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Lys et al.

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(54) **SYSTEMS AND METHODS FOR CONTROLLING ILLUMINATION SOURCES**

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(65) **Prior Publication Data**

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Related U.S. Application Data

(63) Continuation-in-part of application No. 09/971,367, filed on Oct. 4, 2001, which is a continuation-in-part of application No. 09/669,121, filed on Sep. 25, 2000, which is a continuation of application No. 09/425,770, filed on Oct. 22, 1999, now Pat. No. 6,150,774, which is a continuation of application No. 08/920,156, filed on Aug. 26, 1997, now Pat. No. 6,016,038, application No. 10/174,499, and a continuation-in-part of application No. 09/870,193, filed on May 30, 2001, now Pat. No. 6,608,453, and a continuation-in-part of application No. 09/215,624, filed on Dec. 17, 1998, now Pat. No. 6,528,934, and a continuation-in-part of application No. 09/213,607, filed on Dec. 17, 1998, now abandoned, and a continuation-in-part of application No. 09/213,189, filed on Dec. 17, 1998, now Pat. No. 6,459,919, and a continuation-in-part of application No. 09/213,581, filed on Dec. 17, 1998, and a continuation-in-part of application No. 09/213,540, filed on Dec. 17, 1998, now Pat. No. 6,720,745, and a continuation-in-part of application No. 09/333,739, filed on Jun. 15, 1999, and a continuation-in-part of application No. 09/815,418, filed on Mar. 22, 2001, now Pat. No. 6,577,080, which is a continuation of application No. 09/213,548, filed on Dec. 17, 1998, now Pat. No. 6,166,460, application No. 10/174,499, and a continuation-in-part of application No.

10/045,604, filed on Oct. 23, 2001, and a continuation-in-part of application No. 09/989,095, filed on Nov. 20, 2001, now Pat. No. 6,717,326, and a continuation-in-part of application No. 09/489,747, filed on Nov. 20, 2001, and a continuation-in-part of application No. 09/989,677, filed on Nov. 20, 2001.

(Continued)

(51) **Int. Cl.**⁷ **G05F 1/00**

(52) **U.S. Cl.** **315/292**; 315/307; 315/318; 315/362; 315/169.3; 711/100; 711/202; 711/221

(58) **Field of Search** 315/292, 307, 315/362, 318, 169.3; 711/100, 115, 202, 212, 221; 345/46, 77, 82

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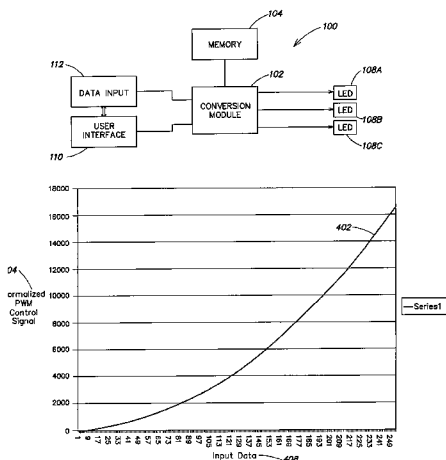
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(57) **ABSTRACT**

Provided are methods and systems for controlling the conversion of data inputs to a computer-based light system into lighting control signals. The methods and systems include facilities for controlling a nonlinear relationship between data inputs and lighting control signal outputs. The nonlinear relationship may be programmed to account for varying responses of the viewer of a light source to different light source intensities.

134 Claims, 5 Drawing Sheets



Related U.S. Application Data

- (60) Provisional application No. 60/071,281, filed on Dec. 17, 1997, provisional application No. 60/068,792, filed on Dec. 24, 1997, provisional application No. 60/078,861, filed on Mar. 20, 1998, provisional application No. 60/079,285, filed on Mar. 25, 1998, provisional application No. 60/090,920, filed on Jun. 26, 1998, provisional application No. 60/277,911, filed on Mar. 22, 2001, provisional application No. 60/242,484, filed on Oct. 23, 2000, provisional application No. 60/252,004, filed on Nov. 20, 2000, provisional application No. 60/262,022, filed on Jan. 16, 2001, provisional application No. 60/262,153, filed on Jan. 17, 2001, provisional application No. 60/268,259, filed on Feb. 13, 2001, and provisional application No. 60/296,219, filed on Jun. 6, 2001.

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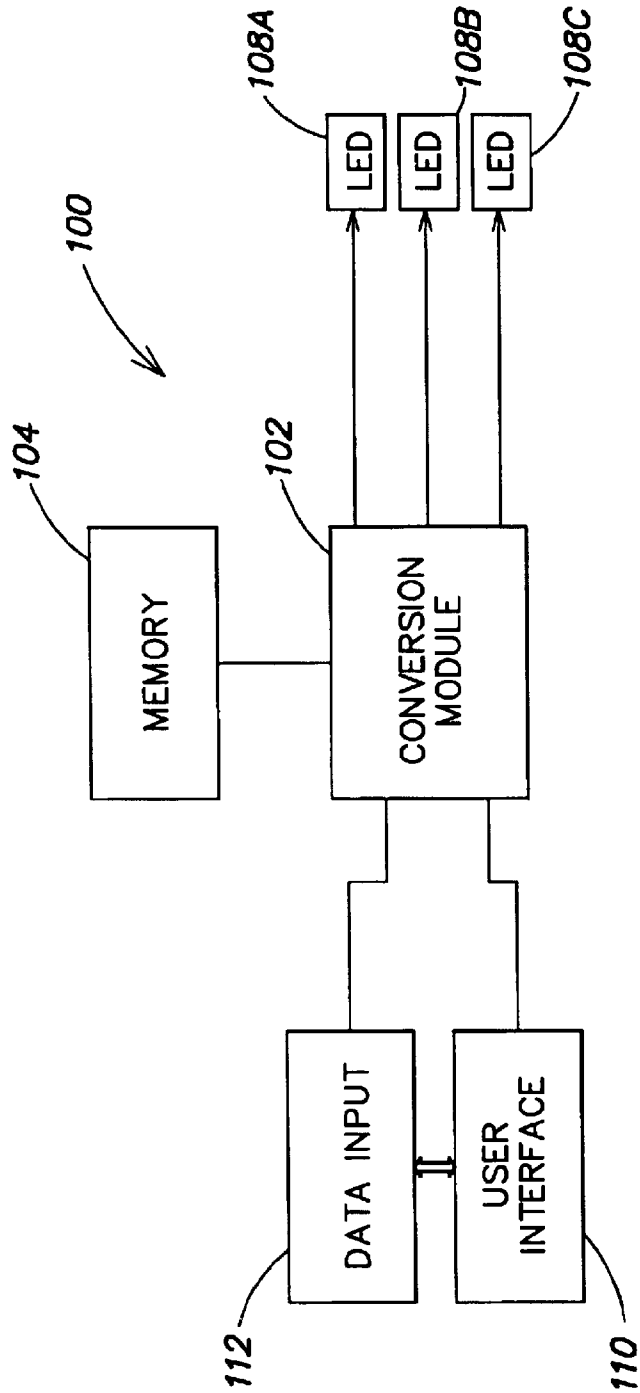


