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(54) **DEVICE AND METHOD FOR DYNAMICALLY CHANGING COLOR**

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PCT Pub. Date: **Feb. 26, 2009**

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F21S 2/00	(2006.01)

(52) **U.S. Cl.**
USPC **358/520**; 315/291

(58) **Field of Classification Search** 315/291, 315/307, 224, 292, 293, 297, 308, 362, 363; 362/230, 231; 345/204, 690, 22; 358/518, 358/520
See application file for complete search history.

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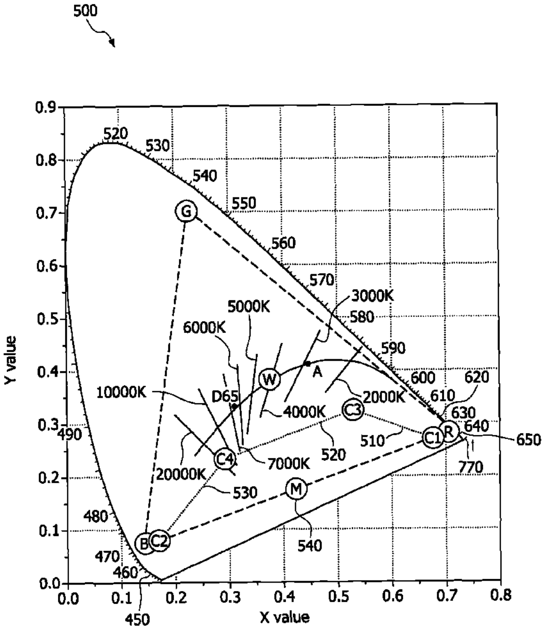
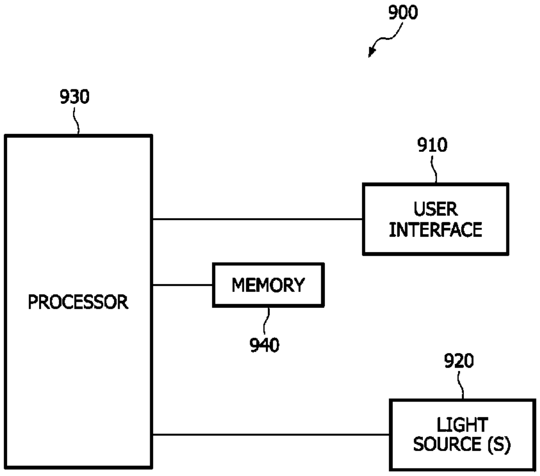
(57) **ABSTRACT**

A lighting system (**900**) has a light source (**920**) configured to provide a light, and a controller (**930**) configured to control hue and saturation of the light to change a color of the light from an initial color to a final color during at least two phases.

11 Claims, 14 Drawing Sheets





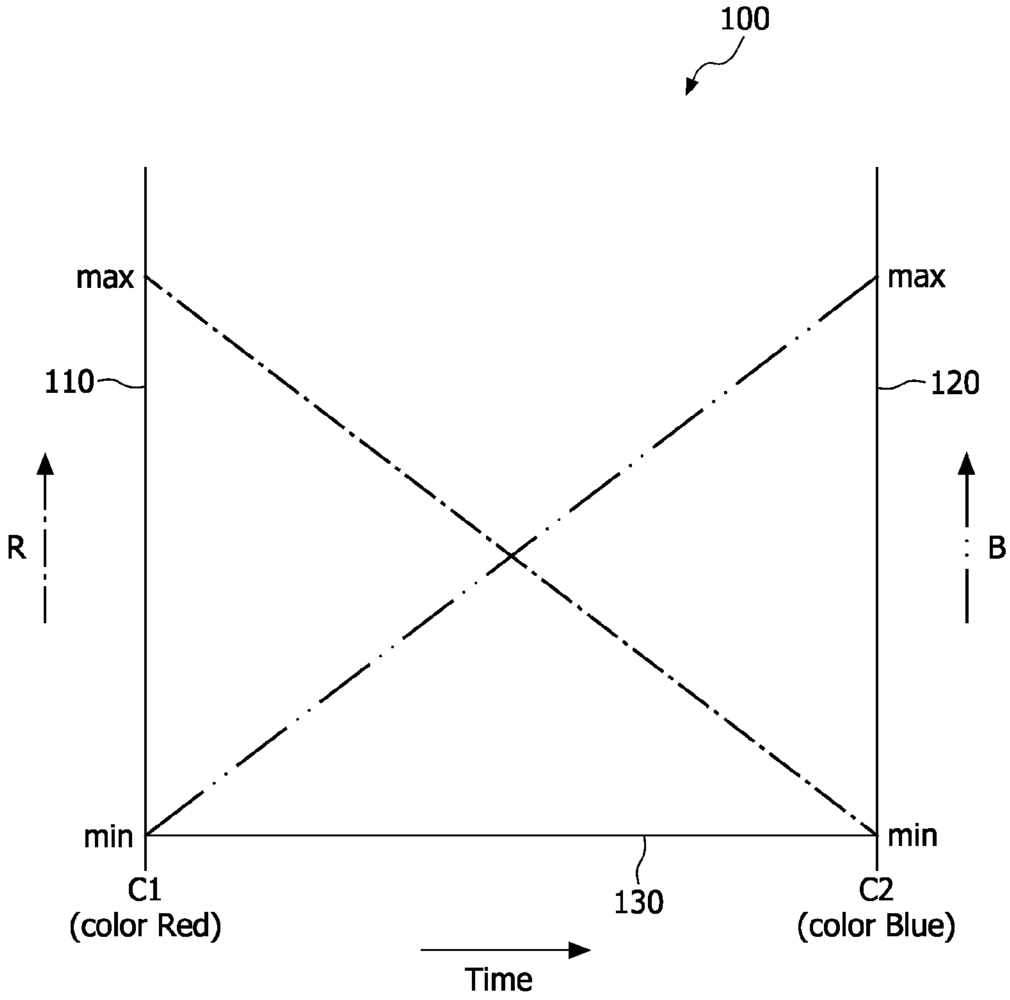

100
max
max
110
120
R
B
min
min
C1
(color Red)
130
C2
(color Blue)
Time

FIG. 1

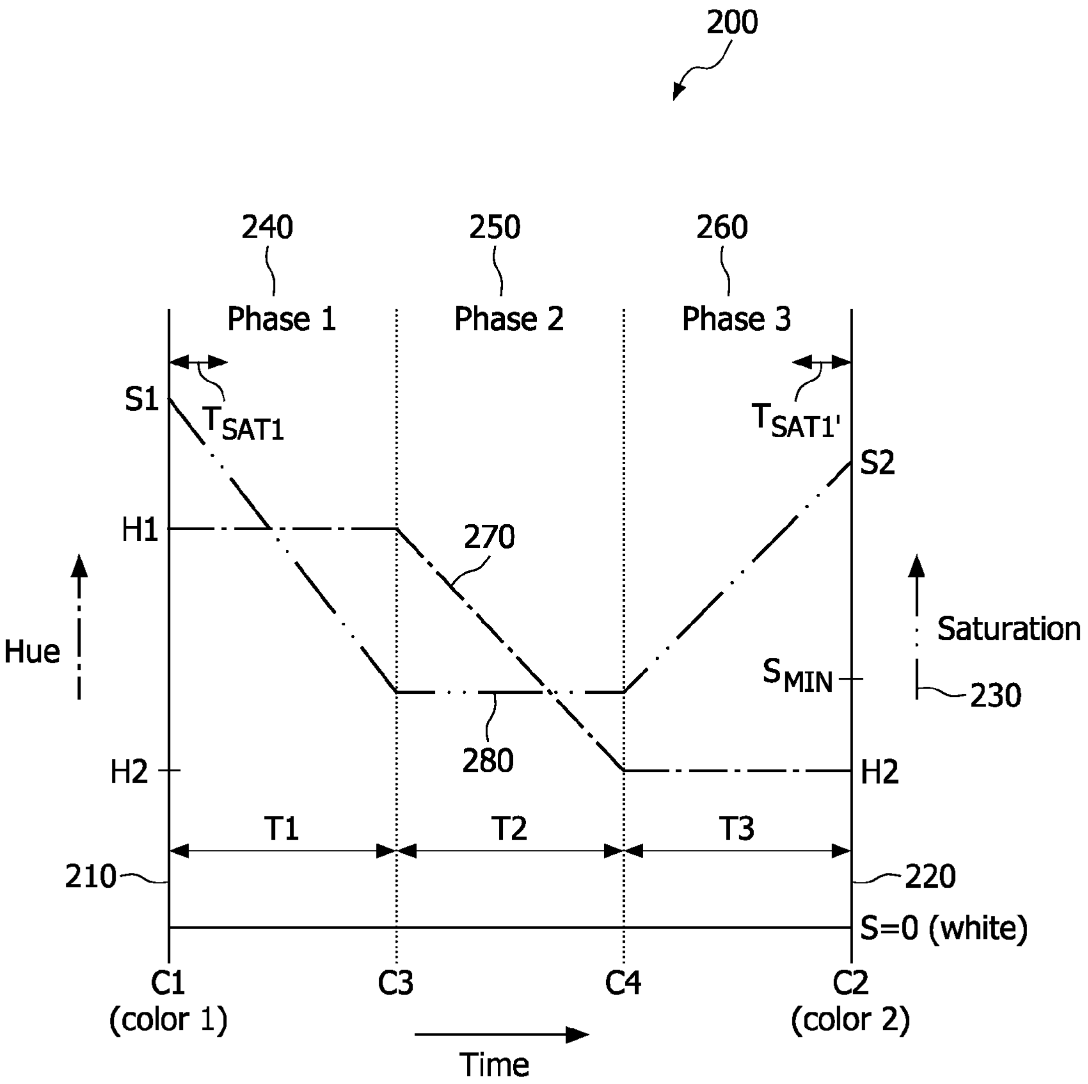

200
240
250
260
Phase 1
Phase 2
Phase 3
T_{SAT1}
$T_{SAT1'}$
S1
S2
H1
H2
H2
270
280
Hue
Saturation
S_{MIN}
230
T1
T2
T3
210
220
S=0 (white)
C1
(color 1)
C3
C4
C2
(color 2)
Time

