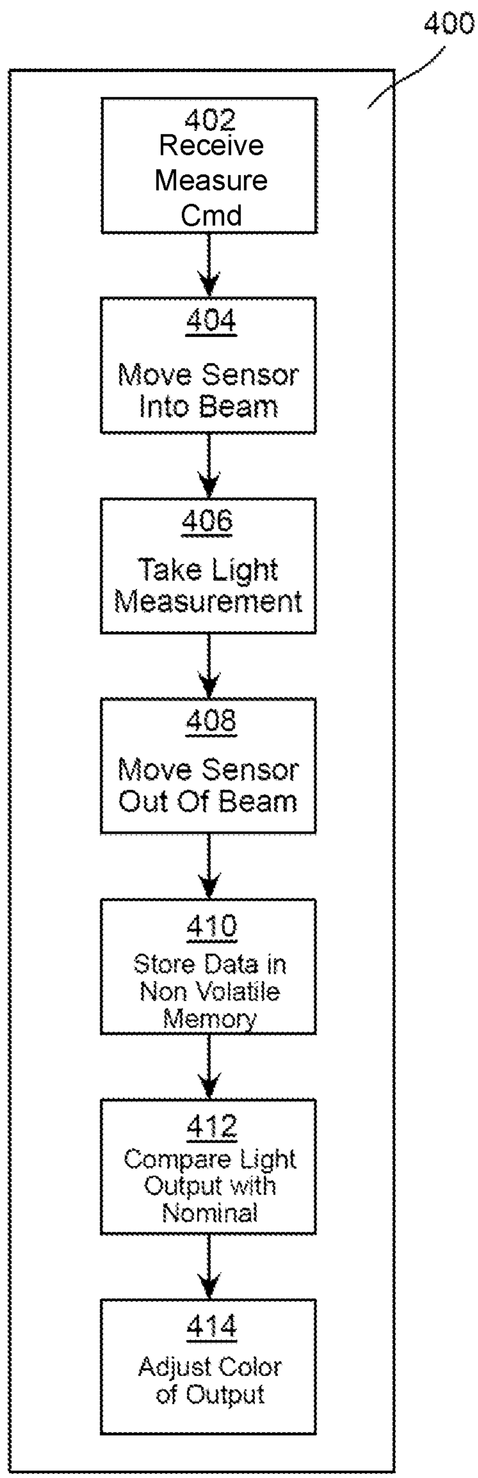
400
402
Receive
Measure
Cmd
404
Move Sensor
Into Beam
406
Take Light
Measurement
408
Move Sensor
Out Of Beam
410
Store Data in
Non Volatile
Memory
412
Compare Light
Output with
Nominal
414
Adjust Color
of Output

FIGURE 4

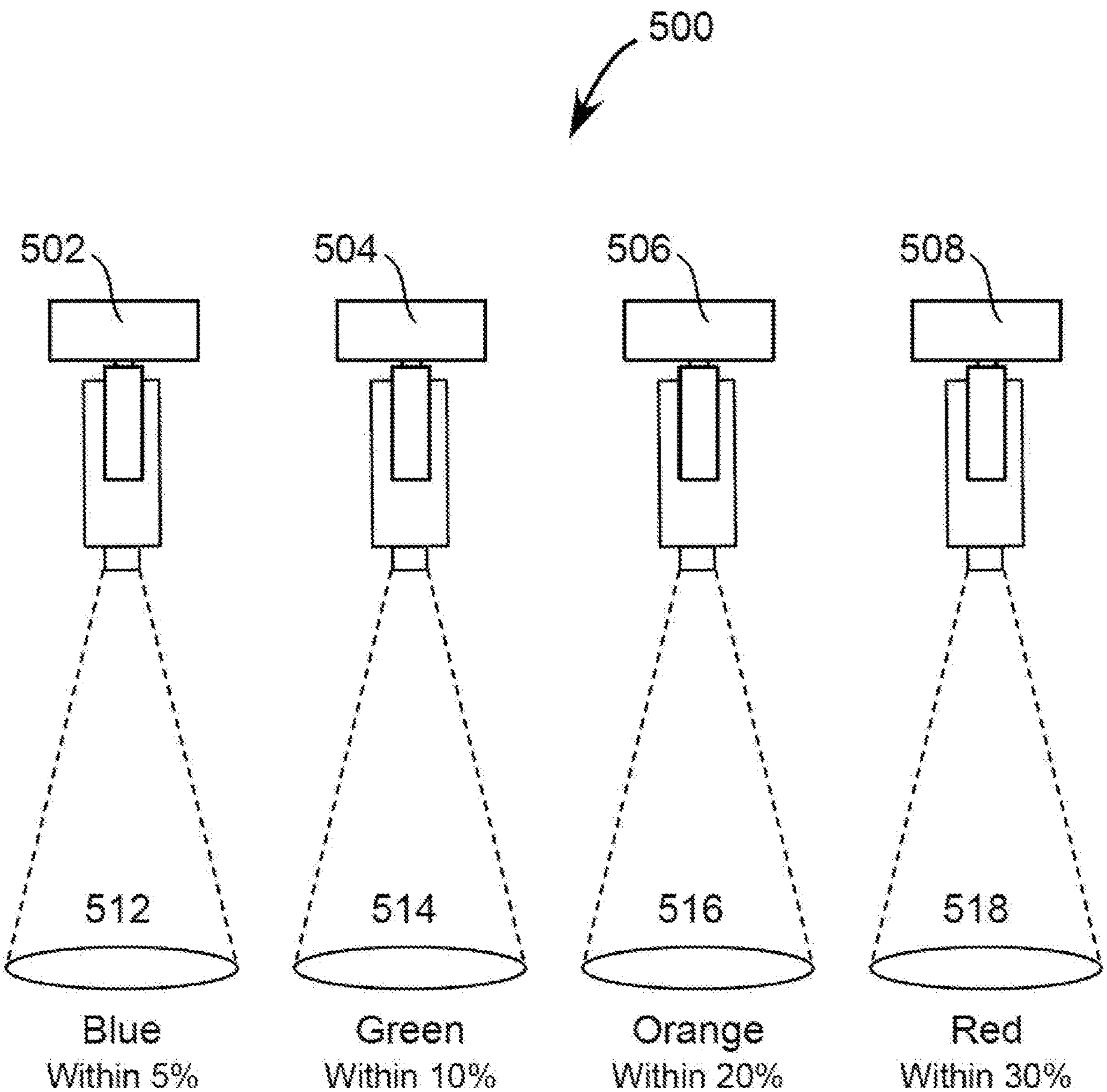
500
502
504
506
508
512
514
516
518
Blue
Within 5%
Green
Within 10%
Orange
Within 20%
Red
Within 30%