FIG. 1

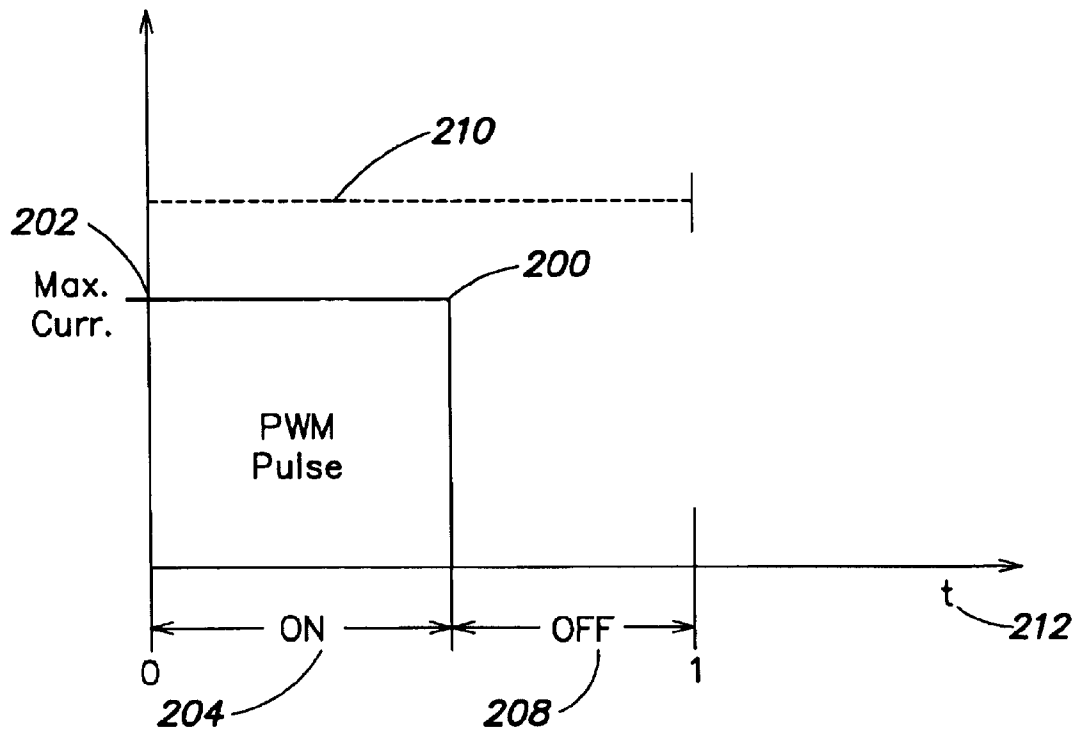


FIG. 2

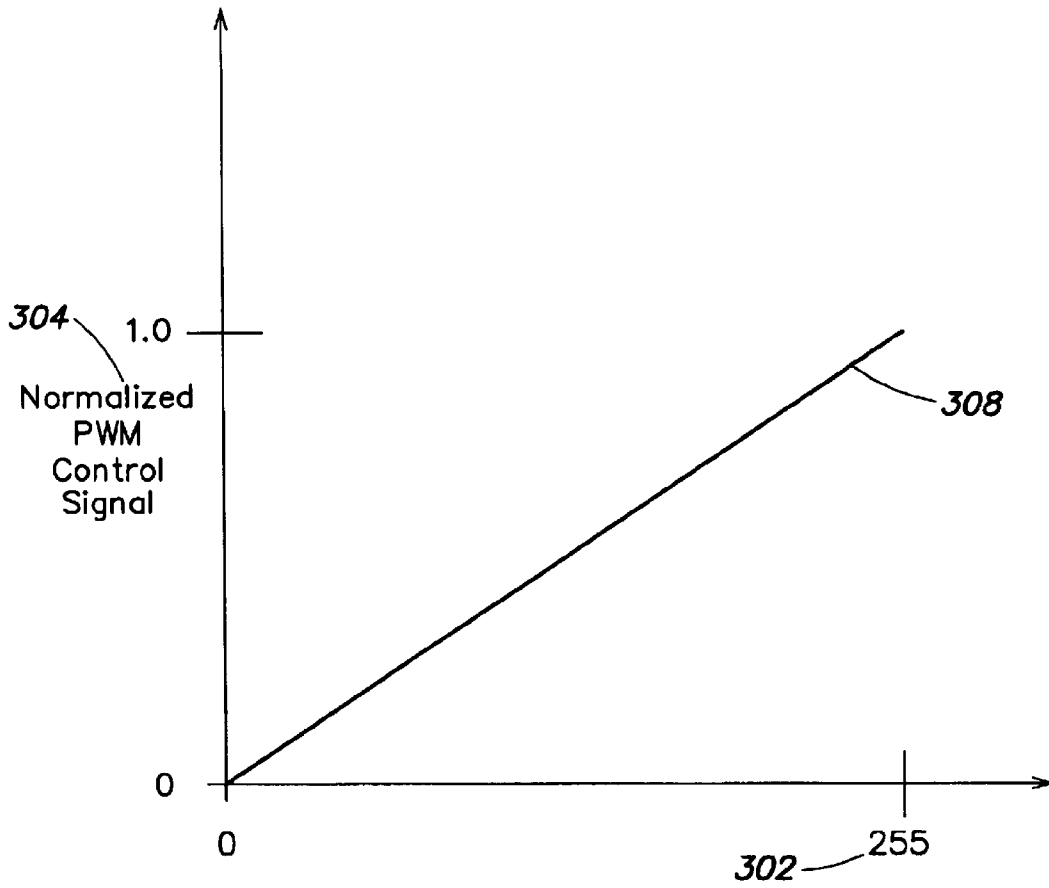


FIG. 3

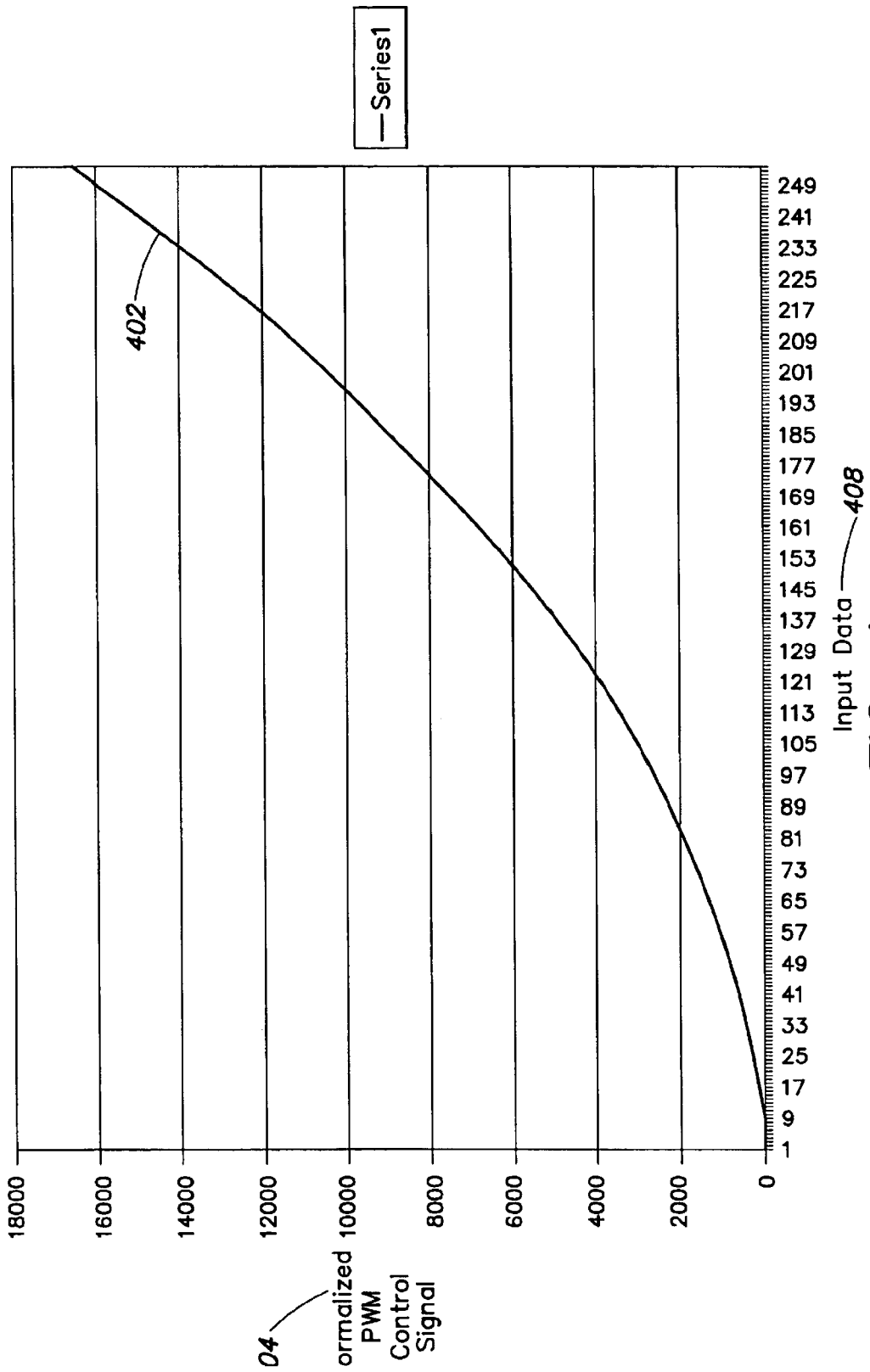


FIG. 4

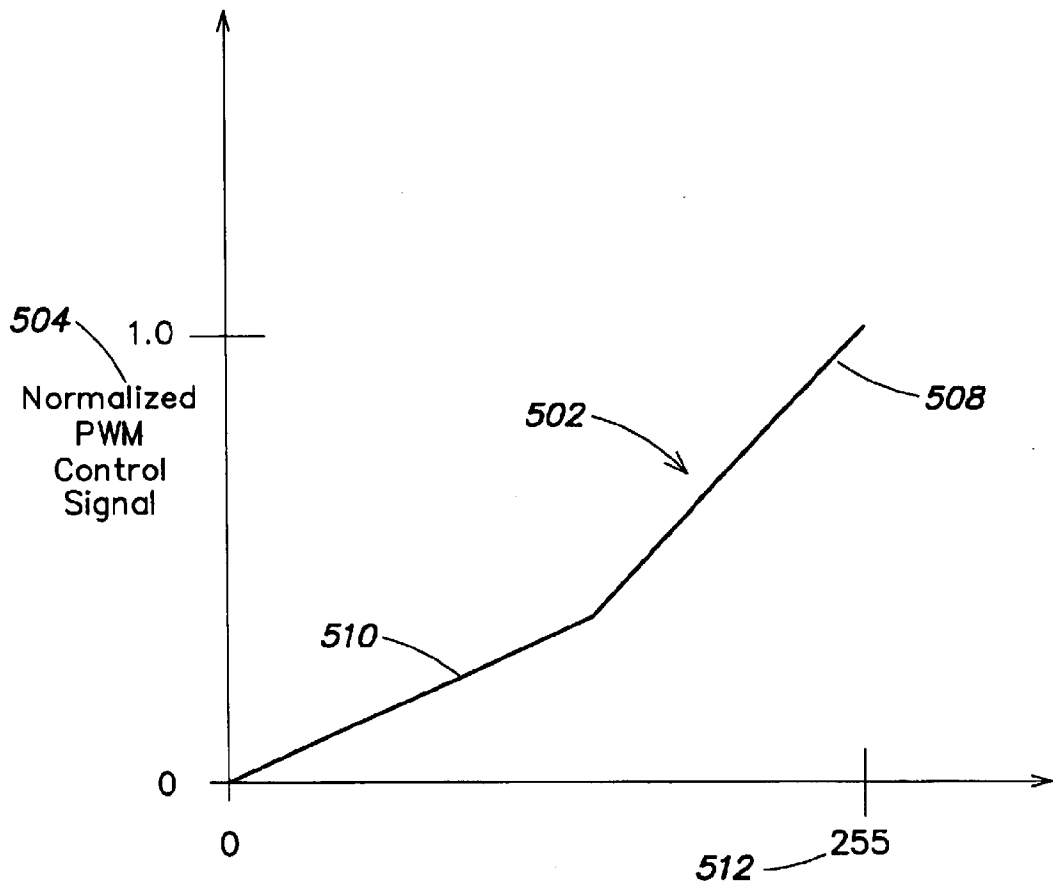


FIG. 5

SYSTEMS AND METHODS FOR CONTROLLING ILLUMINATION SOURCES

CROSS REFERENCE TO RELATED APPLICATIONS

This application is based upon, claims priority to, and incorporates by reference a U.S. Provisional Patent Application Serial No. 60/298,471 entitled Systems and Methods for Controlling Illumination Sources, filed Jun. 15, 2001, naming Ihor Lys, Frederick Morgan, Michael Blackwell and Alfred Ducharme as inventors.

In addition, this patent application claims the benefit under 35 U.S.C. §119(e) of the following U.S. Provisional Applications:

Serial No. 60/301,692, filed Jun. 28, 2001, entitled "Systems and Methods for Networking LED Lighting Systems";

Serial No. 60/328,867, filed Oct. 12, 2001, entitled "Systems and Methods for Networking LED Lighting Systems;" and

Serial No. 60/341,476, filed Oct. 30, 2001, entitled "Systems and Methods for LED Lighting."

This application also claims the benefit under 35 U.S.C. §120 as a continuation-in-part (CIP) of U.S. Non-provisional application Ser. No. 09/971,367, filed Oct. 4, 2001, entitled "Multicolored LED Lighting Method and Apparatus," which is a continuation of U.S. Non-provisional application Ser. No. 09/669,121, filed Sep. 25, 2000, entitled "Multicolored LED Lighting Method and Apparatus," which is a continuation of U.S. Ser. No. 09/425,770, filed Oct. 22, 1999, now U.S. Pat. No. 6,150,774, which is a continuation of U.S. Ser. No. 08/920,156, filed Aug. 26, 1997, now U.S. Pat. No. 6,016,038.

This application also claims the benefit under 35 U.S.C. §120 as a continuation-in-part (CIP) of the following U.S. Non-provisional Applications:

Ser. No. 09/870,193, filed May 30, 2001, now U.S. Pat. No. 6,608,453, entitled "Methods and Apparatus for Controlling Devices in a Networked Lighting System;"

Ser. No. 09/215,624, filed Dec. 17, 1998, now U.S. Pat. No. 6,528,954, entitled "Smart Light Bulb," which in turn claims priority to the following U.S. Provisional Applications:

Serial No. 60/071,281, filed Dec. 17, 1997, entitled "Digitally Controlled Light Emitting Diodes Systems and Methods;"