FIG. 2

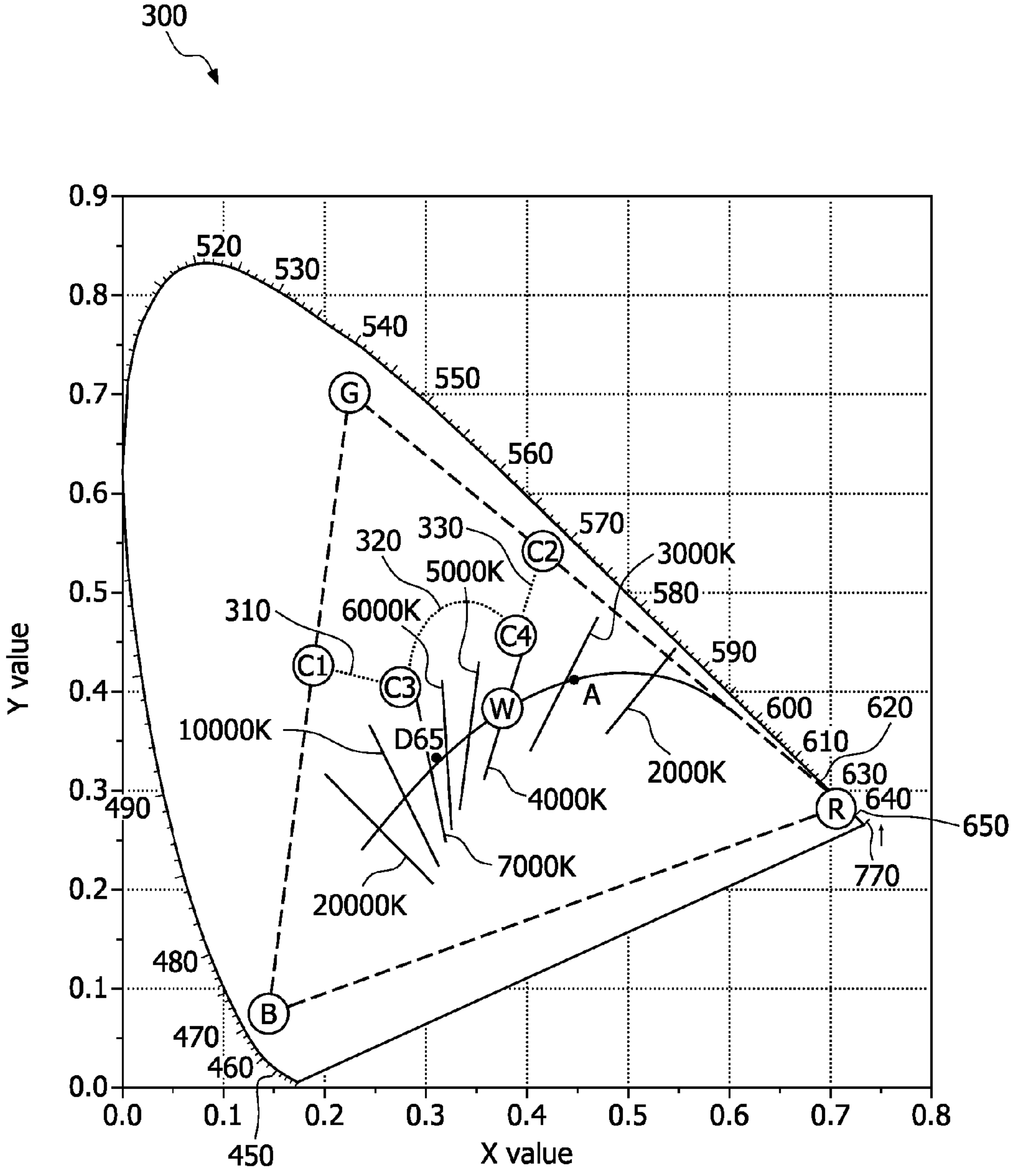

300
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Y value
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
X value
520
530
540
550
560
570
580
590
600
610
620
630
640
650
770
490
480
470
460
450
G
C2
C1
C3
C4
W
A
D65
B
R
310
320
330
3000K
5000K
6000K
10000K
20000K
7000K
4000K
2000K

FIG. 3

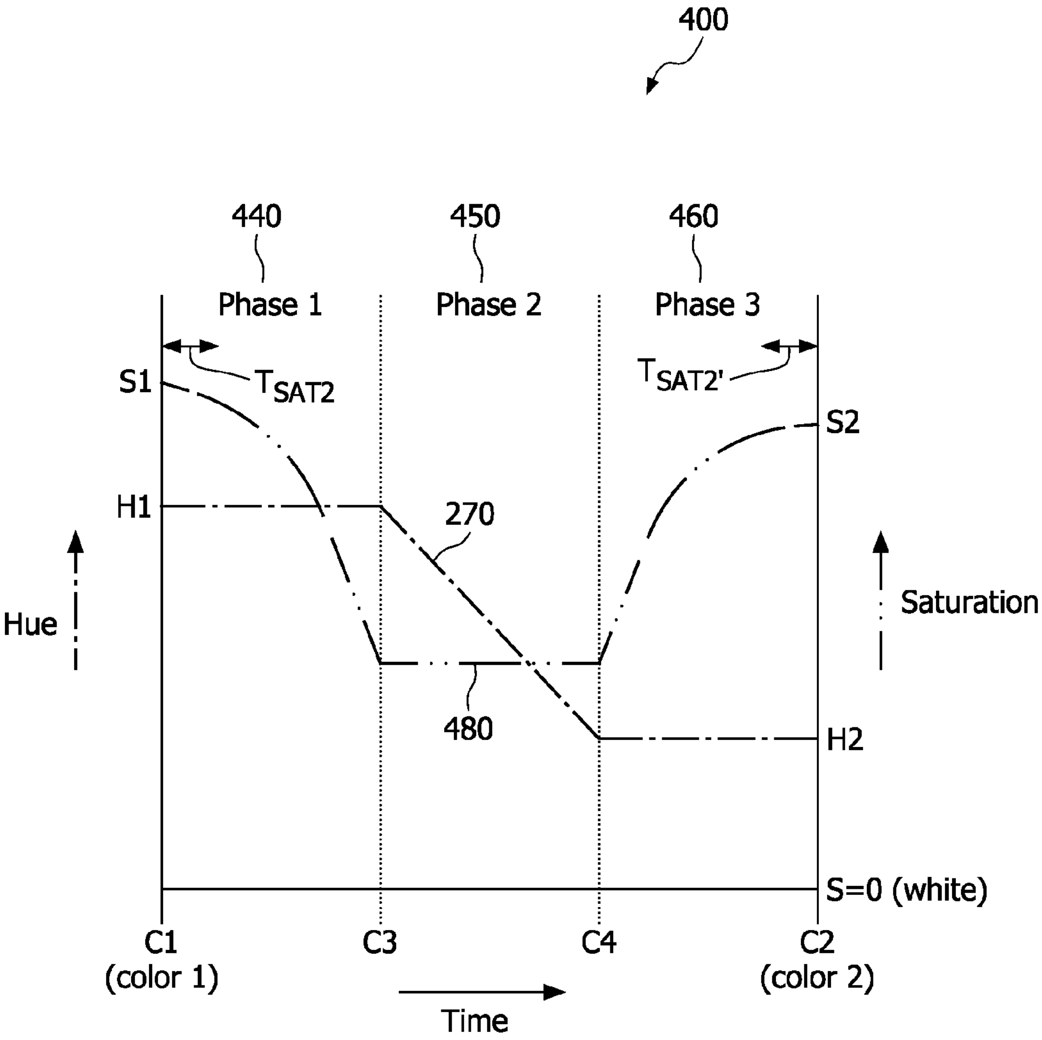

400
440
450
460
Phase 1
Phase 2
Phase 3
T_{SAT2}
$T_{SAT2'}$
S1
S2
H1
270
Hue
Saturation
480
H2
S=0 (white)
C1
(color 1)
C3
C4
C2
(color 2)
Time

FIG. 4A

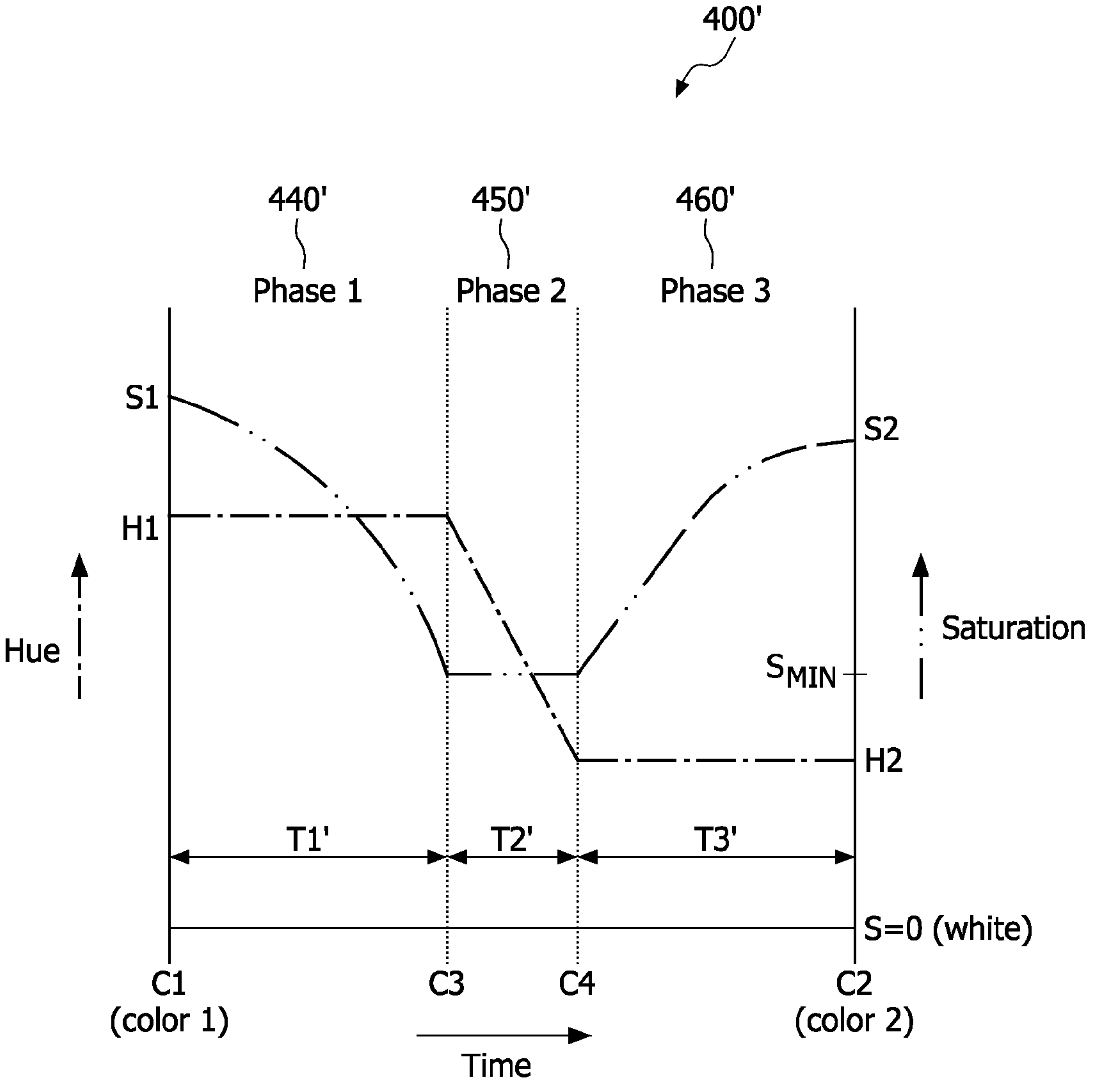

400'
440'
450'
460'
Phase 1
Phase 2
Phase 3
S1
H1
Hue
S2
Saturation
S_{MIN}
H2
T1'
T2'
T3'
S=0 (white)
C1
(color 1)
C3
C4
C2
(color 2)
Time