FIGURE 5

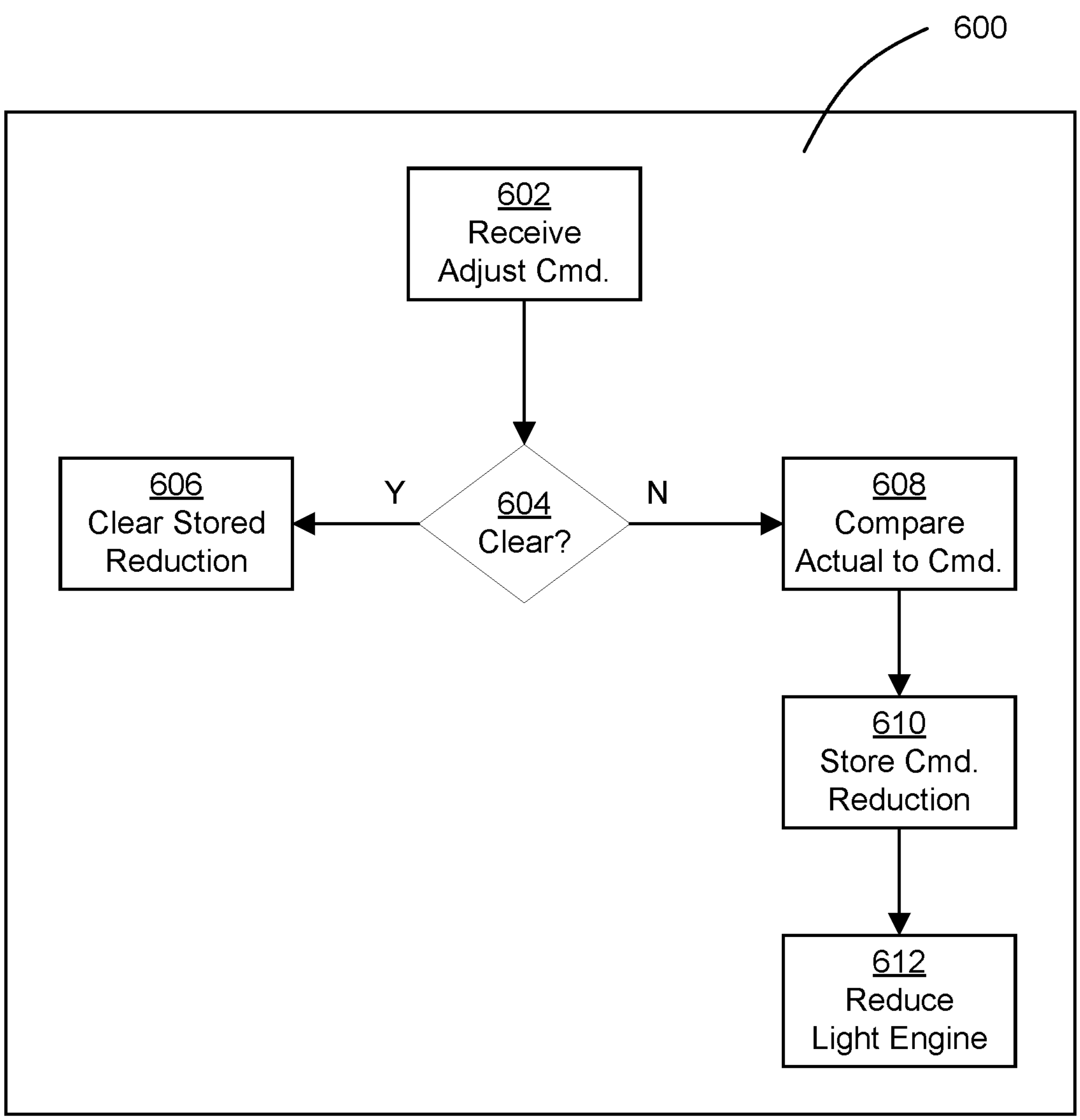
600
602
Receive Adjust Cmd.
604
Clear?
Y
N
606
Clear Stored Reduction
608
Compare Actual to Cmd.
610
Store Cmd. Reduction
612
Reduce Light Engine

