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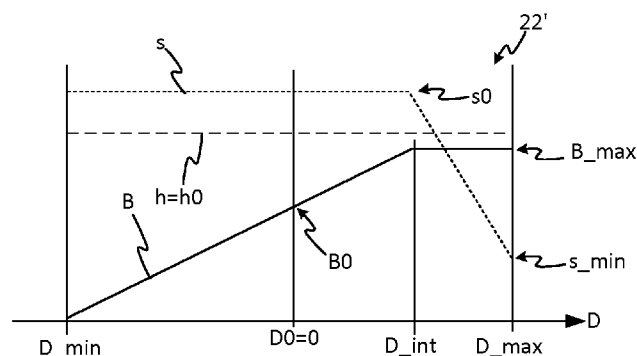
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(54) Title: DIMMING CONTROLLER.

**FIG. 3**

(57) Abstract: A dimming controller for a lighting system, the dimming controller comprises: a dimming input configured to receive from a user a dimming level that is adjustable by the user; and a control unit configured to generate a control signal for controlling a luminous intensity and a chromaticity of light emitted by at least one luminaire of the lighting system. The control unit is configured to respond to successive increases in the dimming level by successively increasing the luminous of the emitted light whilst maintaining a substantially constant chromaticity of the emitted light until reaching a maximum luminous intensity for that chromaticity, and thereafter by successively reducing a saturation of the chromaticity of the emitted light.



Dimming controller

TECHNICAL FIELD

The present invention related to a dimming controller for a lighting system capable of rendering colored light, i.e. having both a controllable brightness and a controllable chromaticity.

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BACKGROUND

Forms of dimming control, wherein a user can manually adjust a brightness of light emitted by a lighting system, have been available for some time. The user sets a dimming level (i.e. a one-dimensional dimming control parameter), according to which the brightness is adjusted. The dimming level can be set in a number of ways, for example using a traditional dimmer switch incorporating a variable resistor, in which the dimming level is embodied as an electrical resistance of the variable resistor, and is continuously adjustable by means of movable switch element (e.g. a sliding or rotary dimmer switch) coupled to the variable resistor for varying its resistance. In more modern lighting systems, the dimming level may be adjustable, for example, using a wireless remote control (e.g. using a pair of function buttons of the remote control to adjust the dimming level up or down in a stepwise fashion, or using a movable switch element of the remote control to adjust it continuously), or using an application executed on a computer, such as a smartphone, via a graphical user interface (GUI) provided by the application.

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The brightness can be adjusted according to a dimming level in a number of ways. For example, a voltage or current supplied to one or more luminaires of the lighting system may be adjusted according to the dimming level. As another example, a duty cycle of the light emitted by the luminaire(s) may be adjusted, referred to as pulse width modulation (PWM), which is particularly well-suited to some forms of LED lighting system.

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SUMMARY

In the past, lighting systems found in day-to-day environments, such as a home or office, were designed around an assumption that they will emit just white or-near white light of fixed chromaticity. However, with the recent advancements in LED technology

in particular, it is possible to create rich and colorful light scenes as well as pleasant near-white light with LED light sources. As such, many modern lighting systems provide increasing levels of flexibility, by offering a greater level of control over both the brightness and the chromaticity of not only the light emitted by a lighting system as a whole, but also individual brightness and chromaticity control for, say, individual luminaires (or groups of luminaires). This, in turn, can be used to provide rich features, such as allowing a scene controller of a lighting system to render a complex lighting scene in a variety of ways. For example, by providing separate user input elements (e.g. on a GUI generated by a lighting control application) to control brightness hue and saturation independently for individual luminaires (or groups of luminaire), or by providing a mechanism by which the user can select an image and rendering different illumination colors to match colors of the selected image.

Whilst this level of control can be at times desirable for the user due to the high level of flexibility it affords, at other times it may be more convenient for the user to have available a simpler control mechanism, whereby he can tune multiple characteristics of the illumination with a single control action. To this end, various aspects of the present invention are directed to a dimming controller which, unlike conventional dimming controllers, is adapted for controlling not only the brightness but also the chromaticity of the illumination based on a single dimming level in an intuitive manner.

A first aspect of the present invention is directed to a dimming controller for a lighting system, the dimming controller comprising: a dimming input configured to receive from a user a dimming level that is adjustable by the user; and a control unit configured to generate a control signal for controlling a luminous intensity (i.e. "actual" brightness – see below) and a chromaticity of light emitted by at least one luminaire of the lighting system; wherein the control unit is configured to respond to successive increases in the dimming level by successively increasing the luminous intensity of the emitted light, whilst maintaining a substantially constant chromaticity of the emitted light, until reaching a maximum brightness for that chromaticity, and (immediately) thereafter by successively reducing a saturation of the chromaticity (i.e. a color saturation) of the emitted light whilst maintaining at least the maximum luminous intensity.