FIG. 4B

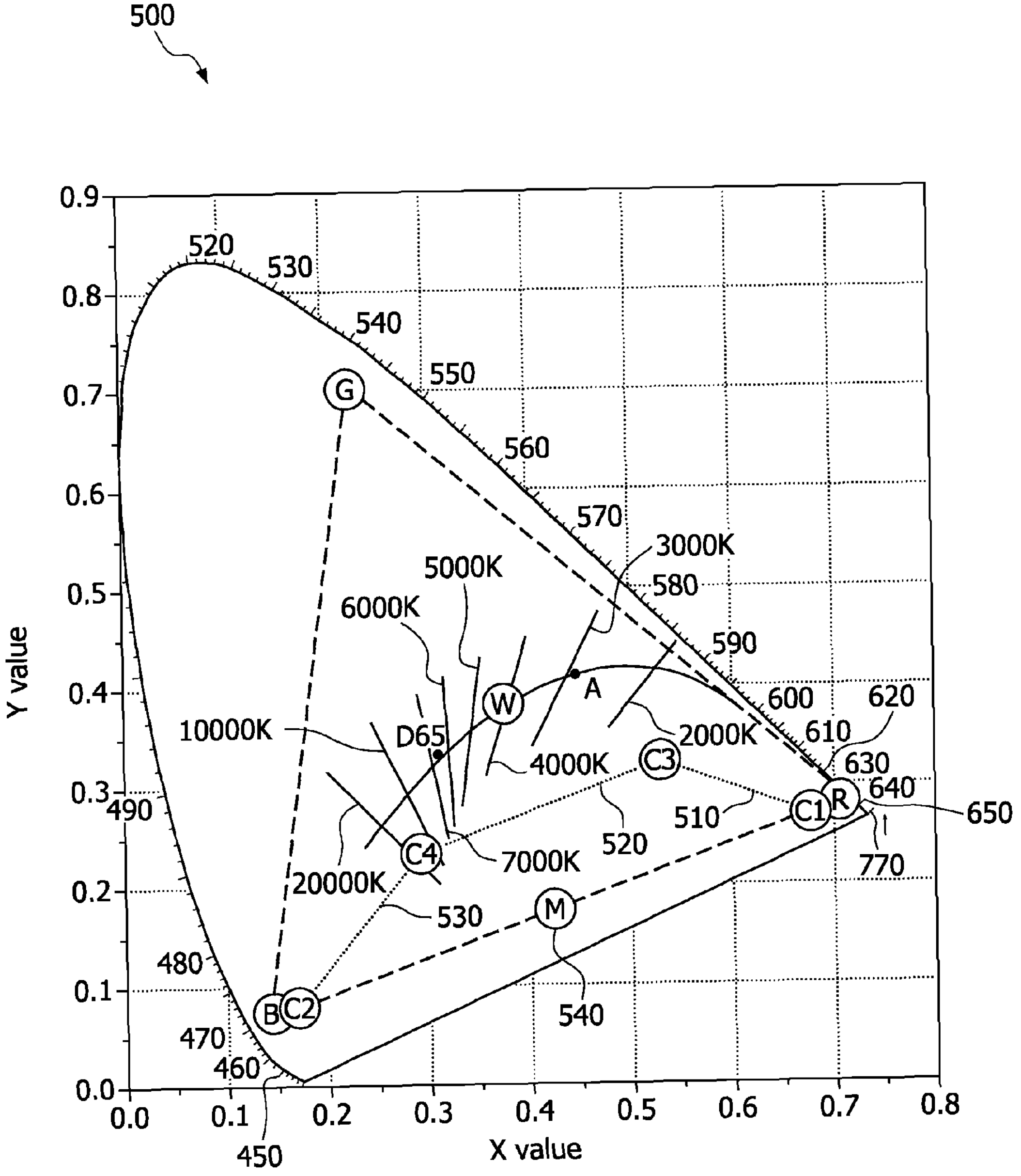

500
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Y value
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
X value
520
530
540
550
560
570
580
590
600
610
620
630
640
650
770
490
480
470
460
450
G
R
B
C1
C2
C3
C4
W
M
A
D65
3000K
5000K
6000K
10000K
2000K
4000K
7000K
20000K
510
520
530
540

FIG. 5

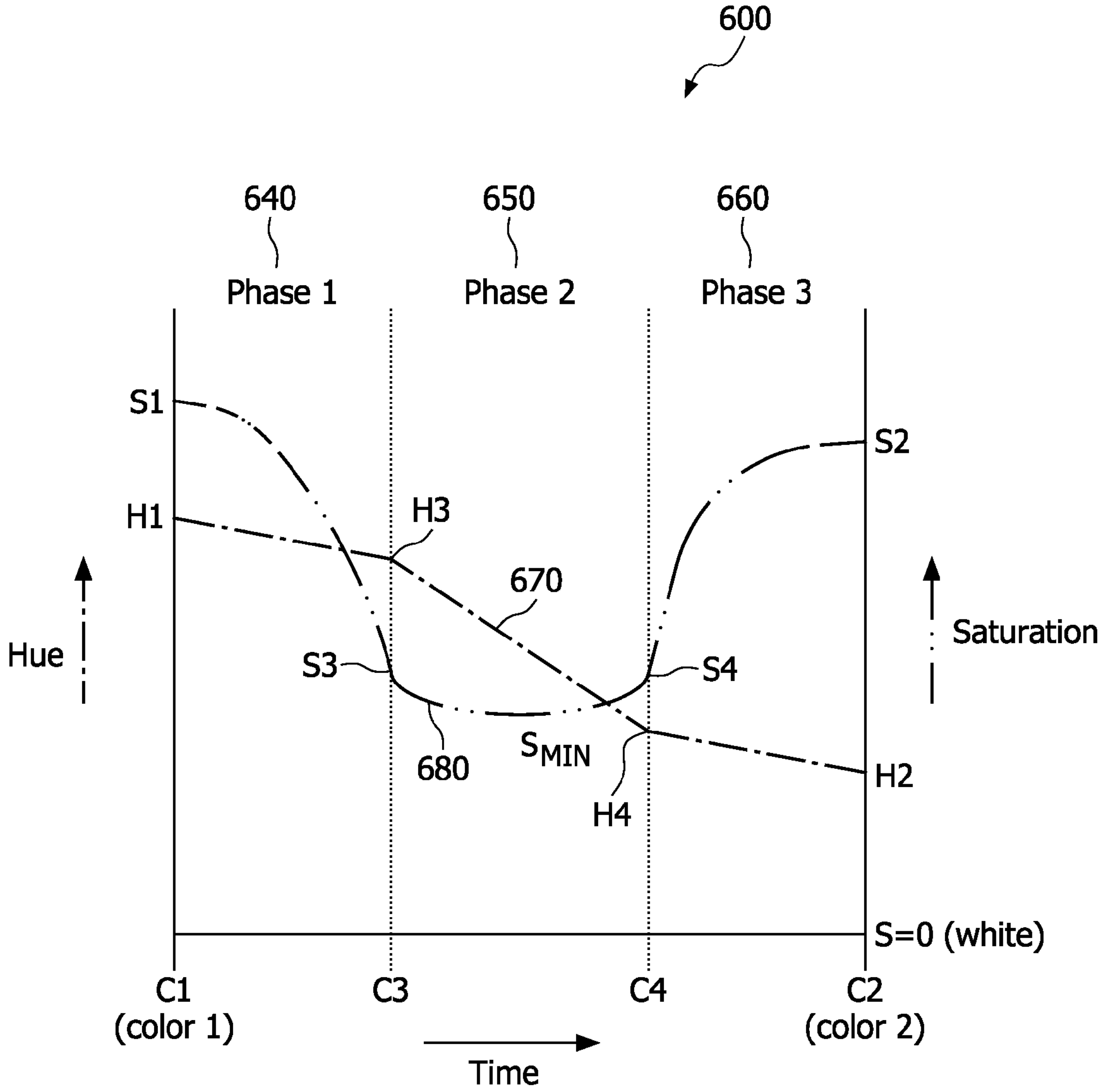

600
640
650
660
Phase 1
Phase 2
Phase 3
S1
H1
H3
670
S2
Hue
Saturation
S3
S4
680
S_{MIN}
H4
H2
S=0 (white)
C1
(color 1)
C3
C4
C2
(color 2)
Time

FIG. 6

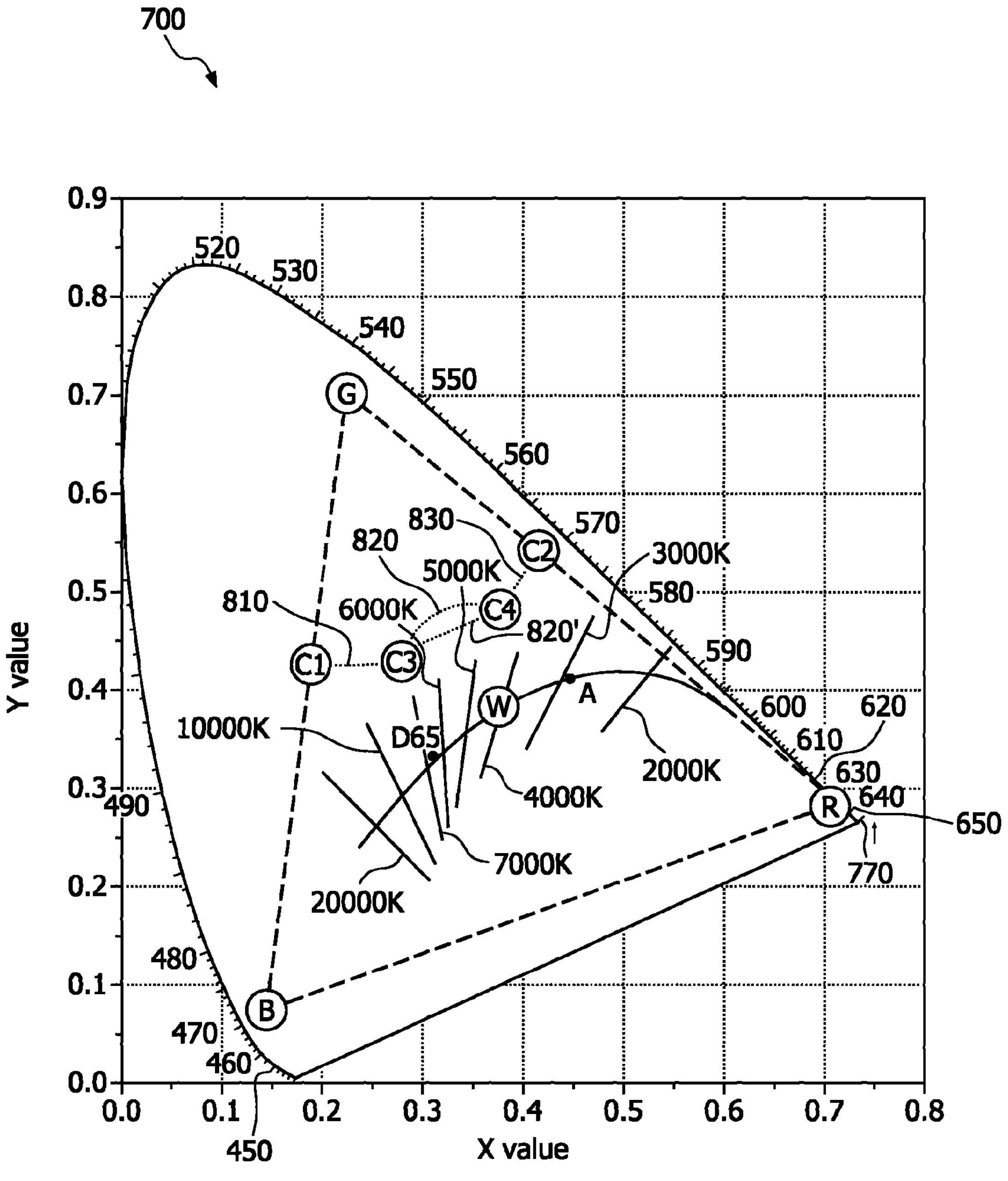

700
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Y value
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
X value
520
530
540
550
560
570
580
590
600
610
620
630
640
650
770
490
480
470
460
450
G
C2
C4
C1
C3
W
B
R
A
D65
810
820
820'
830
3000K
5000K
6000K
4000K
2000K
10000K
7000K
20000K