FIGURE 6

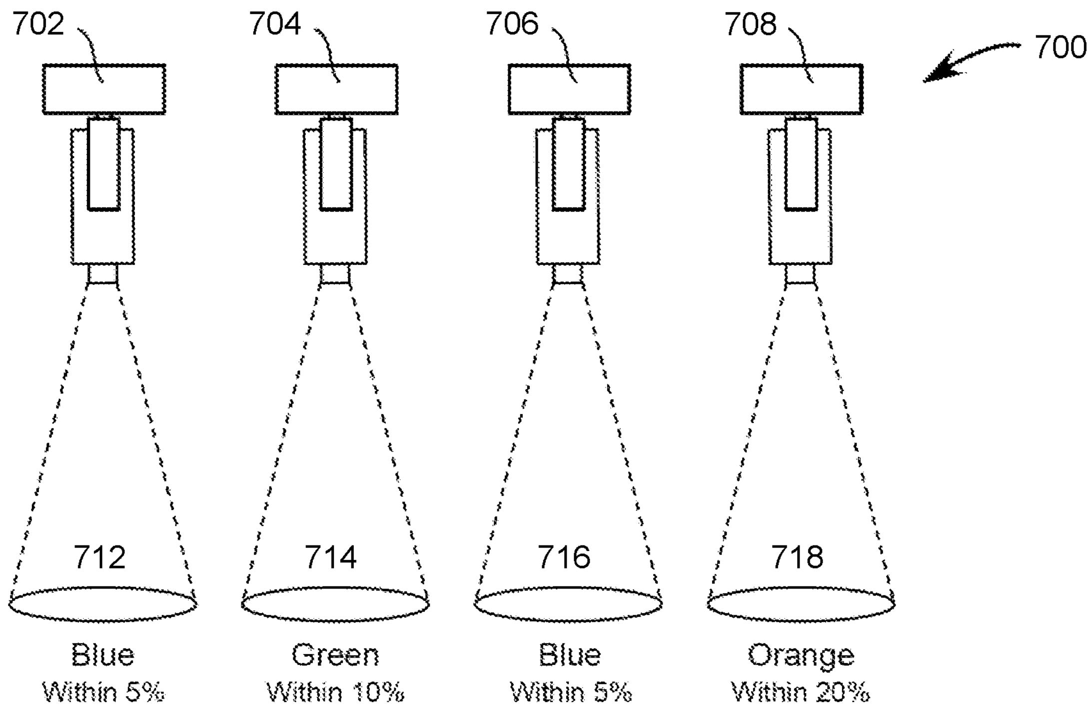

FIGURE 7A

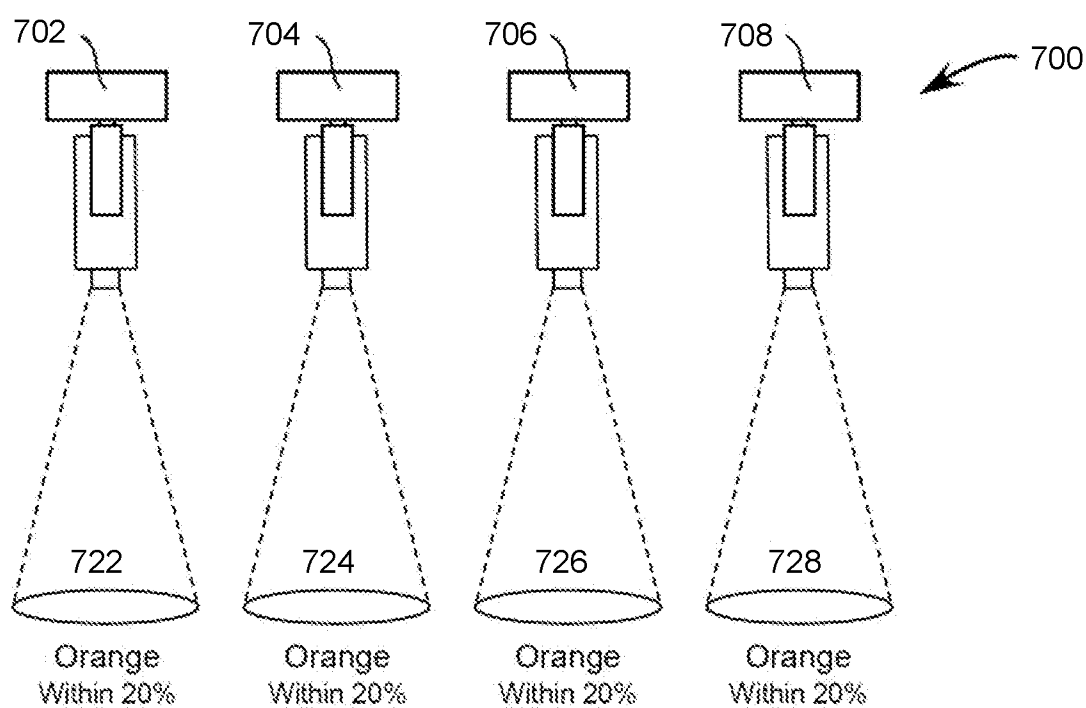

FIGURE 7B

SYSTEM AND METHOD FOR MATCHING LIGHT OUTPUT FROM LED LUMINAIRES

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority to U.S. Provisional Application No. 62/895,357 filed on Sep. 3, 2019 by Jindřich Vavřik, et al. entitled, "System and Method for Matching Light Output from LED Luminaires", which is incorporated by reference herein as if reproduced in its entirety.

TECHNICAL FIELD OF THE DISCLOSURE

The disclosure generally relates to automated luminaires, and more specifically to a method for matching light output from light-emitting diode (LED) luminaires.

BACKGROUND

Luminaires with automated and remotely controllable functionality (referred to as automated luminaires) are well known in the entertainment and architectural lighting markets. Such products are commonly used in theatres, television studios, concerts, theme parks, night clubs, and other venues. A typical automated luminaire provides control from a remote location of the pan and tilt functions of the luminaire allowing the operator to control the direction the luminaire is pointing and thus the position of the light beam on the stage or in the studio. Typically, this position control is done via control of the luminaire's position in two orthogonal rotational axes usually referred to as pan and tilt. Many automated luminaires additionally or alternatively provide control from the remote location of other parameters such as intensity, focus, beam size, beam shape, and/or beam pattern of light beam(s) emitted from the luminaire. In particular, control is often provided for the color of the output beam which may be provided by controlling the insertion of dichroic colored filters across the light beam.

SUMMARY

In a first embodiment, a luminaire includes a light-emitting diode (LED) light source, a light sensor, and a control system. The LED light source emits a light beam. The light sensor is optically coupled to the LED light source, measures an intensity of the light beam, and produces an intensity signal based on the measured intensity. The control system is electrically coupled to the LED light source, a non-volatile memory, and to the light sensor. The control system receives via a data link a Measure command that instructs the luminaire to measure the current intensity of the LED light source's light beam. In response to the Measure command, the control system obtains the intensity signal from the light sensor, stores current intensity data that represents the intensity signal in the non-volatile memory, obtain previous intensity data that represents a previously measured intensity of the LED light source's light beam, selects an indicator color to represent an amount by which the current intensity data is less than the previous intensity data, and causes the luminaire to emit a beam of light having the indicator color. The control system also receives via the data link an Adjust command having total reduction data that represents a total intensity reduction amount for a reduced intensity light beam from the LED light source. In response to the Adjust command, the control system obtains a current reduction amount that represents the amount by which the current intensity data is less than the previous intensity data, determines whether the total intensity reduction amount is greater than the current reduction amount, and causes the LED light source to emit a reduced intensity light beam when the total reduction amount is greater than the current reduction amount.