Serial No. 60/068,792, filed Dec. 24, 1997, entitled "Multi-Color Intelligent Lighting;"

Serial No. 60/078,861, filed Mar. 20, 1998, entitled "Digital Lighting Systems;"

Serial No. 60/079,285, filed Mar. 25, 1998, entitled "System and Method for Controlled Illumination;" and

Serial No. 60/090,920, filed Jun. 26, 1998, entitled "Methods for Software Driven Generation of Multiple Simultaneous High Speed Pulse Width Modulated Signals;"

Ser. No. 09/213,607, filed Dec. 17, 1998, now abandoned entitled "Systems and Methods for Sensor-Responsive Illumination;"

Ser. No. 09/213,189, filed Dec. 17, 1998, now U.S. Pat. No. 6,459,919, entitled "Precision Illumination;"

Ser. No. 09/213,581, filed Dec. 17, 1998, entitled "Kinetic Illumination;"

Ser. No. 09/213,540, filed Dec. 17, 1998, now U.S. Pat. No. 6,720,745, entitled "Data Delivery Track;"

Ser. No. 09/333,739, filed Jun. 15, 1999, entitled "Diffuse Illumination Systems and Methods;"

Ser. No. 09/815,418, filed Mar. 22, 2001, now U.S. Pat. No. 6,577,080, entitled "Lighting Entertainment System," which is a continuation of U.S. Ser. No. 09/213,548, filed Dec. 17, 1998, now U.S. Pat. No. 6,166,496;

Ser. No. 10/045,604, filed Oct. 23, 2001, entitled "Systems and Methods for Digital Entertainment;" which in turn claims priority to the following U.S. Provisional Applications:

Serial No. 60/277,911, filed Mar. 22, 2001, entitled "Systems and Methods for Digital Entertainment;"

Serial No. 60/242,484, filed Oct. 23, 2000, entitled, "Systems and Methods for Digital Entertainment;"

Serial No. 60/262,022, filed Jan. 16, 2001, entitled, "Color Changing LCD Screens;"

Serial No. 60/262,153, filed Jan. 17, 2001, entitled, "Information Systems;"

Serial No. 60/268,259, filed Feb. 13, 2001, entitled, "LED Based Lighting Systems for Vehicles;"

Ser. No. 09/989,095, filed Nov. 20, 2001, entitled "Automotive Information Systems," which in turn claims priority to the following U.S. Provisional Applications:

Serial No. 60/252,004, filed Nov. 20, 2000, entitled, "Intelligent Indicators;" and

Serial No. 60/296,219, filed Jun. 6, 2001, entitled, "Systems and Methods for Displaying Information;"

Ser. No. 09/989,747, filed Nov. 20, 2001, entitled "Packaged Information Systems;" and

Ser. No. 09/989,677, filed Nov. 20, 2001, entitled "Information Systems."