FIG. 7

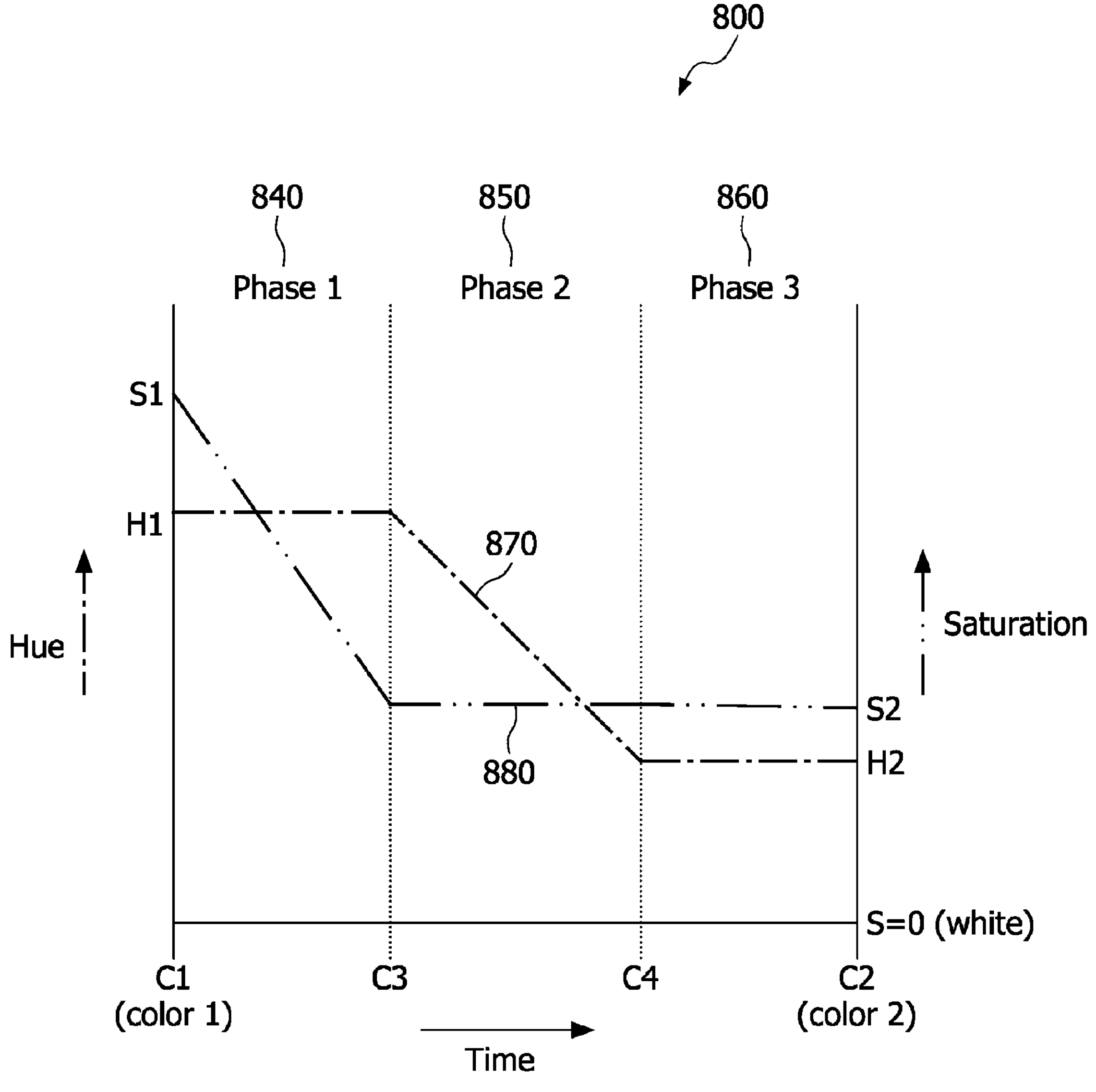

800
840
850
860
Phase 1
Phase 2
Phase 3
S1
H1
870
Hue
Saturation
S2
880
H2
S=0 (white)
C1
(color 1)
C3
C4
C2
(color 2)
Time

FIG. 8

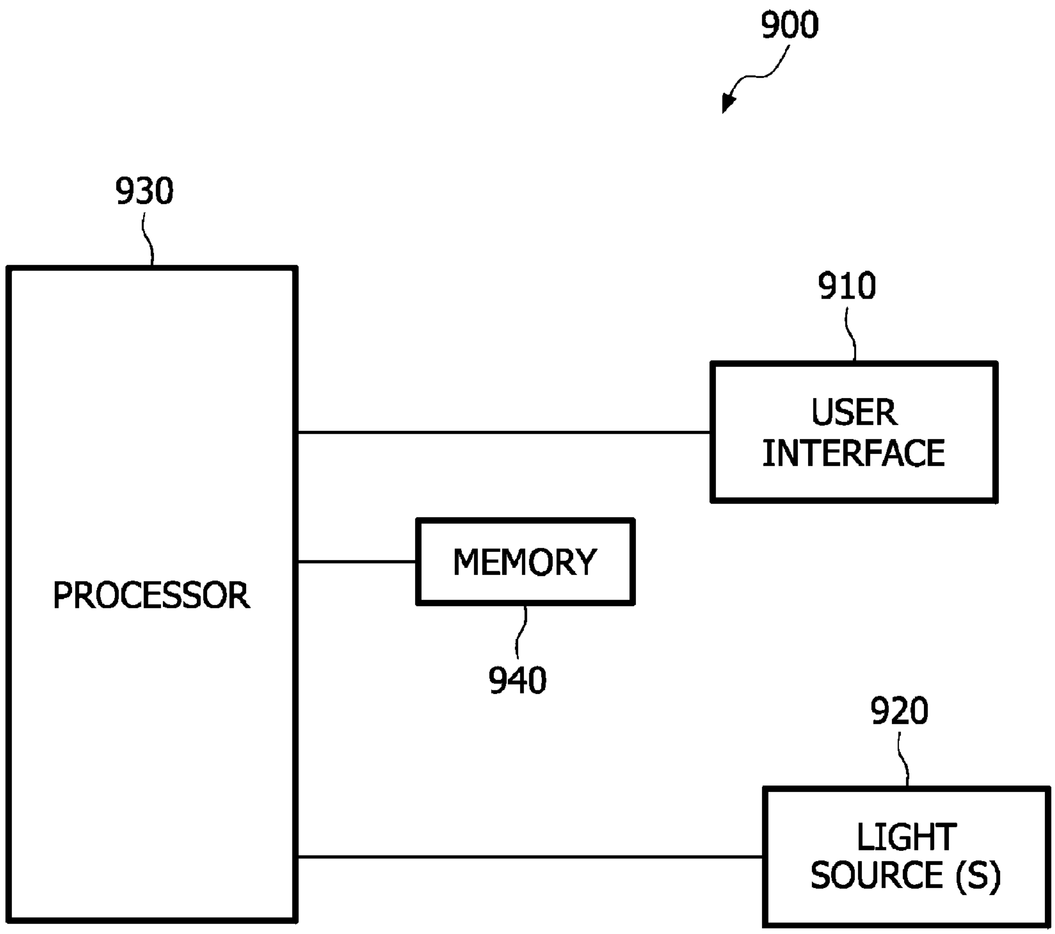

900
930
PROCESSOR
910
USER INTERFACE
MEMORY
940
920
LIGHT SOURCE (S)

FIG. 9

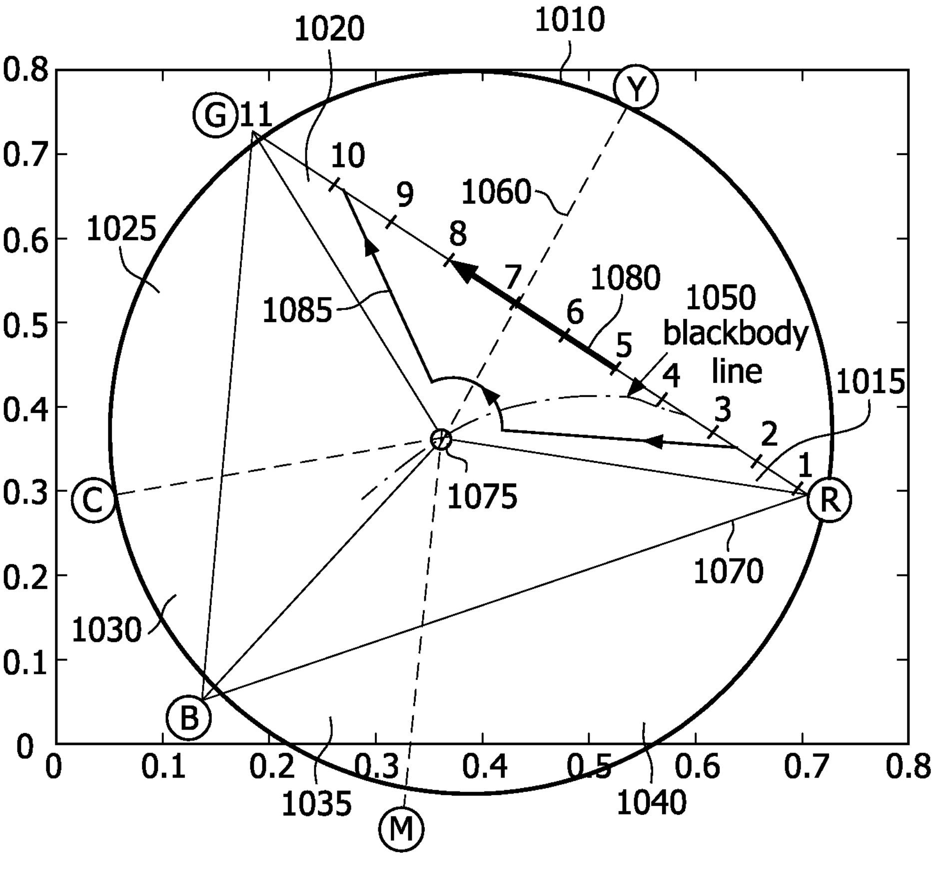
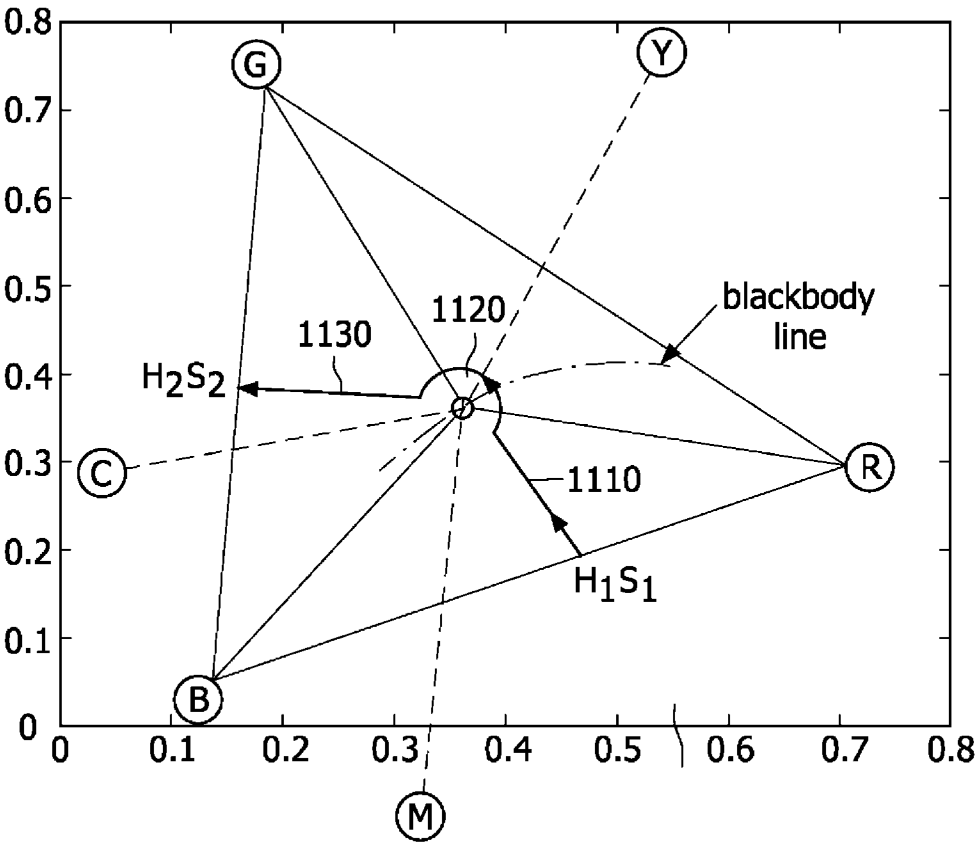