In a second embodiment, a luminaire includes an LED light source, a light sensor, and a control system. The LED light source emits a light beam. The light sensor is optically coupled to the LED light source, measures a current intensity of the light beam, and produces an intensity signal based on the measured intensity. The control system is electrically coupled to the LED light source, a non-volatile memory, and the light sensor. The control system obtains the intensity signal from the light sensor, stores current intensity data representing the intensity signal in the non-volatile memory, obtains previous intensity data that represents a previously measured intensity of the light beam emitted by the LED light source, selects an indicator color to represent an amount by which the current intensity data is less than the previous intensity data, and causes the luminaire to emit a beam of light having the indicator color.

In a third embodiment, a luminaire includes an LED light source and a control system. The LED light source emits a light beam. The control system is electrically coupled to the LED light source and receives via a data link an Adjust command having total reduction data that represents a total intensity reduction amount for a reduced intensity light beam from the LED light source. In response to the command, the control system obtains a current reduction amount that represents an amount by which a current intensity of the LED light source's full intensity light beam is less than a previously measured intensity of the LED light source's full intensity light beam, determines whether the total intensity reduction amount is greater than the current reduction amount, and causes the LED light source to emit a reduced intensity light beam when the total reduction amount is greater than the current reduction amount.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of this disclosure, reference is now made to the following brief description, taken in conjunction with the accompanying drawings in which like reference numerals indicate like features.

FIG. **1** presents a schematic view of a luminaire system according to the disclosure;

FIG. **2** presents a block diagram of a control system for a luminaire according to the disclosure;

FIG. **3** presents a schematic diagram of an optical system of a luminaire that includes an LED light engine according to the disclosure;

FIG. **4** presents a block diagram of a light measurement procedure according to the disclosure;

FIG. **5** presents a system of luminaires each indicating light output according to the disclosure;

FIG. **6** presents a flowchart of a light adjustment procedure according to the disclosure; and

FIGS. **7**A and **7**B present a system of luminaires according to the disclosure.

DETAILED DESCRIPTION

Preferred embodiments are illustrated in the figures, like numerals being used to refer to like and corresponding parts of the various drawings.

FIG. **1** presents a schematic view of a luminaire system **10** according to the disclosure. The luminaire system **10** includes a plurality of luminaires **12** according to the disclosure. The luminaires **12** each contains on-board a light source, one or more of color changing systems, light modulation devices, and pan and/or tilt systems to control an orientation of a head of the luminaire **12**. Mechanical drive systems to control parameters of the luminaire **12** include motors or other suitable actuators coupled to a control system, as described in more detail with reference to FIG. **2**, which is configured to control the motors or other actuators.

In addition to being connected to mains power either directly or through a power distribution system, the control system of each luminaire **12** is connected in series or in parallel by a data link **14** to one or more control desks **15**. Upon actuation by an operator, the control desk **15** sends control signals via the data link **14**, where the control signals are received by the control system of one or more of the luminaires **12**. The control systems of the one or more of the luminaires **12** that receive the control signals may respond by changing one or more of the parameters of the receiving luminaires **12**. The control signals are sent by the control desk **15** to the luminaires **12** using DMX-512, Art-Net, ACN (Architecture for Control Networks), Streaming ACN, or other suitable communication protocol.

The luminaires **12** may include stepper motors to provide the movement for internal optical systems. Examples of such optical systems include gobo wheels, effects wheels, and color mixing (or other color changing) systems, as well as prism, iris, shutter, and lens movement systems.

Some luminaires **12** include an LED based light source designed to collate and direct light through the optical systems installed in the luminaire **12**. The LED light sources along with associated collimating and directing optics are referred to herein as a light engine. Some LED light engines include LEDs of a single color, such as white. Other LED light engines include LEDs of a range of colors, the brightness of each LED or each color of LED controllable individually to provide additive mixing of the LED outputs.

Some LEDs used in such light engines are subject to losing light output (or light intensity) through the life of the LED. As used herein, “light output” means a measurement of light beam intensity such as a measurement proportional to lux, footcandles, or candela. Time, temperature, and operating conditions are some of the factors that may affect the rate of light output loss. The LEDs in heavily used luminaires may lose light output more rapidly than the LEDs in other, more lightly used luminaires in the same system, even though all the luminaires entered use at the same time.

LED luminaires may be calibrated at the time of manufacture such that the light output of each luminaire is substantially the same, for example within an allowed tolerance of 5%. However, when the luminaires undergo different usage patterns, their light outputs are likely to reduce (or degrade) at different rates, and with the passage of time the light output of the luminaires will no longer be substantially the same. Such differences in light output may become visible to a user of the system, but it is difficult for the user to determine what changes to make to the commanded intensities of the individual fixtures to compensate for the differences in light output. In some luminaire systems, such changes are determined through trial and error, or the light output of each fixture is individually measured and recorded. The luminaire system **10** according to the disclosure, enables the user to more easily determine the amount of reduction of light outputs from each of the luminaires in the system and, additionally, to adjust the light outputs from some or all of the luminaires so that they more closely match.

FIG. **2** presents a block diagram of a control system (or controller) **200** for a luminaire **12** according to the disclosure. The control system **200** is suitable for use with the LED light engine and other systems according to the disclosure. The control system **200** is also suitable for controlling other control functions of the luminaire system **10**. The control system **200** includes a processor **202** electrically coupled to a memory **204**. The processor **202** is implemented by hardware and software. The processor **202** may be implemented as one or more Central Processing Unit (CPU) chips, cores (e.g., as a multi-core processor), field-programmable gate arrays (FPGAs), application specific integrated circuits (ASICs), and digital signal processors (DSPs).