In addition, this patent application claims the benefit under 35 U.S.C. §119(e) of the following U.S. Provisional Applications: Ser. No. 60/301,692, filed Jun. 28, 2001, entitled "Systems and Methods for Networking LED Lighting Systems"; Serial No. 60/328,867, filed Oct. 12, 2001, entitled "Systems and Methods for Networking LED Lighting Systems;" and Serial No. 60/341,476, filed Oct. 30, 2001, entitled "Systems and Methods for LED Lighting."

This application also claims the benefit under 35 U.S.C. §120 as a continuation-in-part (CIP) of U.S. Non-provisional application Ser. No. 09/971,367, filed Oct. 4, 2001, entitled "Multicolored LED Lighting Method and Apparatus," which is a continuation of U.S. Non-provisional application Ser. No. 09/669,121, filed Sep. 25, 2000, entitled "Multicolored LED Lighting Method and Apparatus," which is a continuation of U.S. Ser. No. 09/425,770, filed Oct. 22, 1999, now U.S. Pat. No. 6,150,774, which is a continuation of U.S. Ser. No. 08/920,156, filed Aug. 26, 1997, now U.S. Pat. No. 6,016,038.

This application also claims the benefit under 35 U.S.C. §120 as a continuation-in-part (CIP) of the following U.S. Non-provisional applications: Ser. No. 09/870,193, filed May 30, 2001, entitled "Methods and Apparatus for Controlling Devices in a Networked Lighting System;" Ser. No. 09/215,624, filed Dec. 17, 1998, entitled "Smart Light Bulb;" Ser. No. 09/213,607, filed Dec. 17, 1998, entitled "Systems and Methods for Sensor-Responsive Illumination;" Ser. No. 09/213,189, filed Dec. 17, 1998, entitled "Precision Illumination;" Ser. No. 09/213,581, filed Dec. 17, 1998, entitled "Kinetic Illumination;" Ser. No. 09/213,540, filed Dec. 17, 1998, entitled "Data Delivery Track;" Ser. No. 09/333,739, filed Jun. 15, 1999, entitled "Diffuse Illumination Systems and Methods;" Ser. No. 09/815,418, filed Mar. 22, 2001, entitled "Lighting Entertainment System," which

is a continuation of U.S. Ser. No. 09/213,548, filed dec. 17, 1998, now U.S. Pat. No. 6,166,496; Ser. No. 10/045,604, filed Oct. 23, 2001, entitled "Systems and Methods for Digital Entertainment;" Ser. No. 09/989,095, filed Nov. 20, 2001, entitled "Automotive Information Systems;" Ser. No. 09/989,747, filed Nov. 20, 2001, entitled "Packaged Information Systems;" and Ser. No. 09/989,677, filed Nov. 20, 2001, entitles "Information Systems."

This application also claims the benefit under 35 U.S.C. §120 of each of the following U.S. Provisional Applications, as at least one of the above-identified U.S. Non-provisional Applications similarly is entitled to the benefit of at least one of the following Provisional Applications: Serial No. 60/071,281, filed dec. 17, 1997, entitled "Digitally Controlled Light Emitting Diodes Systems and Methods;" Serial No. 60/068,792, filed dec. 24, 1997, entitled "Multi-Color Intelligent Lighting;" Serial No. 60/078,861, filed Mar. 20, 1998, entitled "Digital Lighting Systems;" Serial No. 60/079,285, filed Mar. 25, 1998, entitled "System and Method for Controlled Illumination;" Serial No. 60/090,920, filed Jun. 26, 1998, entitled "Methods for Software Driven Generation of Multiple Simultaneous High Speed Pulse Width Modulated Signals;" Serial No. 60/277,911, filed Mar. 22, 2001, entitled "Systems and Methods for Digital Entertainment;" Serial No. 60/242,484, filed Oct. 23, 2000, entitled, "Systems and Methods for Digital Entertainment;" Serial No. 60/252,004, filed Nov. 20, 2000, entitled, "Intelligent Indicators;" Serial No. 60/262,022, filed Jan. 16, 2001, entitled, "Color Changing LCD Screens;" Serial No. 60/262,153, filed Jan. 17, 2001, entitled, "Information Systems;" Serial No. 60/268,259, filed Feb. 13, 2001, entitled, "LED Based Lighting Systems for Vehicles;" and Serial No. 60/296,219, filed Jun. 6, 2001, entitled, "Systems and Methods for Displaying Information."

Each of the foregoing applications is hereby incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This disclosure relates to the field of illumination, and more particularly to the field of illumination sources controlled by a computer.

2. Description of the Related Art

LED lighting systems are used in a variety of applications to provide light, including for illumination, display and indication. One method of operating an LED in these systems is through pulse width modulation (PWM). That is, the current through the LED is fixed at a desired level and the duration the LED is activated varies to generate the appearance that the LED is dimming or increasing in intensity. The human eye integrates light it receives, and if the LED is on for a very short period of time, the LED appears dim even though the LED was operated at its optimum current. Another method of operating LEDs is through analog techniques where the amplitude of either the voltage or the current is modulated to change the light output of the LEDs. There are other techniques for operating LEDs, for example amplitude modulation of a pulsed signal or other techniques for modulating the power dissipated by the LED per unit of time. Certain techniques for the computer control of LEDs to generate illumination are disclosed in U.S. Pat. No. 6,016,038, which is hereby incorporated by reference.

One of the problems with changing the apparent or actual light output of an LED from a low light level to a higher light level is that the output changes may appear as stepped function rather than a smooth transition. This is common to

other light sources, besides LEDs, as well. This is because the eye is highly sensitive to discrete changes in light output at low light levels. When the light is changed from one low light output level to another low light output level, the eye perceives the change as stepped. It would be useful to provide a lighting system that reduced the apparent stepped transition in light output from such a lighting system.

SUMMARY

Provided herein are methods and systems for providing control signals for lights and light systems. The methods and systems include methods and systems for accessing a control module for generating an output control signal to control the output of a light, providing a conversion module for converting a data input to the output control signal, determining the response of a viewer to different levels of output of the light, and converting data inputs to output control signals in a nonlinear relationship to account for the response of a viewer to different levels of output of the light.

The methods and systems can include relationships in which the changes in the output control signal are smaller at low levels of light output and larger at higher levels of light output and methods and systems wherein the ratio of the output control signal to the data input increases continuously throughout the intensity range of the light.

The relationship between the data input and the output control signal can be a continuously increasing relationship. The relationship between the data input and the output control signal can be based on a function, such as an exponential function, a quadratic function, a squared function, a cubed function or other function.

The light may be an LED, and the output control signal can be a pulse width modulation (PWM) signal.

The ratio of the output control signal to the data input can increase continuously throughout the intensity range of the light.

The relationship between the data input and the output control signal can comprise multiple relationships, such as two linear relationships of different slopes or a linear relationship and a non-linear relationship. Where two linear relationships are used, one can apply to lower levels of data input with a lower slope than a second relationship that applies to higher levels of data input and that has a higher slope. Where there is a linear relationship and a nonlinear relationship, they can apply to different data ranges, and the nonlinear relationship can be based on a function, such as an exponential function, a quadratic function, a squared function, a cubed function, or any other function.

The relationships used herein can account for the responses viewers to lights and illumination sources, such as those having LEDs of colors of different frequency ranges, such as red, green, blue, white, UV, IR, and amber LEDs. In embodiments the viewer response can be calculated based on reflected illumination, such as that reflected from a white surface, a wall, a colored surface, a mirror, a lens, or any other element. The relationships can be used to account for viewer responses to color-mixed light output. The color-mixed output can come from LEDs, such as red, green, blue, white, UV, IR, and/or amber LEDs.