1020
1010
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Y
G
11
10
9
8
7
6
5
4
3
2
1
1060
1025
1080
1050
blackbody
line
1015
1085
1075
C
R
1070
1030
B
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
1035
M
1040

FIG. 10



0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
G
Y
R
B
C
M
blackbody line
1120
1130
H_2S_2
1110
H_1S_1

FIG. 11

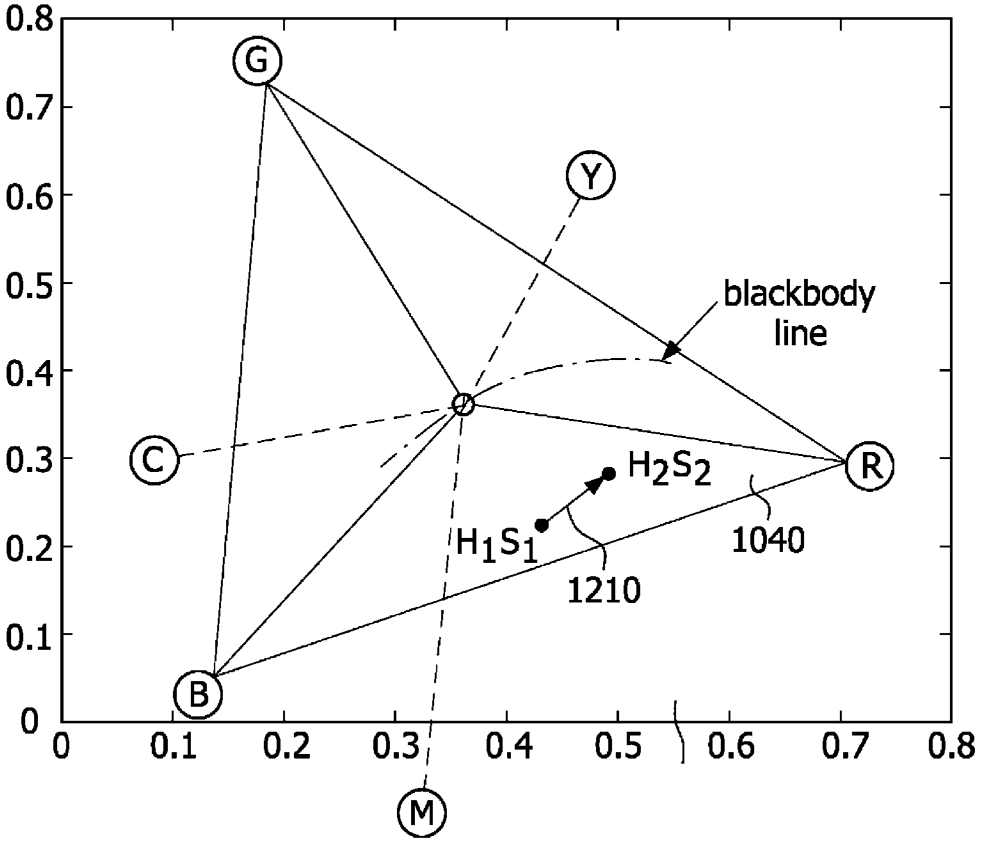

G
Y
C
R
B
M
blackbody line
H_2S_2
H_1S_1
1040
1210
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8

FIG. 12

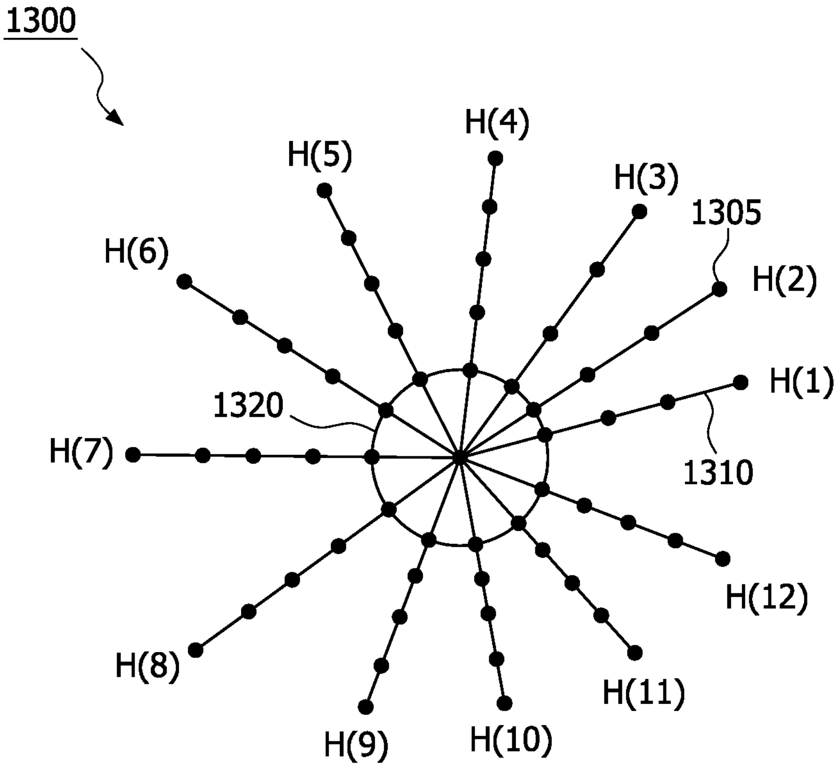


FIG. 13

DEVICE AND METHOD FOR DYNAMICALLY CHANGING COLOR

The present invention relates to a device and method to dynamically change the color of light emanating from a light source from one color to another color in a well-perceived manner, based on changing hue and/or saturation, in accordance with predetermined relationships.

Lighting systems are increasingly being used to provide an enriching experience and improve productivity, safety, efficiency and relaxation. Light systems are becoming more advanced, flexible and integrated. This holds especially for professional domains like the retail domain, but new lights or light systems will also enter the home domain. This change is stimulated by the advent of LED lighting (Light Emitting Diodes or Solid State lighting). It is expected that LED lighting systems will proliferate due to increased efficiency as compared to today's common light sources, as well as to the ease of providing light of changeable color.

Advanced lighting sources and systems are able to provide light of desired attributes, such as projecting a color to a wall or to a corner of a room, where the color is dynamically changed in time, for example, from one color to another color.

The inventor has learned that in some occasion users would like to change colors in time, for example from one preferred color to another. It was also learned that people do not prefer or even dislike certain colors. This means that using a normal-used "edge" of the color gamut is not a good method to change colors. For example, when changing colors from Yellow to Cyan, if a hue-color triangle is followed, then one will pass the Green Color. When a user dislikes the pure Green color, then such a method of changing colors is not desirable.

Furthermore it is observed that people do not like the white color as an in-between or a transition color when changing from one color to another. The purpose of a color-changing lamp is to make colors, and white is often not perceived as a color, or white is disliked and therefore should be avoided. One way to change colors is to linearly interpolate between the Red, Green and Blue (RGB) values of first color to the RGB values of a second color, such as by following the dotted line **340** from initial color of red to final color of green shown in FIG. **3**, for example. That is, a color change is achieved by following a linear path that connects two endpoints colors, namely, a starting color and a destination (or desired) color. However, such a method may lead to situations where disliked colors (e.g., a white color) are obtained. FIG. **1** shows an example of a linear interpolation method **100** for changing colors from Red, shown as the left intensity axis **110** to Blue shown as the right intensity axis **120**, moving upward from minimum intensity to maximum intensity. The color change occurs over time as shown by the horizontal axis **130**.

When linearly interpolating the RGB values (in this case from R to B), one will get Magenta color in between as shown by reference numeral **540** in FIG. **5**. If a user does not like this pure Magenta color, then this linear interpolation method **100** is not a good method to change colors.

Accordingly, there is a need for simple light control systems that control light sources to change the light color from one desired color to another desired color in a pleasing way, such as avoiding undesirable light attributes, e.g., avoiding or minimizing light emissions of a particular color such as white.

One object of the present systems and methods is to overcome the disadvantages of conventional control systems.

According to one illustrative embodiment, a lighting system comprises a light source, and a controller configured to control hue and/or saturation of the light to change a color of

the light from an initial color to a final color during at least two phases. The systems and methods allow dynamically changing the color from one color to another color in a well-perceived manner, without using colors that users dislike, and/or without using a white color setting.

Further areas of applicability of the present devices, systems and methods will become apparent from the detailed description provided hereinafter. It should be understood that the detailed description and specific examples, while indicating exemplary embodiments of the systems and methods, are intended for purposes of illustration only and are not intended to limit the scope of the invention.

These and other features, aspects, and advantages of the apparatus, systems and methods of the present invention will become better understood from the following description, appended claims, and accompanying drawing where:

FIG. **1** shows a conventional method to change the color of a light;

FIG. **2** shows a three-phased method according to one embodiment;

FIG. **3** shows an illustrative example of a color coordinate system according to one embodiment;

FIGS. **4A-4B** show three-phased methods according to further embodiments;

FIG. **5** shows another illustrative example of a color coordinate system according to an embodiment;

FIG. **6** shows a three-phased method according to another embodiment;

FIG. **7** shows an illustrative example of a color coordinate system according to a further embodiment;

FIG. **8** shows another method according to another embodiment;

FIG. **9** shows a block diagram of a control system according to a further embodiment;

FIGS. **10-12** show color triangles in CIE1931 (x,y) space, and paths for changing color according to further embodiments; and

FIG. **13** shows a graphical representation of a color table according to another embodiment.

The following description of certain exemplary embodiments is merely exemplary in nature and is in no way intended to limit the invention, its applications, or uses. In the following detailed description of embodiments of the present systems and methods, reference is made to the accompanying drawings which form a part hereof, and in which are shown by way of illustration specific embodiments in which the described systems and methods may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the presently disclosed systems and methods, and it is to be understood that other embodiments may be utilized and that structural and logical changes may be made without departing from the spirit and scope of the present system.

The following detailed description is therefore not to be taken in a limiting sense, and the scope of the present system is defined only by the appended claims. The leading digit(s) of the reference numbers in the figures herein typically correspond to the figure number, with the exception that identical components which appear in multiple figures are identified by the same reference numbers. Moreover, for the purpose of clarity, detailed descriptions of well-known devices, circuits, and methods are omitted so as not to obscure the description of the present system.