The processor **202** is further electrically coupled to and in communication with a communication interface **206**. The communication interface **206** is coupled to, and configured to communicate via, the data link **14**. The processor **202** is also coupled via a control interface **208** to one or more sensors, motors, actuators, controls and/or other devices, which may control one or more of gobo wheels, effects wheels, and color mixing (or other color changing) systems, as well as prism, iris, shutter, and lens movement systems. In the luminaire **12**, a light level sensor that produces an analog or digital signal representing a light intensity measured by the light sensor is electrically coupled to the processor **202** by the control interface **208**. The processor **202** is further electrically coupled to and in communication with an LED light engine **300**. The processor **202** is configured to receive control signals from the data link **14** via the communication interface **206** and, in response, to control the LED light engine and other mechanisms of the luminaire **12**.

The LED light engine **300** may also contain a control system that is similar to the control system **200** and is configured to receive signals from and send signals to the processor **202**. In other embodiments, the LED light engine **300** may include electronic circuitry that is communicatively coupled to the processor **202** by one or more serial links and/or data buses.

The control system **200** is suitable for implementing processes, module control, LED brightness control, and other functionality as disclosed herein, which may be implemented as instructions stored in the memory **204** and executed by the processor **202**. The memory **204** comprises one or more disks and/or solid-state drives and may be used to store instructions and data that are read and written during program execution. The memory **204** may be volatile and/or non-volatile and may be read-only memory (ROM), random access memory (RAM), ternary content-addressable memory (TCAM), and/or static random-access memory (SRAM). Similarly the LED light engine **300** may contain a processor and memory, which includes at least writable non-volatile memory, such as flash memory, which retains its contents when power is removed.

FIG. **3** presents a schematic diagram of an optical system **350** of a luminaire **12** according to the disclosure. The optical system **350** includes an LED light engine **300** (or other LED light source) according to the disclosure. The LED light engine **300** includes a plurality of LED emitters **304** mounted on a substrate **302**. The LED light engine **300** also includes electrical connectors **308**, configured to power the LED emitters **304** and to transmit and receive data. In some embodiments, electronic circuitry **306** is mounted on substrate **302**. In some such embodiments, the electronic circuitry **306** includes a processor, non-volatile memory, and logic components. In such embodiments, the control system **200**, described with reference to FIG. **2**, is suitable for use as the electronic circuitry **306**. In some embodiments, the LED light engine **300** includes a Near-Field Communication (NFC) module **310** that is electrically coupled to the electronic circuitry **306**. NFC is a standard protocol for short-range, low-power wireless communication and may be supported in devices such as cellular phones.

The LED light engine **300** further includes optical devices **314**, configured to receive the light beam **312***a* emitted by LED emitters **304** and to emit a modified light beam **312***b*. In some embodiments, the optical devices **314** include a collimation and homogenization system, as well as optical systems such as gobos, irises, color wheel(s), framing shutters, a variable focus lens system, and other optical devices suitable for use in theatrical luminaires. In embodiments where the optical system is a projection optical system, the modified light beam **312***b* passes through a projection lens system **316** before exiting the luminaire.

A light sensor **318** is positioned in the modified light beam **312***b* at position **318***a*, where it is optically coupled to the LED light engine **300** and configured to measure a light level proportional to the current light output from LED emitters **304**. In other embodiments, the light sensor **318** may be positioned in the light beam **312***a*. In some embodiments, the light sensor **318** is configured to measure only a light level (or light intensity) of the portion of the light beam in which it is positioned.

In other embodiments, the light sensor **318** is configured to measure light level and spectral color information. In some such embodiments, the light sensor **318** comprises a spectrophotometer. In other such embodiments, the light sensor **318** comprises a plurality of light sensors, each covered by a color filter passing light of a selected color band. Such color bands may be selected according to the colors of LEDs comprising the LED light engine **300**. In such embodiments, the light sensor **318** measures not only the physical portion of the light beam in which it is positioned, but also the spectral portion of the beam for which it is filtered.

In some embodiments, the light sensor **318** is mounted on a mechanism such as an arm or a wheel that is configured to move the light sensor **318** to position **318***b*, where it is out of the modified light beam **312***b*. In other embodiments, the light sensor **318** is mounted to one of the optical devices **314**, such as a prism, and configured so that when the prism is inserted into the modified light beam **312***b*, so is the light sensor **318**.

In some embodiments, the light sensor **318** is electrically and communicatively connected to the control system **200** of the luminaire **12**. In other embodiments, the light sensor **318** is electrically and communicatively connected to the electronic circuitry **306** of the LED light engine **300**.

FIG. **4** presents a block diagram of a light measurement and indication procedure **400** according to the disclosure. A luminaire **12** according to the disclosure is configured to determine an amount by which its light output has degraded from when it was first manufactured, and to signal the amount of degradation through a temporary color of the light beam emitted from the luminaire. Such a luminaire according to the disclosure may also be configured to adjust its light output to a level lower than the output it is capable of.

The processor **202** of the control system **200** of the luminaire **12** receives a Measure command in step **402** via data link **14**, the Measure command instructing the luminaire **12** to perform a light level reading. In response to the Measure command, the processor **202** first obtains an intensity signal produced by the light sensor **318**, the signal representing an intensity of a light beam emitted by the LED light engine **300**.

In step **404**, the processor **202** moves the light sensor **318** into the light beam, as described with reference to FIG. **3**. Once the light sensor **318** is in position, in step **406** the processor **202** receives a measurement signal from the light sensor **318** relating to the intensity of the light beam. After receiving the measurement signal from the light sensor **318**, the processor **202** moves the light sensor **318** out of the light beam in step **408**. As described with reference to FIG. **2**, in some embodiments the signal received from the light sensor **318** is a digital signal. In other embodiments, the signal is an analog signal that is digitized in the control interface **208**.