The methods and systems disclosed herein also include methods and systems for providing a lighting control signal and may include methods and systems for providing a processor, providing memory, providing a light, providing a data input, providing a user interface, and using the processor to access a table stored in the memory to determine a control signal for the light, wherein the processor accesses

the table to determine the control signal and wherein the table stores a nonlinear relationship between the data input and the control signal. The table can store a function that defines the nonlinear relationship. A user interface can allow a user to modify a parameter of the function, such as a PWM parameter and/or a scaling factor. In embodiments the user interface can allow a user to modify the table or select one or more tables from a plurality of tables. A function can define the relationship between the data input and the control signal, and can cause the output signal to increase continually in increasing amounts throughout the range of the data input.

Also provided herein are methods and systems of providing a conversion module having a processor for applying a nonlinear relationship to convert a data input to an output control signal for the light to account for the response of a viewer of the light to varying light levels.

BRIEF DESCRIPTION OF THE FIGURES

The following figures depict certain illustrative embodiments of the invention in which like reference numerals refer to like elements. These depicted embodiments are to be understood as illustrative of the invention and not as limiting in any way.

FIG. 1 is a schematic diagram depicting components for a system for controlling the output of a light system that is capable of receiving a data input.

FIG. 2 is a schematic diagram of elements of a pulse width modulation control signal.

FIG. 3 illustrates a linear relationship between a data input and a lighting control output signal.

FIG. 4 illustrates a non-linear relationship between a data input and a lighting control output signal.

FIG. 5 illustrates a two-part relationship between a data input and a lighting control output signal.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

The description below pertains to several illustrative embodiments of the invention. Although many variations of the invention may be envisioned by one skilled in the art, such variations and improvements are intended to fall within the compass of this disclosure. Thus, the scope of the invention is not to be limited in any way by the disclosure below.

Referring to FIG. 1, in an embodiment, a lighting system 100 may generate light in response to control signals that are generated upon receipt of data. In embodiments the lighting system 100 includes one or more lights 108A, 108B, 108C, which may be LEDs of different colors, such as white, red, green, blue, amber, UV, IR or the like. In embodiments the LEDs 108 light at different intensities in response to control signals, currents, or the like, such as pulse width modulation (PWM) control signals. The lighting system 100 optionally has a data input 112. As data inputs 112, such systems may receive the data via a network, an interface card, a USB facility, a serial data facility, a wireless data facility, a radio frequency facility, a receiver, a telecommunications facility, a power line, a wire, a circuit, a bus, or through computer-based methods, such as from internal or external memory 104, for example. Several examples of LED-based lighting systems can be found in U.S. Pat. Nos. 6,016,038 and 6,166,496, which are hereby incorporated by reference. The receipt of data into a lighting system can take many forms and it should be understood that the present invention is not limited to the methods described herein.

Referring still to FIG. 1, upon receipt of data, the lighting system 100 may change the light generated by the lighting system 100. For example, at a given time the lighting system may be generating a low level of light, then at a later time new data may indicate that the level should be increased or decreased.

In an embodiment a lighting system 100 may have a conversion module 102 that converts a data signal or input 112 into a given control signal or signals to control the lights 108. After receipt of the data 112, the output signal of the conversion module 102 may be a converted signal that would be used to control the LED or plurality of LEDs. The conversion module 102 may consist of a processor, as well as various hardware, firmware and software elements that are conventionally used to convert data inputs 112 into control signals or currents that are sent to the lights 108. In embodiments, the light system 100 may include a user interface 110, which may be used to control the data inputs 112 or may be used to program or otherwise control the conversion module 102. Thus, the conversion module 102 may be programmable, so that the conversion of a given data input 112 to a control signal can be varied by a user over time. The user interface 110 may be a computer, a dial, a switch, a power-cycle facility, or a wide variety of different kinds of user interfaces. In an embodiment the user interface 110 is a user interface for a computer, such as a keypad, mouse and display.

In an embodiment, the control signal can be a pulse width modulation (PWM) control signal and the conversion module can be a table that correlates particular data inputs to particular PWM control signal outputs that are sent to the lights 108.

Referring to FIG. 2, in PWM, the output of a current source is divided over a period of time 212 into PWM pulses 200, which have an "on" phase 204 and an "off" phase 208. Thus, for a device that runs at an optimal current 202, the PWM signal delivers that current but is only on for a portion of a potential pulse time 210. Over many cycles of pulse time 210, PWM-driven devices effectively "integrate" the "on" phases 204 and produce an output that reflects the ratio of "on" time to "off" time. Light sources such as LEDs are an example of a device that can be driven by a PWM signal. A given pulse width of PWM signal is "integrated" by the eye to achieve perceived light of a wide range of apparent intensities, even though the current to the light source is either at the desired level or is turned off at any point in time. Many variants of PWM are known to those of ordinary skill in the art and are described in the pending applications that are referenced above and incorporated by reference herein.

In a PWM-based system, a conventional table serving as a conversion module 102 would provide a linear correlation between the data and the output PWM control signals. For example, in an 8-bit system, the data may comprise 256 steps (2⁸) and the table would contain 256 linearly progressing PWM control signals, or data indicative of such control signals. As a result, the system can control a given LED or plurality of LEDs with 256 steps of resolution with an 8-bit system. FIG. 3 illustrates the relationship 308 of received data 302 to the activation duration of a PWM signal 304 of a conventional system. One can readily observe the linear nature of the relationship 308.

In certain applications, the linear relationship 308 has a tendency to generate perceptible stepping when data changes are made in the lower values. The eye is very sensitive to illumination changes at low levels of illumination intensity, and, as a result, changes in the illumination

conditions at those intensity levels may cause perceived flicker or stepping. A system according to the principles of the present invention may have a non-linear relationship between the data received and the PWM control signal duration. FIG. 4 illustrates such a relationship 402. In an embodiment, the relationship 402 may be relatively flat in the low data values with increasing slope as the data values increase. In an embodiment, the slope may continuously increase throughout the intensity range of the light 108. This increasing non-linear relationship 402 generates much finer control over the low LED intensities and as a result reduces the perceived flicker of the LEDs. This relationship also generates less resolution in the higher data values such that the range of LED intensities can still be as large as the linear relationship 308. For example, an LED system with a non-linear relation 402 may be used to provide high resolution control over low light levels but still allow the system to achieve high light levels. This gives the appearance of an overall higher resolution system. This is due in part because the lower resolution changes in the upper portion of the curve 402 do not result in perceived flicker due to the higher illumination levels. A user may feel as though the 8-bit system has been converted into a 16-bit system. In an embodiment, a non-linear relationship 402 may be used to increase the overall range of control while maintaining acceptable performance throughout the entire operating range. For example, the PWM range may appear to span 4095 steps (12 bit resolution), 16383 steps (14 bits) or other resolution with only 255 (8-bit) data input. It should be understood that other data and other PWM resolutions may be used and these illustrative embodiments should not be used to limit the present invention in anyway. FIG. 4 illustrates a non-linear relationship 402 with input data 408 represented on the horizontal axis (represented as 8 bit data) and 14 bit control data, 404, represented on the vertical axis, with higher resolution of output data at lower values of input data. Thus, it is possible to generate values of less than one for low channels of input data.

The relationship 402 may be an exponential, quadratic, squared, cubed or other non-linear function that increases the intensity at a greater rate with increasing light intensities. The relationship does not need to be a continuous function and may be two or more linear functions. For example, referring to FIG. 5, a relationship 502 between input data 512 and output control signals 504 may consist of a first linear function 510 and a second linear function 508. The first linear function 510 may have a small slope and be used to generate the relationship between the variables at low data levels. The second linear function 508 may be used, with a higher slope, to form the relationship in the higher portion of the curve.

In other embodiments, the relationship between input data and output control signals may be a combination between linear and non-linear functions or any other combination of functions or tables.