FIG. **2** shows a three-phased method **200** to dynamically change colors, according to one illustrative embodiment, using Hue and Saturation as parameters for the color setting, where a color point C is associated with a hue value H and a saturation level S. FIG. **2** shows how to change the colors dynamically between color **1** or C**1**, defined with parameters hue H**1** and saturation S**1**, to color **2** or C**2**, defined with parameters hue H**2** and saturation S**2**. As shown in FIG. **2**, the left axis **210** may be the hue axis having different values of hue, and the right axis **220** may be the saturation axis having different levels of saturation. In particular, different colors or hue values are provided along the hue axis **210**, such as a first hue value H**1** associated with a first color **1** or C**1**, and a second hue value H**2** associated with a second color **2** or C**2**. Saturation values increase along the saturation axis **220** in the upper direction shown by arrow **230**.

The method includes controlling the hue and saturation values in predetermined relations with each other during a plurality of phases of equal or different time durations, such as three phases, along predefined paths to change color and/or saturation of light emanating from a controllable light source **920** (shown in FIG. **9**) in a manner pleasing and desirable to users, viewers and observers. The following embodiments describe various methods and systems to change the light color from an initial to a final color using three phases. In particular, the initial color C**1** is changed to a first intermediate color C**3** in phase **1**, which is then changed to a second intermediate color C**4** in phase **2**, which in turn is changed to a final or desired color C**2** in phase **3**. Of course, it should be understood that any number of phases may be used in addition to or instead of using three phases.

In the embodiment shown in FIG. **2**, the method **200** includes controlling the hue values (e.g., changing the color) of the light from the controllable light source **920** (shown in FIG. **9**) in three phases **240**, **250**, **260** which may have substantially the same time duration T**1**, T**2**, T**3**. Alternatively, time duration T**2** of the second phase **2** may be greater or less then the time durations T**1**, T**3** of the first and third phases **1**, **3**, respectively, where T**1** may be substantially equal to T**3**.

The method **200** of this embodiment includes controlling the hue values along a hue graph **270** shown as a dashed line where dashes are separated by a single dot, while simultaneously controlling the saturation values along a saturation graph **280** shown as a dashed line where dashes are separated by two dots. It should be noted that brightness is not essential because it is a parameter that expresses the light output, and is not related to color.

As shown in FIG. **2**, in the first phase **240**, the hue is kept constant at level H**1**, as seen from the hue graph **270**, and the saturation is changed from an initial value S**1** to a lower intermediate value SMIN along the saturation graph **280**. It should be noted that the saturation does not go to zero, which is the white point. The minimum value for saturation may be from 40% to 70% of the maximum value, e.g., of the initial value S**1**. In the second phase **250**, the saturation graph **280** is kept constant at the intermediate value S_{MIN} while the hue value is changed from the initial hue value H**1** to a different or desired hue value H**2**. At the end of the first phase **240** or beginning of the second phase **250**, the color is changed from C**1** to C**3**, where color is associated with hue and saturation values. That is, the initial color C**1**, having hue and saturation values of H**1**, S**1**, is changed to the first intermediate color C**3** having hue and saturation values of H**1**, S_{MIN}. Thus, in the first phase **240**, the saturation of the initial light emanating from the controllable light source **920** is reduced to SMIN without changing the hue value H**1** to result in the first intermediate color C**3**; and in the second phase **250**, the hue value is changed to the final or desired value H**2** without changing the saturation value SMIN to result in the second intermediate color C**4**.

In the third phase **260**, the hue value, namely, the final value H**2**, is kept constant and the saturation value is changed, namely, increased from the reduced value SMIN to the desired or final value S**2**, which may be the substantially same or different from the initial values S**1**, to result in a final or desired color C**2** having the final hue and saturation values of H**2**, S**2**. It should be noted that the intermediate value SMIN is the minimum value as compared to the initial and/or the final saturation values S**1**, S**2**, so that the third phase **260** includes an increase (instead of a decrease, for example,) of the saturation value from the intermediate value SMIN to the final saturation value S**2**.

With this method, disliked colors and the white color setting may be minimized or prevented because they are saturated (with a saturation value of SMIN which is) much less than the initial and final saturation values S**1**, S**2**. Thus, the white and/or disliked colors are not substantially visible or noticeable to the user. Such a method is more user-friendly and desirable as compared to a method that does not reduce the saturation, or a method that changes the color via the white color point.

FIG. **3** shows an illustrative example of a color coordinate system **300** where the three primary colors, Red (R), Green (G) and Blue (B) are shown as corners of a dashed triangle of the color coordinate system **300**. As shown by the dotted lines in FIG. **3**, a controller **930** shown in FIG. **9** is configured to change the color of light from the controllable light source **920** from an initial cyan-turquoise like color C**1** to a final lime-yellow color C**2**. The controller **930** is configured to change the light from the initial color C**1** to the first intermediary color C**3** along path **310** in Phase **1** (shown as reference numeral **240** in FIG. **2**). In phase **2** (**250** of FIG. **2**), the controller **930** is configured to change the light from the first intermediary color C**3** to the second intermediary color C**4**; and in phase **3** (**260** of FIG. **2**), the controller **930** is configured to change the light from the second intermediary color C**4** to the final color C**2**. It should be noted that the pure Green color G (e.g., a disliked color) and the white point W are avoided, where the white point W shown in FIG. **3** is substantially on or near a blackbody line.

FIG. **4**A, shows a method **400** which is variation on the method **200** show in FIG. **2**. The method **400** shown in FIG. **4**A, also includes three phases **440**, **450**, **460** where the controller **930** is configured to simultaneously control the hue and saturation of light from the light source **920**, along the hue curve **270** and the saturation curve **480**, respectively. The hue curve **270** is similar to the one shown in FIG. **2**, but the saturation path or curve **480** is different from its counterpart **280** shown in FIG. **2**. In particular, the controller **930** is configured to slowly change the saturation of the light emanating from the controllable light source **920** near the initial and final colors C**1** and C**2**, and to change the saturation faster near intermediate colors C**3** and C**4**, where the slopes of the saturation curve **480** near the intermediary colors C**3**, C**4** are steeper (e.g., more positive or more negative), than the slopes near the end points, or initial and final colors C**1**, C**2**.

This method **400** is sometimes preferred because users often prefer the more saturated colors, and in this method **400**, the dynamically changing color stays a larger part of the time near the higher saturated colors C**1** and C**2**. That it, the time periods TSAT**2**, TSAT**2'** where the colors are highly saturated is greater in the method **400** shown in FIG. **4**, as compared to TSAT**1**, TSAT**1'** in the method **200** of FIG. **2**.

Another variation is to make the time period of phase **2** much shorter, as shown in the method **400'** of FIG. **4**B, where the time period T**2'** of the second phase **450'** is substantially less than the time periods T**1'**, T**3'** of first and last phases **440'**,

460'. The first and last phases T1', T3' may be substantially equal. In the method **400'**, hue changes much faster due to the short duration of the second phase time period T2' however, because the saturation during the second phase **450'** is at a lower value SMIN, this faster hue change is not perceived as being too fast.

FIG. **5** shows a color diagram or coordinate system **500** of the method **400'** shown in FIG. 4B for an illustrative example of changing colors from an initial color C**1** of Red to Blue (i.e., final color C**2**). The color change will look follow the dotted paths **510**, **520**, **530** during the three phases **440'**, **450'**, **460'**, respectively. That is, a disliked color such as pure Magenta M **540** (in the direct path between initial and final colors C**1** Red and C**2** Blue) is prevented, and the time T2' (FIG. **4**B) between the intermediate colors C**3**, C**4**, where the light is in the less saturated Magenta color, is minimized.

FIG. **6** shows yet another method **600** where constant values for both the hue and saturation are prevented. That is, both the hue and saturation are always dynamically and simultaneously changed during the transition from the initial and to the final color. In particular, during the first phase **640**, hue is slightly changed from the initial value of H**1** to a first intermediate value H**3**, and the saturation is substantially changed from an initial value S**1** to a first intermediate value S**3**. As shown in FIG. **6**, the rate of change of the hue curve **670** is relatively constant and low (constant and relatively flat or small slope) as compared to the overall rate of change of the saturation curve **680**, which is varied and starts by slowly changing near the initial color C**1** and changes faster (steep slope) towards the first intermediate color C**3**.

During the second phase **650**, hue is substantially changed from the first intermediate value H**3** to a second intermediate value H**4**, and the saturation is varied slowly from the first intermediate value S**3** to a lower value SMIN and then increased back up to a second intermediate value S**4**. The first and second intermediate values S**3**, S**4** may be the same or different values. During the third phase **660**, the hue value is slowly changed (relatively flat or small slop) from the second intermediate value H**4** to the final value H**2**, while simultaneously the saturation value is initially increased at a fast rate (large or steep slope) and then at a slower rate from the second saturation intermediate value S**4** to the final saturation value S**2**.

As shown in FIG. **6**, the rate of change of the hue curve **670** in the first and third phases **640**, **660** is relatively constant and low (i.e., relatively flat or small slope) as compared to the overall rate of change of the saturation curve **680**, which is varied and starts by slowly changing near the initial color C**1** and changes fast (steep slope) towards the first intermediate color C**3**. In the second phase **650**, the rate of change of the hue curve **670** is still substantially constant but is higher (i.e., steeper slope) than the rate of change during the first and third phases **640**, **660**.

The following is a summary of this method **600** shown in FIG. **6**:

(a) in the first phase **640**, the Hue changes little and the Saturation changes fast;

(b) in the second phase **650**, the Saturation changes little and the Hue changes fast; and

(c) in the third phase **660**, the Hue again changes little and the Saturation changes fast.

FIG. **7** shows a color diagram in a color coordinate system **700** of the method **600** shown in FIG. **6** for the illustrative example of changing colors from an initial color C**1** to a final color C**2**. The color change will follow the dotted paths **710**, **720**, **730** during the three phases **640**, **650**, **660**, respectively. Instead of the dotted path **720**, a different path **720'** may be followed to change the color between the intermediate colors C**3**, C**4**, such as by differently varying the hue and/or saturation curves **670**, **680** during the second phase **650**.

FIG. **8** shows yet another method **800** for the situation where the saturation of the starting color C**1** or of the end color C**2** is lower than the preferred minimum saturation value S_{MIN} of the second phase, e.g., S**2** is less than S_{MIN}, where S_{MIN} is the preferred minimum saturation value in phase **2** as described in connection with the previous methods, e.g., typically 40% to 70% of the maximum value S**1** and/or S**2**. As shown in the illustrative example of FIG. **8**, when the final saturation value S**2** is less then the preferred minimum saturation value S_{MIN}, then the saturation value in the second phase **850** is not reduced any further. Rather, the saturation value in the second phase **850** is set to equal the final saturation value of S**2** of the third phase **860**. Thus, the saturation value is kept constant at the low value of S**2**, being below S_{MIN}, during both the second and third phases **850**, **860**. In this illustrative method **800**, the hue is changed along a hue cure **870** which is similar to the hue curve **270** described in connection with FIG. **2**.

Of course, any other desired hue curve may be used in combination with further saturation curves, to dynamically and simultaneously control both the hue and saturation to provide a pleasing color change of light emanating from the controllable light source **920**. That is, the controller or processor **930** may be configured to control the light source **920** to change the color of light emanating therefrom using any desired predetermined or programmable hue and saturation curves, which may be any combination of linear, exponential, parabolic, or other curves satisfying any polynomial equation, for example.

FIG. **9** shows a light control system **900** according to one embodiment where a user interface **910** allows for user input, e.g., to set the desired color and initiate control of the light source(s) **920** to change color and output light having the desired color. The light source **920** may be a table lamp or a projector that projects light to any desired area, such as a wall, ceiling, floor, an/or a corner of a room, for example. The light control system **900** may be applied in any color controlled lighting products, consumer electronics products, e.g., Ambilight™ televisions, domestic appliance products e.g., wake-up lamps; retail environment to provide desired lighting effects, and/or medical appliances and lighting, e.g., as applied in operation rooms, recovery rooms, emergency rooms and the like.