In step **410**, the processor **202** stores current intensity data representing the current intensity of the light beam (as measured by the light sensor **318**) in non-volatile memory of the electronic circuitry **306** of the LED light engine **300** and/or non-volatile memory of the memory **204** of the control system **200**. In step **412**, the processor **202** compares the current intensity data with previous intensity data representing a previously measured light output (or nominal light output) of the LED light engine **300**. Such a previous measurement may have been performed when the LED light engine **300** was first installed into the luminaire **12** in the factory or during a subsequent calibration procedure. The nominal light output is also stored in non-volatile memory of the LED light engine **300**. In step **412**, the processor **202** also calculates a reduction in measured light output from the stored nominal light output of the LED light engine **300**.

In the embodiment disclosed herein, the calculated reduction is expressed as a percentage drop (or reduction) in light output. In other embodiments, the amount of reduction may be expressed in units of light intensity or illuminance, such as lumens, lux, footcandles, or candelas.

In embodiments of the luminaire **12** where the LED light engine **300** comprises LEDs emitting light in a plurality of colors and the light sensor **318** comprises a spectrophotometer or a plurality of filtered light sensors, the measurement obtained in step **406** may include a plurality of measurements, which indicate light output from LEDs having a common color or having colors in a spectral range of colors. In such embodiments, the reduction in measured light output that is calculated in step **412** may be calculated based on all of the plurality of measurements, or may be calculated based only on the color or range of colors that have experienced the largest reduction in light output.

In some embodiments, step **412** includes the processor **202** storing data relating to the calculated percentage drop in measured light output. The data may be stored in non-volatile memory of the electronic circuitry **306** of the LED light engine **300** and/or non-volatile memory of the memory **204** of the control system **200**.

In step **414**, the processor **202** selects an indicator color to represent the calculated amount of reduction in measured light output—in this embodiment, the calculated percentage drop in measured light output. For example, in some embodiments, the indicator color blue is assigned to luminaires whose light output has dropped by 5% or less, the indicator color green is assigned to luminaires whose drop is between 5% and 10%, the indicator color orange is assigned to luminaires whose drop is between 10% and 20%, and the indicator color red is assigned to luminaires whose drop is between 20% and 30%. It should be understood that these indicator colors and ranges are only examples, and any indicator color could be assigned to any range of percentages. Additionally, in other embodiments, the ranges may have different sizes than those in the disclosed embodiment. For example, in some embodiments the ranges may be 0-2%, 3-4%, 5-6%, etc. or 0-5%, 6-10%, 11-15%, etc.

In step **414**, the processor **202** also activates a color mechanism of the optical devices **314** to cause the luminaire **12** to emit a beam of the selected indicator color. In embodiments where the LED light engine **300** includes LEDs of a range of colors, the processor **202** commands the electronic circuitry **306** to differentially power the LED emitters **304** to produce light of the selected indicator color. In some embodiments, in step **414** the processor **202** also activates the pan and/or tilt mechanisms of the luminaire **12** to cause the light beam to be emitted from the luminaire **12** in a preset (or user-selected) direction, such as straight down onto the stage or floor, in order to make identification of the colors simpler for the user.

FIG. **5** presents a system **500** of luminaires according to the disclosure, each indicating the light output of its LED light engine **300** after performing the light measurement and indication procedure **400** described with reference to FIG. **4**. Luminaires **502**, **504**, **506**, and **508** are pointing down towards the stage and projecting light beams **512**, **514**, **516**, and **518**, respectively. The luminaire **502** is projecting a blue light beam **512**, indicating to the user that its light output has a drop that is within 5% of the nominal light output. The luminaire **504** is projecting a green light beam **514** indicating to the user that its light output drop is between 5% and 10% of the nominal light output. The luminaire **506** is projecting an orange light beam **516** indicating to the user that its light output drop is between 10% and 20% of the nominal light output. And, the luminaire **508** is projecting a red light beam **518** indicating to the user that its light output drop is between 20% and 30% of the nominal light output. The user can determine from the color of the light beams **512**, **514**, **516**, and **518** which luminaires are the brightest, and which have lost the most output.

Using this information, the user may move luminaires with a greater drop in light output to positions in the system **500** that the user considers to be less critical to performance of the show. Alternatively, the user may replace luminaires with a greater drop in light output with luminaires having higher light outputs that are not currently being used in the system **500**. The user may additionally or alternatively use light adjustment procedure **600** described below.

FIG. **6** presents a flowchart of a light adjustment procedure **600** according to the disclosure. A luminaire **12** according to the disclosure is configured to receive an Adjust command from a control desk **15** (as described in more detail below with reference to FIGS. **7**A and **7**B) and to adjust the light output of its LED light engine **300** according to an adjustment amount that is specified in the received Adjust command. The adjustment amount is data specifying a total reduction in light output from the nominal light output of the LED light engine **300** when it was factory calibrated.

In step **602**, the processor **202** of the control system **200** of the luminaire **12** receives an Adjust command signal via data link **14**. The Adjust command includes a control parameter value. In step **604**, the processor **202** determines whether the received control parameter is Clear flag data or is an adjustment parameter specifying a total reduction amount to reduce the light output of the LED light engine **300** from its nominal light output when it was factory calibrated. The Clear flag data may be a single bit or may be a multi-bit data value. If the received control parameter is a Clear flag, then in step **606**, the processor sends a command to the LED light engine **300** to operate at full (or unreduced) light output and causes the clearing of any additional reduction amount stored in the LED light engine **300** and/or in the control system **200**.

In step **608**, the processor **202** calculates a current percentage drop in light output of the LED light engine **300** by comparing the most recent measured light output of the LED light engine **300** with the nominal light output of the LED light engine **300** when it was factory calibrated. In embodiments where data relating to a previously calculated percentage drop is stored in non-volatile memory, the current percentage drop may be obtained by reading it from such non-volatile memory, rather than by recalculation.

Also in step **608**, the processor **202** compares the total reduction amount (or total reduction data) specified in the adjustment parameter of the Adjust command with the current percentage drop in light output of the LED light engine **300**. In step **610**, if the total reduction amount specifies a greater reduction than the current percentage drop in light output of the LED light engine **300**, the processor stores the total reduction amount specified in the adjustment parameter in non-volatile memory of the LED light engine **300** and/or the control system **200**.