There are many ways of generating the non-linear relationship 402 and it should be understood that the relationship is not limited to the specific embodiments illustrated in FIG. 4. In an embodiment, the non-linear relationship may be a function that is generated on a conversion module 102 using a processor (illustrated in FIG. 1). The conversion module 102 may generate a PWM signal based on a function wherein the received data is a variable within the function. In another embodiment, the PWM signals, or data indicative of such signals, may be stored in a table or tables and, when data is received, the conversion module 102 may select a PWM signal that corresponds with the received data from

the table and then communicate the signal to the lights 108. In an embodiment, the information or data contained in the table may be used by the processor of the conversion module 102 to generate a PWM signal or other control signal. In another embodiment, the data may be sent to the lighting device and the data may indicate how a PWM signal should be adjusted or generated before being communicated to an LED. It should be appreciated that there are many systems and methods that may be used to generate the non-linear effects described herein and the present invention is not limited in any way by the illustrative embodiments presented herein. In another embodiment, a code may be communicated to a conversion module 102 such that the conversion module 102 selects another table or function from memory 104 upon receipt of new data. This new table selection or function selection may then be used for the selection of PWM signals. In an embodiment, the code may also be used to provide other tables, functions, or modifications thereof and the code may be stored in non-volatile memory such that subsequently received data can be interpreted through the newly coded parameters.

Referring again to FIG. 1, FIG. 1 illustrates a lighting system 100 according to the principles of the present invention. The system 100 may include a conversion module 102, memory 104, at least one light 108A, data input 112 and a user interface 110. The conversion module 102 may be a processor that is used to generate a function and/or select a value from a table that is stored in memory 104 and communicate control signals to the at least one light 108A. In an embodiment, the lighting system may also include a user interface 110. The user interface 110 may be used to modify a relationship 402, a function or a table. The user interface may also be used to select a table or function, for example. A light system 100 according to the principles of the present invention may be provided with factory-installed functions or tables and the user interface may be used to modify such settings. In an embodiment, the modification may be accomplished through adjustable scaling factors that are used to modify the relationship 402. For example, a lighting system may include a table with PWM signals as well as a scaling factor. The scaling factor may be used to modify the contents of all or a portion of the table. When shipped from the factory, the scaling factor may be set to unity but the scaling factor may be adjustable. In an embodiment, the scaling factor may be adjusted by communicating a new scaling factor to the data input 112. In an embodiment, the new scaling factor may replace the old scaling factor or the new scaling factor may be used to adjust the old scaling factor. For example, the system may take the new scaling factor and multiply it by the old scaling factor and the resultant factor may be used to adjust the contents of a table. The new scaling factor may be permanently or temporarily stored in the lighting system 100. In an embodiment, the lighting system 100 may receive data indicating which PWM signal to select from a table and the data may also contain a scaling factor. In an embodiment, a lighting system may download scaling factors, tables, functions or other information to change the relationship 402 through data input 112.

In an embodiment, a lighting system 100 may include two or more independently controllable lights 108A and 108B. The lights 108A and 108B may be LEDs that produce different colors when energized. In another embodiment, a lighting system may include three different colored individually controllable lights 108A, 108B, and 108C (for example, red, green and blue LEDs, respectively). In an embodiment, one or more of these may be combined with

one or more white LEDs **108**, such as white LEDs of different color temperature ranges. Each of these LEDs **108A**, **108B**, and **108C** may be controlled by the processor of the conversion module **102** and the processor may select control signals to be communicated to the lights **108A**, **108B**, and **108C** through a table or function, as described herein.

In an embodiment, the table may be comprised of control signal data and the conversion module **102** may generate control signals from the control signal data. In an embodiment, such a system, with two or more lights **108** operated in a non-linear fashion, may be used to produce color-changing effects. The non-linearity of the system may improve the color mixing abilities of the system. For example, with a linear relationship **308** used to control the separate LEDs, the color mixing at high light levels may not work as well as at the lower light levels. This is due in part to the fact that at high intensities a linearly progressing step does not change the light output by enough to visually change the illumination conditions or the color of the emitted light as perceived by the eye. In order to cause a perceptible change in the illumination or color of the emitted light, at the higher light levels, the control signal may need to be changed by more than a linearly progressing step. A non-linear relationship **402**, according to the principles of the present invention, increases the difference in control signal steps at the high light levels and as a result may provide perceptible color or illumination changes with fewer steps. In an embodiment, a non-linear relationship **402** may result in higher resolution at the low light levels to minimize the apparent snapping from one light level to the next as well as provide for lower resolution in the higher light levels to provide perceptible color or illumination changes with fewer steps.

In an embodiment, a program may be executed that is associated with the conversion module **102** wherein data (such as in an 8-bit input system that provides 256 steps of data) is communicated to the input **112** of a lighting system **100** and this data causes the conversion module **102** to generate, either by table or function or by other methods, a control signal to at least one light **108A**. The relationship between the data and the control signals may be non-linear **402** such that high resolution is provided at low light levels and low resolution is provided at high light levels. In an embodiment three channels of such data may be communicated to the conversion module **102** through input **112** and the conversion module **102** may generate three lighting control signals in response. A system according to the principles of the present invention may be used to provide illumination, white illumination of a varying color temperature, colored illumination, color changing effects or other illumination or display conditions. A lighting system **100** may control the individual lights **108**, such as LEDs, with a relationship **402** as illustrated in FIG. 4, for example. The control signals communicated to each of the lights **108A**, **108B** and **108C** in the lighting system **100** may be generated using the same table, set of tables or functions or may be controlled through a different table, set of tables or function.

While many of the embodiments described herein relate to LED systems, the systems and methods taught by the present invention may relate to other illumination sources as well. As used herein, the term "LED" means any system that is capable of receiving an electrical signal and producing a color of light in response to the signal. Thus, the term "LED" should be understood to include light emitting diodes of all types, light emitting polymers, semiconductor dies that

produce light in response to current, organic LEDs, electro-luminescent strips, and other such systems. In an embodiment, an "LED" may refer to a single light emitting diode having multiple semiconductor dies that are individually controlled. It should also be understood that the term "LED" does not restrict the package type of the LED. The term "LED" includes packaged LEDs, nonpackaged LEDs, surface mount LEDs, chip on board LEDs and LEDs of all other configurations. The term "LED" also includes LEDs packaged or associated with material (e.g. a phosphor) wherein the material may convert energy from the LED to a different wavelength.

While many of the illustrative embodiments described herein relate to PWM control, the systems and methods taught by the present invention may relate to other illumination control techniques as well. Thus, the term "pulse width modulation" or "PWM" should be understood to encompass all control techniques used in modulating the intensity of an illumination source. For example, when controlling an LED with analog voltage control, the control signal may be changed to change the illumination from the LED and the rate at which this control signal is changed may be accomplished using systems or methods taught by the present invention.

An LED system is one type of light or illumination source. As used herein "light" and "illumination source" should each be understood to include all light and illumination sources, including LED systems, as well as incandescent sources, including filament lamps, pyro-luminescent sources, such as flames, candle-luminescent sources, such as gas mantles and carbon arc radiation sources, as well as photo-luminescent sources, including gaseous discharges, fluorescent sources, phosphorescence sources, lasers, electro-luminescent sources, such as electro-luminescent lamps, light emitting diodes, and cathode luminescent sources using electronic saturation, as well as miscellaneous luminescent sources including galvano-luminescent sources, crystallo-luminescent sources, kine-luminescent sources, thermo-luminescent sources, triboluminescent sources, sonoluminescent sources, and radioluminescent sources. Illumination sources may also include luminescent polymers capable of producing primary colors.

The term "illuminate" should be understood to refer to the production of a frequency of radiation by an illumination source. The term "color" should be understood to refer to any frequency of radiation within a spectrum; that is, a "color," as used herein, should be understood to encompass frequencies not only of the visible spectrum, but also frequencies in the infrared and ultraviolet areas of the spectrum, and in other areas of the electromagnetic spectrum.

All articles, patents, patent applications and other documents mentioned are hereby incorporated by reference. While the invention has been disclosed in connection with the embodiments shown and described in detail, various equivalents, modifications, and improvements will be apparent to one of ordinary skill in the art from the above description.

What is claimed is:

1. A method of providing a control signal for a light, comprising:

- accessing a control module for generating an output control signal to control the output of a light;
- providing a conversion module for converting a data input to the output control signal;
- determining the response of a viewer to different levels of output of the light; and

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converting data inputs to output control signals in a nonlinear relationship to account for the response of a viewer to different levels of output of the light.