The light source **920** and user interface **910** are operationally coupled to a processor or controller **930** configured to receive an input, such as from the user interface **910** and in response, is configured to control at least one or more controllable light sources **920** to change color in accordance with one or a combination of the described methods, which may be stored as computer readable and executable instruction in a memory **940**, operationally coupled to the processor or controller **930**.

The user interface **910** may be, for example, located on the light source **920**, on a hand-held remote controller, on a wall, and/or may be a soft switch such as displayed on a screen for control with any input device, such as a mouse or pointer in the case the screen is a touch sensitive screen. Further, touch sensitive elements (e.g., capacitively coupled strips or circular elements) of the user interface may be used to provide user input, such as to select the final or desired color along a color wheel, as well as to chose one of the various described methods, or combinations thereof, to change color.

The control system **900** may also be part of a master control system that may control various aspects of an environment, such as lighting, temperature, humidity, etc. Further, control system **900** may be configured to control any combination of light attributes such as intensity, color, color temperature, hue, diffuseness, focus, directivity, chromaticity, luminance, and/or saturation, in addition to changing the light color in accordance with codes stored in the memory **940** to perform any one or combination of the described methods. For example, various scripts of program codes may be stored in the memory for selection by the user to automatically change the color of light emanating from the light source **920** based on various predetermined or programmable parameters, such as time of day, day of week, the weather, season, etc., where appropriated sensors are providers, such as timers, calendars, photo-detectors to detect ambient light, temperature sensors, and the like.

The controller **930** may include any type of processor, controller, or control unit, for example. The controller or processor **930** is operationally coupled to controllable light source(s) **920**, such as LEDs, for controlling and changing attributes of light emanating therefrom. Light emitting diodes (LEDs) are particularly well suited light sources to controllably provide light of varying attributes, as LEDs may easily be configured to provide light with changing colors, intensity, hue, saturation and other attributes, and typically have electronic drive circuitry for control and adjustment of the various light attributes. However, any controllable light source may be used that is capable of providing lights of various attributes, such as different colors, hues, saturation and the like, such as incandescent, fluorescent, halogen, or high intensity discharge (HID) light and the like, which may have a ballast or drivers for control of the various light attributes.

Further, the controller **930** includes or is operationally coupled to the memory **940**. The memory **940** may be configured to store application data for proper operation of the controller **930** and other data, such as algorithm associated with the various hue and saturation curves according to the various described embodiments, and combinations thereof.

It should be understood that the various components of the lighting control system **900** may be interconnected through a bus, for example, or operationally coupled to each other by any type of link, including wired or wireless link(s), for example. Further, the controller **930** and memory **940** may be centralized or distributed among the various system components where, for example, multiple LED light sources **920** may each have their own controller and/or memory.

In another embodiment, the controller **930** is configured to select between a first method A and a second method B of going form the initial color to the final color based on how close are the hue values of the initial and final colors. For example, when the hue values of the colors in the starting and final scenes are not close, and the colors are saturated (like with LEDs), then changing the scene gradually from the starting scene to the final scene may cause a very colorful color change ('rainbow' like). All these intermediate colors have no meaning, neither for the starting scene nor for the final scene. Thus in this case, it is advantageous to use Method B for gradually changing the colors, where saturation is first decreased, hue changed and then saturation increased. However, in case the colors in the starting and final scenes are close, and the colors are saturated (like with LEDs), then changing the scene gradually from starting scene to final scene will cause a very smooth color change. Thus, Method A is sufficient and will be used where a direct or the shortest path between the initial and final colors or scenes is determined (e.g., by linear interpolation) and followed.

Consider the color triangle for a RGB color mixing luminaire in CIE1931 (x,y) space. Its shape is determined by the

primary colors Red (R), Green (G) and Blue (B) as shown in FIG. **10**. It should be noted that a similar color space includes white (W), and the description related to the RGB space equally applies to the RGBW space using RGBW color mixing luminaires and the same or similar graphs or figures equally apply, where the white primary color is added to improve color rending quality (and W also defines the reference point **1075**).

Consider a Hue, Saturation, Brightness (HSB) space, that includes a reference white point, e.g., point **1005** in FIG. **10** on or near the blackbody line **1050**. Discrete Hue values are at different radial lines **1060** (or **1310** in FIG. **13**) from the reference white point to a color on the color triangle **1070**, for example. Further, as shown in FIG. **13** discrete Saturation values are shown as dots **1305** and are along a radial line **1310** (or **1060** in FIG. **10**) in the color triangle **1070** through the reference white point and each of the defined Hue's along the color triangle. It should be noted that the Hue distribution need not be equidistant in the Hue angle definition of the CIE1931 (x,y) space. Further, it should be noted that the number of Saturation levels is not necessarily a constant that has for all Hue's the same value, neither it is necessarily a constant step size in CIE1931 (x,y) space. Of course, the brightness values are percentage of the maximum brightness in lumens that can be created at each color. Different hue values may by defined such as hue values that identify the colors yellow (Y), cyan (C) and magenta (M), as shown in FIG. **10**.

It should be noted that Even if the HSB color space is not defined with a discrete table, but instead is defined with formulas or equations, for example, the control of a luminaire via a user interface will be usually discrete, with a discrete number of Hue, Saturation and Brightness steps. Change can easily be seen or measured using these discrete steps in color and intensity. There is also an end-user need for color changing steps to be discrete, e.g., to ensure that the light change after an action on the user interface (going from one hue to the next for example) is always a clearly visible change (feedback to the user). Otherwise the user may be confused and may not understand what is happening if the color change of light from a light source is too little or takes too long time before any effect is visible.

Discrete number of Hue steps are desirable as experienced (or measurable) by the user, when using a user interface of the color mixing luminaire. Since a product designer of a color mixing luminaire in general strives to have a more or less perceptual equal distribution of colors, controlled via discrete steps on the user interface device, using discrete hues and saturation values is desirable. Moreover, the fact that usually color mixing luminaires have a digital control of the light levels of the primaries colors means that any color change will be discrete by definition. As described, there are various methods to change from an initial to a final color or scene, which may be preset and stored in the memory **940** shown in FIG. **9**.

In one embodiment, the controller **930** may be configured to select between two methods of changing colors, such as between Method A and Method B as will be described, based on closeness of initial and final hue values. In particular, initial and final hue values are close when they are located in adjacent segments of a color circle **1010** shown in FIG. **10**. FIG. **10** shows the color circle **1010** or the color triangle **1070** being divided into six segments, where each segment has its own number of discrete hue values. Of course, instead of six segments, any number of segments may be used. FIG. **13** also shows a schematic graphical representation of a discrete Hue-Saturation table with twelve discrete radial or hue lines H(**1**) to H(**12**), where each hue line H(i), i=1 to 12, has five discrete saturation values S(j), j=1 to 5, shown as dots **1305** along radial hue lines **1310**. Each of the twelve radial hue lines **1310** represents a constant hue value.

Returning to FIG. **10**, each segment of the six segments contains a part of the total range of the hue values and has its own number of discrete hue values where:

1. the first segment **1015** is between Red-Yellow (R-Y), with a number N_RY of Hue values, such as N_RY being seven RY hue values **1** to **7** shown in FIG. **10**;
2. the second segment **1020** is between Yellow-Green (Y-G), with a number N_YG Hue values, such as N_YG being five YG hue values **7** to **11** shown in FIG. **10**;
3. the third segment **1025** is between Green-Cyan (G-C), with a number N_GC Hue values;
4. the fourth segment **1030** is between Cyan-Blue (C-B), with a number N_CB Hue values;
5. the fifth segment **1035** is between Blue-Magenta (B-M), with a number N_BM Hue values;
6. the sixth segment **1040** is between Magenta-Red (M-R), with a number N_MR Hue values.

It should be noted that the segments may be the same or different size. For example, the six segments **1015**, **1020**, **1025**, **1030**, **1035**, **1040** may be the same size by dividing the color circle **1010** into six equal segments. Of course, the color circle **1010** may be divided into any desired number of segments. Similarly, the number of hue points in each segment may be the same or different in the six segments, where in FIG. **10**, the first and second segments **1015**, **1020** have different number of hue points, namely, seven RY hue values (**1** through **7**) in the first segment (i.e., RY segment) **1015**, and five YG hue values (**7** through **11**) in the second segment (i.e., YG segment) **1020**.

In a first case, when the initial and final hue values are not in adjacent or neighboring segments, then they are deemed to be far, or not close, and thus the controller **930** selects method B. Method B comprises indirectly going from the initial to final colors through an intermediate color or reference white point **1075**, which may be any point substantially on or near a blackbody line **1050**. For example, using method B, saturation of the initial color, e.g., Red having a first or initial hue value H_1 and a first or initial saturation value S_1, is decreased from to S_1 to S_{min}, where S_{min} is the saturation value of the intermediate color or reference point **1075** (e.g., substantially on or near a blackbody line **1050**) which may be substantially white and S_{min} may be substantially zero.

Of course, the saturation may be decreased to a lower value possibly near zero, instead of zero, as shown in FIG. **11**, where the initial saturation S_1 of an initial color (having initial hue and saturation H_1S_1) is first decreased along path **1110** to an intermediate value S_{min} to a first intermediate point H_1 S_{min}, then the hue is changed along path **1120** (where the saturation remains as the intermediate value S_{min}) from the initial hue value H_1 to the final hue value H_2, where a second intermediate point is reached H_2S_{min}. Next, the saturation is increased along path **1130** from the intermediate value S_{min} to the final saturation value S_2 thus reaching the final color having the final hue and saturation values H_2S_2.

In a second case, when the initial and final hue values are in the same segment, then they are deemed to be close, and thus the controller **930** selects method A, where the initial color is changed to the final color directly, such as using linear interpolation to go directly from the initial color to the final color, as shown by the direct path **1210** in FIG. **12** between initial and final colors H_1S_1, H_2S_2, which are in the sixth segment M-R **1040**.

In a third case, when the initial and final hue values are in adjacent or neighboring segments, then the distance a hue distance HD between the initial and final hue values is determined, and the controller **930** selects method A or B based on the determined value of the hue distance HD. In particular, the hue distance HD is defined as the number of discrete hue values, or the minimum number of steps in a discrete Hue table to incrementally step from the initial hue value H_1 to the final hue value H_1 of the initial and final colors.

FIG. **13** shows a graphical representation **1300** of a color table that may be stored in the memory **940** (shown in FIG. **9**) having a fixed or discrete number of hue and saturation values or steps, which may be any desired number hue and saturation values (independent of brightness). In FIG. **13**, the number of hue values is twelve, namely H(**1**) to H(**12**). That is, the color circle **1010** shown in FIG. **10** is divided into radial lines **1310**, where each line represents a particular hue value, where twelve lines or discrete hue values are shown in FIG. **13**. The hue values may be grouped into segments containing an equal or different number of hue values, such as the six segments shown in FIGS. **10-12**, for example. That is, a segment is a group of adjacent hue values, being a part of the full color circle.

Further, FIG. **13** shows that each hue value H(**1**) to H(**12**) has five saturation value shown as five dots (including the center dot) along a radial line **1310**. The various radial lines may have the same number or a different number of saturation values or steps. Circle **1320** is shown in FIG. **13** having the same saturation value. Another color table may include **30** hue values (NHue=30) and 10 saturation values (NSat=10), where each color is defined by Hue (i) with i=1 . . . 30, and Sat(j) with j=1 . . . 10. One can change color from an initial color having values [Hue(**3**), Sat(**5**)] to a final color [Hue(**10**), Sat(**10**)], for example.