As will be explained in greater detail with reference to FIGS. **7**A and **7**B, the total reduction amount is a light output selected by a user so that at least some of the luminaires **12** performing the light adjustment procedure **600** will be able to emit light at the specified reduced output level. In step **612**, if the total reduction amount specified in the adjustment parameter indicates a greater reduction than the current percentage drop in light output of the LED light engine **300**, the processor **202** calculates an additional reduction amount that the LED light engine **300** must reduce its light output over its current percentage drop in light output to reach the total reduction amount specified in the adjustment parameter. If the total reduction amount specifies a lesser reduction than the current percentage drop in light output of the LED light engine **300**, no additional reduction amount is required.

Also in step **612**, the processor **202** causes the LED light engine **300** to further reduce its light output by the additional reduction amount (if any) by sending a command signal to the LED light engine **300**. In some embodiments, the processor **202** further causes the LED light engine **300** to store data representing the additional reduction amount (if any) in non-volatile memory. In such embodiments, either by storing the data in non-volatile memory or by sending a separate command signal, the processor **202** also causes the LED light engine **300** to continue reducing its light output by the additional reduction amount (if any) each time the luminaire **12** is powered up from a powered-off state until the processor **202** receives a Clear flag in an Adjust command and commands the LED light engine **300** to return to full power in step **606**.

In step **610** of some embodiments, the processor **202** stores the total reduction amount specified in the adjustment parameter of the Adjust command in non-volatile memory of the electronic circuitry **306** of the LED light engine **300** and/or non-volatile memory of the memory **204** of the control system **200**. In such embodiments, when performing the light measurement and indication procedure **400**, the processor **202** performs an additional step of retrieving the stored total reduction amount, recalculating an amount of additional reduction (if any) that is needed to reach the total reduction amount based on the newly measured current percentage drop in light output. In such embodiments, the processor **202** also causes the LED light engine **300** to further reduce its light output by this newly calculated additional reduction amount (if any), to store data representing this newly calculated additional reduction amount in non-volatile memory, and to continue reducing its light output by this additional reduction amount (if any) each time the luminaire **12** is powered up from a powered-off state until the luminaire **12** is commanded to return to full power in step **606** by receiving a Clear flag in an Adjust command. In step **606** of such embodiments, the processor **202** additionally clears the total reduction amount stored in non-volatile memory.

FIGS. **7**A and **7**B present a system **700** of luminaires **702**, **704**, **706**, and **708** according to the disclosure. In FIG. **7**A, the luminaires have performed the light measurement and indication procedure **400** and are indicating their light outputs. In FIG. **7**B, the luminaires have performed the light adjustment procedure **600** and are indicating their new, adjusted light output levels.

In FIG. **7**A, the luminaires **702**, **704**, **706**, and **708** have received Measure commands and performed the light measurement and indication procedure **400** described with reference to FIG. **4**. The luminaires **702**, **704**, **706**, and **708** are now pointing down towards the stage and projecting light beams **712**, **714**, **716**, and **718** respectively. The indicator colors of the beams show that the luminaires **702** and **706** have output drops within 5% of their nominal light output values, the luminaire **704** has an output drop between 5% and 10%, and the luminaire **708** has an output drop between 10% and 20%.

By observing the indicator colors of the beams, a user of the system **700** is able to determine that the luminaire **708** has a 10% to 20% reduction in light output. In response to this determination, rather than repositioning the luminaires in the lighting system according to their light output, as described above, the user may cause some of the luminaires in the system **700** to reduce their light output as needed in order to more closely match the output of the luminaire **708**.

To obtain this result, the user sends an Adjust command through data link **14** with an adjustment parameter requesting that all luminaires adjust their outputs to produce a reduced light output, as described above with reference to light adjustment procedure **600**. The adjustment parameter specified in the Adjust command may be 10%, 15%, 20%, or any other selected value that the user believes will reduce the visible differences in light outputs between fixtures to an acceptable amount. Each of the luminaire **702**, **704**, **706**, and **708**, responds to this command based upon its current measured light output. In the scenario presented in FIG. **7**B, the specified adjustment parameter is 20% and each luminaire compares its current light output with a 20% drop from nominal light output and introduces a reduction in its own output that is selected to produce an overall 20% drop in light output from nominal.

In the scenario shown in FIGS. **7**A and **7**B, in response to the Adjust command, the luminaire **708** has not made any change to its output, as its light output is already reduced between 10% and 20%. The luminaire **704** has responded by reducing its output from its current 10% drop to a 20% drop, and the luminaires **702** and **706** have responded by reducing their outputs from their current 5% drop to a 20% drop. This adjustment procedure results in the configuration shown in FIG. **7**B, where all the luminaires **702**, **704**, **706**, and **708** produce outputs with more closely matching light beam intensities **722**, **724**, **726**, and **728**.

In some embodiments, after performing the light adjustment procedure **600**, the luminaires re-perform the light measurement and indication procedure **400**. In such embodiments, the indicator colors shown in FIG. **7**B represent the luminaires' reduced light output as measured after application of the adjustment parameter specified in the Adjust command, rather than as calculated during application of the adjustment parameter.

In the scenario described with reference to FIGS. **7**A and **7**B, after performing the light measurement and indication procedure **400**, the user has decided that a 10% to 20% reduction in light output still provides an acceptable level of illumination for the performance being illuminated and has performed light adjustment procedure **600**. In another scenario, one or more luminaires may have a light output that is so low that the user chooses not to reduce all the other luminaires to that level. In such scenarios, the user may combine the two strategies described above: (i) performing the light measurement and indication procedure **400**, (ii) replacing luminaires in the system having the lowest light output, (iii) repeating the light measurement and indication procedure **400**, and (iv) performing light adjustment procedure **600** when the required amount of light output reduction to match luminaires is acceptable.

While only some embodiments of the disclosure have been described herein, those skilled in the art, having benefit of this disclosure, will appreciate that other embodiments may be devised which do not depart from the scope of the disclosure herein. While the disclosure has been described in detail, it should be understood that various changes, substitutions and alterations can be made hereto without departing from the spirit and scope of the disclosure.