2. A method of claim 1, wherein changes in the output control signal are smaller at low levels of light output and larger at higher levels of light output.

3. A method of claim 1 wherein the ratio of the output control signal to the data input increases continuously throughout the intensity range of the light.

4. A method of claim 1 wherein the relationship between the data input and the output control signal is a continuously increasing relationship.

5. A method of claim 1 wherein the relationship between the data input and the output control signal is based on a function selected from the group consisting of an exponential function, a quadratic function, a squared function, and a cubed function.

6. A method of claim 1, wherein the light is an LED.

7. A method of claim 1, wherein the output control signal is a pulse-width-modulated control signal.

8. A method of claim 7, wherein the ratio of the output control signal to the data input increases continuously throughout the intensity range of the light.

9. A method of claim 7 wherein the relationship between the data input and the output control signal is based on a function selected from the group consisting of an exponential function, a quadratic function, a squared function, and a cubed function.

10. A method of claim 7 wherein the relationship between the data input and the output control signal comprises at least two relationships.

11. A method of claim 10, wherein the two relationships are two linear relationships of different slopes.

12. A method of claim 11, wherein the first relationship applies to lower levels of data input and has a lower slope than a second relationship that applies to higher levels of data input and has a higher slope.

13. A method of claim 10, wherein the two relationships comprise a first linear relationship that applies to a portion of the data input range and a second nonlinear relationship that applies to a different portion of the data range.

14. A method of claim 13 wherein the nonlinear relationship is based on a function selected from the group consisting of an exponential function, a quadratic function, a squared function, and a cubed function.

15. A method of claim 7, wherein the light is an LED.

16. A method of claim 1, wherein the range of output signals is as large as the range for a linear conversion module.

17. A method of claim 1, wherein the nonlinear relationship accounts for the response of a viewer to an illumination source having LEDs of colors of at least two different frequency ranges.

18. A method of claim 17, wherein the LEDs are selected from the group consisting of red, green, blue, white, UV, IR, and amber LEDs.

19. A method of claim 1, wherein the nonlinear relationship accounts for the response of a viewer of reflected illumination.

20. A method of claim 1, wherein the nonlinear relationship accounts for the response of a viewer of the output of a light source that is a color-mixed light output.

21. A method of claim 20, wherein the light source is an LED light source and wherein the LED is selected from the group consisting of red, green, blue, white, UV, IR, and amber LEDs.

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22. A method of providing a lighting control signal, comprising:

providing a processor;

providing memory;

providing a light;

providing a data input;

providing a user interface; and

using the processor to access a table stored in the memory to determine a control signal for the light, wherein the processor accesses the table to determine the control signal and wherein the table stores a nonlinear relationship between the data input and the control signal.

23. A method of claim 22, wherein the table stores a function that defines the nonlinear relationship.

24. A method of claim 22, wherein the user interface permits a user to modify a parameter of the function.

25. A method of claim 24, wherein the parameter is selected from the group consisting of a PWM parameter and a scaling factor.

26. A method of claim 22, further comprising using the user interface to modify the table.

27. A method of claim 22, further comprising using the user interface to select a table from a plurality of available tables.

28. A method of claim 23, wherein the function defines a relationship between the data input and the control signal that increases continually throughout the range of the data input.

29. A method of claim 22, wherein changes in the output control signal are smaller at low levels of light output and larger at higher levels of light output.

30. A method of claim 22 wherein the ratio of the output control signal to the data input increases continuously throughout the intensity range of the light.

31. A method of claim 22 wherein the relationship between the data input and the output control signal is a continuously increasing relationship.

32. A method of claim 22 wherein the relationship between the data input and the output control signal is based on a function selected from the group consisting of an exponential function, a quadratic function, a squared function, and a cubed function.

33. A method of claim 22, wherein the light is an LED.

34. A method of claim 22, wherein the output control signal is a pulse-width-modulated control signal.

35. A method of claim 22, wherein the ratio of the output control signal to the data input increases continuously throughout the intensity range of the light.

36. A method of claim 35 wherein the relationship between the data input and the output control signal is based on a function selected from the group consisting of an exponential function, a quadratic function, a squared function, and a cubed function.

37. A method of claim 35 wherein the relationship between the data input and the output control signal comprises at least two relationships.

38. A method of claim 37, wherein the two relationships are two linear relationships of different slopes.

39. A method of claim 38, wherein the first relationship applies to lower levels of data input and has a lower slope than a second relationship that applies to higher levels of data input and has a higher slope.

40. A method of claim 38, wherein the two relationships comprise a first linear relationship that applies to a portion of the data input range and a second nonlinear relationship that applies to a different portion of the data range.

41. A method of claim 40 wherein the nonlinear relationship is based on a function selected from the group consisting of an exponential function, a quadratic function, a squared function, and a cubed function.

42. A method of claim 22, wherein the nonlinear relationship accounts for the response of a viewer to an illumination source having LEDs of colors of at least two different frequency ranges.

43. A method of claim 42, wherein the LEDs are selected from the group consisting of red, green, blue, white, UV, IR, and amber LEDs.

44. A method of claim 22, wherein the nonlinear relationship accounts for the response of a viewer of reflected illumination.

45. A method of claim 22, wherein the nonlinear relationship accounts for the response of a viewer of the output of a light source that is a color-mixed light output.

46. A method of claim 45, wherein the light source is an LED light source and wherein the LED is selected from the group consisting of red, green, blue, white, UV, IR, and amber LEDs.

47. A method of providing control of a light, comprising: providing a conversion module having a processor for applying a nonlinear relationship to convert a data input to an output control signal for the light to account for the response of a viewer of the light to varying light levels.

48. A method of claim 47, wherein changes in the output control signal are smaller at low levels of light output and larger at higher levels of light output.

49. A method of claim 47, wherein the ratio of the output control signal to the data input increases continuously throughout the intensity range of the light.

50. A method of claim 47 wherein the relationship between the data input and the output control signal is a continuously increasing relationship.

51. A method of claim 47 wherein the relationship between the data input and the output control signal is based on a function selected from the group consisting of an exponential function, a quadratic function, a squared function, and a cubed function.

52. A method of claim 47, wherein the light is an LED.

53. A method of claim 47 wherein the output control signal is a pulse-width-modulated control signal.

54. A method of claim 53, wherein the ratio of the output control signal to the data input increases continuously throughout the intensity range of the light.

55. A method of claim 53 wherein the relationship between the data input and the output control signal is based on a function selected from the group consisting of an exponential function, a quadratic function, a squared function, and a cubed function.

56. A method of claim 53 wherein the relationship between the data input and the output control signal comprises at least two relationships.

57. A method of claim 56, wherein the two relationships are two linear relationships of different slopes.

58. A method of claim 57, wherein the first relationship applies to lower levels of data input and has a lower slope than a second relationship that applies to higher levels of data input and has a higher slope.

59. A method of claim 57, wherein the two relationships comprise a first linear relationship that applies to a portion of the data input range and a second nonlinear relationship that applies to a different portion of the data range.

60. A method of claim 59 wherein the nonlinear relationship is based on a function selected from the group consisting of an exponential function, a quadratic function, a squared function, and a cubed function.

61. A method of claim 53, wherein the light is an LED.

62. A method of claim 47, wherein the range of output signals is as large as the range for a linear conversion module.

63. A method of claim 47, wherein the nonlinear relationship accounts for the response of a viewer to an illumination source having LEDs of colors of at least two different frequency ranges.

64. A method of claim 63, wherein the LEDs are selected from the group consisting of red, green, blue, white, UV, IR, and amber LEDs.

65. A method of claim 47, wherein the nonlinear relationship accounts for the response of a viewer of reflected illumination.

66. A method of claim 47, wherein the nonlinear relationship accounts for the response of a viewer of the output of a light source that is a color-mixed light output.

67. A method of claim 66, wherein the light source is an LED light source and wherein the LED is selected from the group consisting of red, green, blue, white, UV, IR, and amber LEDs.

68. A system for controlling a light, comprising:

a control module for generating an output control signal to control the output of a light; and

a conversion module for converting a data input to the output control, wherein the conversion module converts data inputs to output control signals in a nonlinear relationship to account for the response of a viewer to different levels of output of the light.