N1 and **N2** are also defined as follows, (which are in addition to defining the hue distance HD as the minimum number of steps or hue values in a hue-saturation table (similar to that shown in FIG. **13**) to incrementally step from the initial hue value H_1 to the final hue value H_2):

N1 is the number of hue values in the segment of the color circle that includes the initial hue value H_1 (e.g., being one of the 6 segments shown in FIG. **10**), and similarly

N2 is the number of hue values in the segment of the color circle that includes the final hue value H_2.

The initial and final hue values H_1, H_2 are defined as being close when:

$HD \leqq \alpha\,(N1+N2)$ for hues in the first and second neighboring segments;

with $0<\alpha<1$, where it may be desirable to set $\alpha=0.5$ or smaller.

It should be noted that the hue distance HD may be defined with further constants that may be selected to have any desired value. For example, the following relationship may be used for the hue distance HD:

$$HD=\alpha N1+\beta N2+\gamma(N1)(N2)+\Delta$$

where α, β, γ, Δ are all constants that are set to a desired value, e.g., by the user. The above general formula for the hue distance HD is reduced to the one described above when $\alpha=\beta$ and $\gamma=\Delta=0$. Of course, if desired, upper and lower limits may be pre-set for the values of one or more of the constants α, β, γ, Δ so that a user cannot set the value(s) of the constant(s) beyond such maximum and minimum values.

In an illustrative example shown in FIG. **10**, assume the initial hue value H1 is inside the R-Y segment **1015**, where $H_1=5$ (or $H_1=H(\mathbf{5})$), and the final hue value H_2 is in the adjacent or neighboring Y-G segment **1020**, where $H_2=8$ (or

H**2**=H(**8**)). The hue distance HD, which is the number of hue steps from H_1 to H_2 is 8-5=3. N**1**=7 since there are 7 hue value in the R-Y segment **1015**, namely H(**1**) to H(**7**), and N**2**=5 since there are 5 hue value in the Y-G segment **1020**, namely H(**7**) to H(**11**). Let α=0.5, so α (N**1**+N**2**)=0.5 (7+5)=6. Since HD$\leqq\alpha$ (N**1**+N**2**) or 3$\leqq$6, then the two colors or hues H(**5**) and H(**7**) are close and Method A is selected and a direct linear path **1080** is followed. If HD>6, then the initial and final hue values are not close, and Method B is selected and path **1085** is followed.

It should be noted that in addition or instead of using a fixed value for a for all combinations of 2 colors in the color transition from an initial Color **1** to a final Color **2** (Color being defined as a combination of Hue and Saturation values HS), a table may be used that includes factors a defined per combination of the initial and final hue values H_1, H_2, or even per H_1 and H_2 values together with their associated initial and final saturation values S_1 and S_2.

It should also be noted that it is desirable to have a minimum value for α, as seen from the following example. If a is approximately zero, then initial and final color are deemed close if the hue distance between them HD$\leqq\alpha$ (N**1**+N**2**) or HD less than or equal to almost zero, when a is approximately zero. In most cases, this means that the color cannot gradually change from the one segment to the next segment. Consider the example shown in FIG. **10**, where the first segment **1015** between Red-Yellow has 7 hues values **1** through **7**, and the second segment **1020** between Yellow-Green has 4 hue values from **7** to **11**.

If α=0.1,

then a (N**1**+N**2**)=0.1(7+4)=1.1

This means that two colors are close only if there distance is less than or equal to 1.1. That is, only colors that are next to each other are deemed close, e.g., H_2 and H_3, where H_2 and H_4 are deemed far since the distance between them is 2 (i.e., HD=2) and based on the formula, HD$\leqq\alpha$ (N**1**+N**2**), then 2>1.1 and thus H_2 and H_4 are deemed to be far apart despite being in the same segment, namely, the first segment **1015**. Of course, such a criteria, where only adjacent colors are deemed to be close, is too restrictive. Therefore, it is desirable to set a lower boundary or value for a that should substantially always lead to having an initial color in the one segment (e.g., the first segment **1015**) and the final color in the adjacent segment (e.g., the second segment **1020**). Such a lower boundary for a may be determined experimentally, for example, depending on the particular situation, such as the number of segments, the number of hue points in each segment, and the like.

For hue values that are close according to the above definition, i.e., when the hue distance HD between initial and final hue values H_1, H_2 satisfies HD$\leqq\alpha$ (N**1**+N**2**), then method A is used during a color change (e.g., linear interpolation directly) between the initial and final colors; otherwise method B is used.

A system and a controller that automatically select between methods A and B as described (e.g., depending on the hue distance HD between the starting point Hue and the end point Hue between which the colors are gradually changed,) allows for a user friendly and gradual change between two colors or presets that may stored in the memory **940** shown in FIG. **9**, thus easily fine-tune the atmosphere between the two pre-sets.

Of course, as it would be apparent to one skilled in the art of communication in view of the present description, various elements may be included in the system or network components for communication, such as transmitters, receivers, or transceivers, antennas, modulators, demodulators, converters, duplexers, filters, multiplexers etc. The communication or links among the various system components may be by any means, such as wired or wireless for example. The system elements may be separate or integrated together, such as with the processor. As is well-known, the processor executes instruction stored in the memory, for example, which may also store other data, such as predetermined or programmable settings related to system control.

Various modifications may also be provided as recognized by those skilled in the art in view of the description herein. The operation acts of the present methods are particularly suited to be carried out by a computer software program. The application data and other data are received by the controller or processor for configuring it to perform operation acts in accordance with the present systems and methods. Such software, application data as well as other data may of course be embodied in a computer-readable medium, such as an integrated chip, a peripheral device or memory, such as the memory **940** or other memory coupled to the processor **930**.

The computer-readable medium and/or memory may be any recordable medium (e.g., RAM, ROM, removable memory, CD-ROM, hard drives, DVD, floppy disks or memory cards) or may be a transmission medium (e.g., a network comprising fiber-optics, the world-wide web, cables, and/or a wireless channel using, for example, time-division multiple access, code-division multiple access, or other wireless communication systems). Any medium known or developed that can store information suitable for use with a computer system may be used as the computer-readable medium and/or memory.

Additional memories may also be used. The computer-readable medium, the memory, and/or any other memories may be long-term, short-term, or a combination of long-and-short term memories. These memories configure the processor/controller to implement the methods, operational acts, and functions disclosed herein. The memories may be distributed or local and the processor, where additional processors may be provided, may be distributed or singular. The memories may be implemented as electrical, magnetic or optical memory, or any combination of these or other types of storage devices. Moreover, the term "memory" should be construed broadly enough to encompass any information able to be read from or written to an address in the addressable space accessed by a processor. With this definition, information on a network, such as the Internet, is still within memory, for instance, because the processor may retrieve the information from the network.

The controllers/processors and the memories may be any type. The processor may be capable of performing the various described operations and executing instructions stored in the memory. The processor may be an application-specific or general-use integrated circuit(s). Further, the processor may be a dedicated processor for performing in accordance with the present system or may be a general-purpose processor wherein only one of many functions operates for performing in accordance with the present system. The processor may operate utilizing a program portion, multiple program segments, or may be a hardware device utilizing a dedicated or multi-purpose integrated circuit. Each of the above systems utilized for changing color may be utilized in conjunction with further systems.

Finally, the above-discussion is intended to be merely illustrative of the present system and should not be construed as limiting the appended claims to any particular embodiment or group of embodiments. Thus, while the present system has been described in particular detail with reference to specific exemplary embodiments thereof, it should also be appreciated that numerous modifications and alternative embodiments may be devised by those having ordinary skill in the art without departing from the broader and intended spirit and scope of the present system as set forth in the claims that follow. The specification and drawings are accordingly to be regarded in an illustrative manner and are not intended to limit the scope of the appended claims.

In interpreting the appended claims, it should be understood that:

a) the word "comprising" does not exclude the presence of other elements or acts than those listed in a given claim;

b) the word "a" or "an" preceding an element does not exclude the presence of a plurality of such elements;

c) any reference signs in the claims do not limit their scope;

d) several "means" may be represented by the same or different item or hardware or software implemented structure or function;

e) any of the disclosed elements may be comprised of hardware portions (e.g., including discrete and integrated electronic circuitry), software portions (e.g., computer programming), and any combination thereof;

f) hardware portions may be comprised of one or both of analog and digital portions;

g) any of the disclosed devices or portions thereof may be combined together or separated into further portions unless specifically stated otherwise;

h) no specific sequence of acts or steps is intended to be required unless specifically indicated; and

i) the term "plurality of" an element includes two or more of the claimed element, and does not imply any particular range of number of elements; that is, a plurality of elements may be as few as two elements, and may include an immeasurable number of elements.

The invention claimed is:

1. A lighting system, comprising:

a light source configured to provide a light;

a user interface for receiving a user input related to a desired final color of the light; and

a controller for controlling at least hue and saturation of the light to change a color of the light along a predetermined path in at least two phases from an initial color going through an intermediate color having reduced saturation relative to the initial color to the final color,

wherein,

during a first phase, the controller is adapted to reduce the saturation to reach the level of the intermediate color while maintaining the hue at an initial value, and

during at least a second phase, the controller is adapted to modify the hue from the initial value to a final value and maintain saturation at the intermediate color to set to the level of provided light to the final color.

2. The light system of claim **1**, wherein, during a third phase after the second phase, the controller increases the saturation from the intermediate level to a final level and changes the hue from the initial value to a final value.

3. The light system of claim **1**, wherein the controller is configured to change the saturation during one phase while keeping the hue constant, and to change the hue in another phase while keeping the saturation constant.

4. The light system of claim **3**, wherein the controller is configured to change the saturation at a slower rate near at least one of an initial setting and a final setting relative to a rate of change near an intermediate setting between the initial setting and the final setting.

5. The light system of claim **1**, wherein the controller is configured to simultaneously change the saturation while maintaining constant the hue during an initial phase and a final phase, and to simultaneously change the hue while maintaining constant the saturation during an intermediate phase.

6. A method of controlling a light source, comprising;

producing a light from the light source;

receiving a user input related to a final color; and

controlling hue and saturation of the light to change a color of the light automatically along a predetermined path from an initial color going through an intermediate color having reduced saturation relative to the initial color to a final color during at least two phases,

wherein,

during a first phase, the saturation is reduced from the initial level to reach and intermediate level to reach the level of the intermediate color while maintaining the hue at an initial value, and

in a second phase, maintaining the saturation at the intermediate level and change the hue from the initial value to a final value to set to the light output level at the final color.

7. The method of claim **6**, wherein, during a third phase, the controlling act increases the saturation from the intermediate level to a final level and changes the hue from the initial value to a final value.

8. The method of claim **6**, wherein the controlling act changes the saturation during one phase while keeping the hue constant and changes the hue in another phase while keeping the saturation constant.

9. The method of claim **8**, wherein the controlling act changes the saturation at a slower rate near at least one of an initial setting and a final setting relative to a rate of change near an intermediate setting between the initial setting and the final setting.

10. The method of claim **6**, wherein the controlling act simultaneously changes the saturation while maintaining constant the hue during an initial phase (**440**) and a final phase (**460**), and changes the hue while maintaining constant the saturation during an intermediate phase (**450**).

11. The method of claim **6**, wherein, in response to a desired setting that includes a saturation level which is below a predetermined level, the controlling act reduces the saturation to the predetermined level during a first phase and maintains constant the saturation at the predetermined level during a second phase.

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