What is claimed is:

1. A luminaire, comprising:

a light-emitting diode (LED) light source configured to emit a light beam;

a light sensor, optically coupled to the LED light source and configured to measure a current intensity of a light beam emitted by the LED light source and produce an intensity signal based on the measured intensity; and

a control system electrically coupled to the LED light source, to a non-volatile memory, and to the light sensor, the control system configured to:

receive a Measure command via a data link, the Measure command instructing the luminaire to measure the current intensity of the light beam emitted by the LED light source and, in response to receiving the Measure command, to:

obtain the intensity signal from the light sensor;

store in the non-volatile memory current intensity data representing the intensity signal;

obtain previous intensity data that represents a previously measured intensity of the light beam emitted by the LED light source;

calculate a numeric value representing a percentage by which the current intensity data is less than the previous intensity data;

determine a percentage range that includes the numeric value, where the percentage range is one of a plurality of percentage ranges, each percentage range of the plurality of percentage ranges having an associated beam color; and

cause the luminaire to emit a beam of light having the beam color associated with the percentage range that includes the numeric value; and

receive an Adjust command via the data link, the Adjust command comprising total reduction data representing a total reduction amount for intensity of a reduced intensity light beam emitted by the LED light source and, in response to the Adjust command, to:

obtain a current reduction amount representing an amount by which the current intensity data is less than the previous intensity data;

determine whether the total reduction amount is greater than the current reduction amount; and

cause the LED light source to emit a reduced intensity light beam having a reduced intensity when the total reduction amount is greater than the current reduction amount.

2. The luminaire of claim 1, wherein the control system is configured to control a color changing system to cause the luminaire to emit the beam of light having the beam color associated with the percentage range that includes the numeric value.

3. The luminaire of claim 1, wherein:

the LED light source comprises a plurality of LED emitters; and

the control system is configured to control individual brightness of at least some LED emitters of the plurality of LED emitters to cause the luminaire to emit the beam of light having the beam color associated with the percentage range that includes the numeric value.

4. The luminaire of claim 1, wherein the control system is configured, in further response to the Measure command, to cause the LED light source to emit a reduced intensity light beam having a reduced intensity when a previously received total reduction amount is greater than the current reduction amount.

5. The luminaire of claim 1, wherein:

the LED light source comprises the non-volatile memory, wherein the current intensity data representing the intensity signal is stored in the non-volatile memory of the LED light source; and

the control system is configured to:

obtain the previous intensity data from the non-volatile memory of the LED light source.

6. The luminaire of claim 1, wherein:

the numeric value is a first numeric value;

the percentage range is a first percentage range; and

the control system is configured to, after causing the LED light source to emit the reduced intensity light beam:

obtain a second intensity signal from the light sensor;

obtain reduced current intensity data representing the second intensity signal;

calculate a second numeric value representing a percentage by which the reduced current intensity data is less than the previous intensity data;

determine a second percentage range that includes the second numeric value, where the second percentage range is one of the plurality of percentage ranges; and

cause the luminaire to emit a beam of light having the beam color associated with the second percentage range that includes the second numeric value.

7. The luminaire of claim 1, wherein the control system is configured to move the light sensor into and out of the light beam emitted by the LED light source.

8. The luminaire of claim 1, wherein the control system is configured, in further response to the Adjust command, to:

calculate an additional reduction amount by which the total reduction amount is greater than the current reduction amount; and

cause the LED light source to emit the reduced intensity light beam by causing the LED light source to reduce an intensity of its emitted light beam by the additional reduction amount.

9. The luminaire of claim 8, wherein the control system is configured, in further response to the Adjust command, to:

store the additional reduction amount in the non-volatile memory; and

cause the LED light source to reduce the intensity of its emitted light beam by the additional reduction amount when the luminaire is powered up from a powered-off state.

10. The luminaire of claim 9, wherein the Adjust command comprises Clear Flag data and the control system is configured to, in response to the Clear Flag data:

clear the additional reduction amount stored in the non-volatile memory; and

cause the LED light source to emit the light beam at full intensity and to emit the light beam at full intensity when the luminaire is powered up from a powered-off state.

11. The luminaire of claim 9, wherein the LED light source comprises the non-volatile memory and the additional reduction amount is stored in the non-volatile memory of the LED light source.

12. A luminaire, comprising:

a light-emitting diode (LED) light source configured to emit a light beam;

a light sensor, optically coupled to the LED light source and configured to measure a current intensity of the light beam and produce an intensity signal based on the measured intensity; and

a control system electrically coupled to the LED light source, to a non-volatile memory, and to the light sensor, the control system configured to:

obtain the intensity signal from the light sensor;

store in the non-volatile memory current intensity data representing the intensity signal;

obtain previous intensity data that represents a previously measured intensity of the light beam emitted by the LED light source;

calculate a numeric value representing a percentage by which the current intensity data is less than the previous intensity data;

determine a percentage range that includes the numeric value, where the percentage range is one of a plurality of percentage ranges, each percentage range of the plurality of percentage ranges having an associated beam color; and

cause the luminaire to emit a beam of light having the beam color associated with the percentage range that includes the numeric value.

13. The luminaire of claim 12, wherein the control system is configured to move the light sensor into and out of the light beam emitted by the LED light source.

14. The luminaire of claim 12, wherein the control system is configured to cause the luminaire to emit the beam of light having the beam color associated with the percentage range that includes the numeric value in a preset direction.

15. The luminaire of claim 12, wherein the control system is configured to control a color changing system to cause the luminaire to emit the beam of light having the beam color associated with the percentage range that includes the numeric drop value.

16. The luminaire of claim 12, wherein:

the LED light source comprises a plurality of LED emitters; and

the control system is configured to control individual brightness of at least some LED emitters of the plurality of LED emitters to cause the luminaire to emit the beam of light having the beam color associated with the percentage range that includes the numeric value.

17. The luminaire of claim **12**, wherein:

the LED light source comprises the non-volatile memory, wherein the current intensity data representing the intensity signal is stored in the non-volatile memory of the LED light source; and

the control system is configured to:

obtain the previous intensity data from the non-volatile memory of the LED light source.

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