69. A system of claim 68, wherein changes in the output control signal are smaller at low levels of light output and larger at higher levels of light output.

70. A system of claim 68 wherein the ratio of the output control signal to the data input increases continuously throughout the intensity range of the light.

71. A system of claim 68 wherein the relationship between the data input and the output control signal is a continuously increasing relationship.

72. A system of claim 68 wherein the relationship between the data input and the output control signal is based on a function selected from the group consisting of an exponential function, a quadratic function, a squared function, and a cubed function.

73. A system of claim 68, wherein the light is an LED.

74. A system of claim 68, wherein the output control signal is a pulse-width-modulated control signal.

75. A system of claim 74, wherein the ratio of the output control signal to the data input increases continuously throughout the intensity range of the light.

76. A system of claim 74 wherein the relationship between the data input and the output control signal is based on a function selected from the group consisting of an exponential function, a quadratic function, a squared function, and a cubed function.

77. A system of claim 74 wherein the relationship between the data input and the output control signal comprises at least two relationships.

78. A system of claim 77, wherein the two relationships are two linear relationships of different slopes.

79. A system of claim 78, wherein the first relationship applies to lower levels of data input and has a lower slope than a second relationship that applies to higher levels of data input and has a higher slope.

80. A system of claim 77, wherein the two relationships comprise a first linear relationship that applies to a portion of the data input range and a second nonlinear relationship that applies to a different portion of the data range.

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81. A system of claim **80** wherein the nonlinear relationship is based on a function selected from the group consisting of an exponential function, a quadratic function, a squared function, and a cubed function.

82. A system of claim **74**, wherein the light is an LED.

83. A system of claim **68**, wherein the range of output signals is as large as the range for a linear conversion module.

84. A system of claim **68**, wherein the nonlinear relationship accounts for the response of a viewer to an illumination source having LEDs of colors of at least two different frequency ranges.

85. A system of claim **84**, wherein the LEDs are selected from the group consisting of red, green, blue, white, UV, IR, and amber LEDs.

86. A system of claim **68**, wherein the nonlinear relationship accounts for the response of a viewer of reflected illumination.

87. A system of claim **68**, wherein the nonlinear relationship accounts for the response of a viewer of the output of a light source that is a color-mixed light output.

88. A system of claim **87**, wherein the light source is an LED light source and wherein the LED is selected from the group consisting of red, green, blue, white, UV, IR, and amber LEDs.

89. A system of providing a lighting control signal, comprising:

a processor;

a memory;

a light;

a data input facility; and

a user interface, wherein the user interface permits a user to use the processor to access a table stored in the memory to determine a control signal for the light, wherein the processor can access the table to determine the control signal and wherein the table can store a nonlinear relationship between the data input and the control signal.

90. A system of claim **89**, wherein the table stores a function that defines the nonlinear relationship.

91. A system of claim **89**, wherein the user interface permits a user to modify a parameter of the function.

92. A system of claim **91**, wherein the parameter is selected from the group consisting of a PWM parameter and a scaling factor.

93. A system of claim **89**, further comprising using the user interface to modify the table.

94. A system of claim **89**, further comprising using the user interface to select a table from a plurality of available tables.

95. A system of claim **90**, wherein the function defines a relationship between the data input and the control signal that increases continually throughout the range of the data input.

96. A system of claim **89**, wherein changes in the output control signal are smaller at low levels of light output and larger at higher levels of light output.

97. A system of claim **89** wherein the ratio of the output control signal to the data input increases continuously throughout the intensity range of the light.

98. A system of claim **89** wherein the relationship between the data input and the output control signal is a continuously increasing relationship.

99. A system of claim **89** wherein the relationship between the data input and the output control signal is based on a function selected from the group consisting of an exponen-

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tial function, a quadratic function, a squared function, and a cubed function.

100. A system of claim **89**, wherein the light is an LED.

101. A system of claim **89**, wherein the output control signal is a pulse-width-modulated control signal.

102. A system of claim **89**, wherein the ratio of the output control signal to the data input increases continuously throughout the intensity range of the light.

103. A system of claim **102** wherein the relationship between the data input and the output control signal is based on a function selected from the group consisting of an exponential function, a quadratic function, a squared function, and a cubed function.

104. A system of claim **102** wherein the relationship between the data input and the output control signal comprises at least two relationships.

105. A system of claim **104**, wherein the two relationships are two linear relationships of different slopes.

106. A system of claim **105**, wherein the first relationship applies to lower levels of data input and has a lower slope than a second relationship that applies to higher levels of data input and has a higher slope.

107. A system of claim **104**, wherein the two relationships comprise a first linear relationship that applies to a portion of the data input range and a second nonlinear relationship that applies to a different portion of the data range.

108. A system of claim **107** wherein the nonlinear relationship is based on a function selected from the group consisting of an exponential function, a quadratic function, a squared function, and a cubed function.

109. A system of claim **89**, wherein the nonlinear relationship accounts for the response of a viewer to an illumination source having LEDs of colors of at least two different frequency ranges.

110. A system of claim **109**, wherein the LEDs are selected from the group consisting of red, green, blue, white, UV, IR, and amber LEDs.

111. A system of claim **89**, wherein the nonlinear relationship accounts for the response of a viewer of reflected illumination.

112. A system of claim **89**, wherein the nonlinear relationship accounts for the response of a viewer of the output of a light source that is a color-mixed light output.

113. A system of claim **112**, wherein the light source is an LED light source and wherein the LED is selected from the group consisting of red, green, blue, white, UV, IR, and amber LEDs.

114. A system of providing control of a light, comprising:

a conversion module having a processor for applying a nonlinear relationship to convert a data input to an output control signal for the light to account for the response of a viewer of the light to varying light levels.

115. A system of claim **114**, wherein changes in the output control signal are smaller at low levels of light output and larger at higher levels of light output.

116. A system of claim **114**, wherein the ratio of the output control signal to the data input increases continuously throughout the intensity range of the light.

117. A system of claim **114** wherein the relationship between the data input and the output control signal is a continuously increasing relationship.

118. A system of claim **114** wherein the relationship between the data input and the output control signal is based on a function selected from the group consisting of an exponential function, a quadratic function, a squared function, and a cubed function.

119. A system of claim 114, wherein the light is an LED.

120. A system of claim 114 wherein the output control signal is a pulse-width-modulated control signal.

121. A system of claim 120, wherein the ratio of the output control signal to the data input increases continuously throughout the intensity range of the light.

122. A system of claim 120 wherein the relationship between the data input and the output control signal is based on a function selected from the group consisting of an exponential function, a quadratic function, a squared function, and a cubed function.

123. A system of claim 120 wherein the relationship between the data input and the output control signal comprises at least two relationships.

124. A system of claim 123, wherein the two relationships are two linear relationships of different slopes.

125. A system of claim 124, wherein the first relationship applies to lower levels of data input and has a lower slope than a second relationship that applies to higher levels of data input and has a higher slope.

126. A system of claim 123, wherein the two relationships comprise a first linear relationship that applies to a portion of the data input range and a second nonlinear relationship that applies to a different portion of the data range.

127. A system of claim 126 wherein the nonlinear relationship is based on a function selected from the group

consisting of an exponential function, a quadratic function, a squared function, and a cubed function.

128. A system of claim 120, wherein the light is an LED.

129. A system of claim 114, wherein the range of output signals is as large as the range for a linear conversion module.

130. A system of claim 114, wherein the nonlinear relationship accounts for the response of a viewer to an illumination source having LEDs of colors of at least two different frequency ranges.

131. A system of claim 130, wherein the LEDs are selected from the group consisting of red, green, blue, white, UV, IR, and amber LEDs.

132. A system of claim 114, wherein the nonlinear relationship accounts for the response of a viewer of reflected illumination.

133. A system of claim 114, wherein the nonlinear relationship accounts for the response of a viewer of the output of a light source that is a color-mixed light output.

134. A system of claim 133, wherein the light source is an LED light source and wherein the LED is selected from the group consisting of red, green, blue, white, UV, IR, and amber LEDs.

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