Because the dimming level is one-dimensional control parameter, it can be set using any one-dimensional user input element (which may be a physical device or a displayed GUI element) i.e. providing only one dimension of control. It may be set in any conventional manner (e.g. using a dimmer switch) or by some other means. By adjusting the

dimming level, the user can for example tune the luminaire(s), with a single control action, from a dimmed saturated scene to a bright de-saturated scene.

After reaching the maximum luminous intensity for the substantially constant chromaticity maintained up to that point, the luminous intensity may remain substantially constant whilst the light is de-saturated, or it may continue to increase as the saturation decreases. Regarding the latter, what may for example play a role here is that, for a luminaire with (say) red, green and blue LEDs, maximum brightness may be reached for a maximally saturated red hue when the red LED is emitting at maximum intensity, and the blue and green LEDs are not emitting or are emitting at much lower levels. Upon reaching this maximum, desaturation can be effected by increasing the intensity of the red and green LEDs whilst maintaining the maximum intensity of the red LED – causing both a de-saturation and an increase in the overall luminous intensity (above and beyond the maximum luminous intensity achievable by the red LED alone).

Multiple controls may not always be desirable from a usability or practical point of view. For example, some end-users may not be familiar with concepts like "hue" and "saturation", and just want what they perceive as "more" or "less" light, and therefore like the simplicity afforded by traditional dimming controllers. An advantage of the present invention's mapping of the dimming level to the brightness and color saturation, whereby the brightness is increased to a maximum brightness and thereafter the light is de-saturated, is that it provides intuitive control: the human visual system is such that, even when the "actual" brightness (i.e. luminous intensity) remains constant during the de-saturation, de-saturating it gives the impression of creating "more" light (as it transitions from deeper-hues to nearer white) i.e. the "perceived" brightness (as perceived by the user) still increases. Of course, in the alternative case that the actual brightness (i.e. luminous intensity) continues to increase during de-saturation, the perceived brightness will also increase as a result. Thus, whether or not the "actual" brightness (i.e. luminous intensity) is increasing or remaining constant during the de-saturation, this "perceived" brightness will increase during at least as result of the de-saturation. The present invention affords the user this simplicity, whilst at the same time offering more control by intelligently combining brightness and saturation control (the lay user may not even be consciously aware of this, but will still reap the benefits as, the dimming controller will be able to provide "more" light from his perspective by de-saturating it after reaching the maximum brightness).

Another advantage is that the dimming controller can be readily incorporated into modern lighting systems, in order to complement the rich and flexible control these

afford. For example, when incorporated into a lighting system equipped with an advanced scene controller capable of rendering a lighting scene based on a selected image and/or complex user selections, a user can set a multi-colored light scene based on an image and subsequently tune the whole scene in one go simply by adjusting the dimming level.

5 In preferred embodiments, the dimming controller comprises a reference input configured to receive a set of one or more reference color parameters (i.e. reference parameter set), and the control unit is configured to control the chromaticity of the emitted light based on a reference chromaticity denoted by the reference parameter set (i.e. the reference parameter set denotes a reference hue and/or a reference saturation).

10 The reference color parameter set may be generated by a scene controller, based on one or more user inputs to the scene controller.

A basic scene controller may allow a user to simply set a reference hue (e.g. selected from a basic color palette), such that the luminous intensity and saturation are controlled entirely by the dimming level.

15 A more sophisticated scene controller may be able to generate a more comprehensive reference color parameter set, e.g. additionally denoting a reference saturation and/or luminous intensity, based on an image selected by the user and/or based on advanced user settings (e.g. the user manually setting reference brightness and chromaticity settings for individual luminaires or bulbs). These reference points are used by the dimming controller to
20 determine how the luminous intensity and saturation at least vary as a function of the dimming level. This provides the same level of flexibility as modern lighting systems whilst at the same time providing an additional, simpler and complementary control mechanism in the form of the adjustable dimming level.

The control unit may be configured to set a hue of the chromaticity
25 independently of the dimming level during said reduction of the saturation (for example, the hue may also remain substantially constant during the de-saturation as well), e.g. to match a reference hue denoted by the reference parameter set (i.e. the substantially constant hue that is maintained up to that point may match the reference hue). Alternatively or in addition, it may be configured to set the saturation of the chromaticity of the emitted light when below
30 the maximum luminous intensity to match a reference saturation denoted by the reference parameter set (i.e. the substantially constant saturation that is maintained up to that point may match the reference saturation). The control unit may be configured to set the chromaticity (i.e. both hue and saturation) of the emitted light when below the maximum luminous intensity to match the reference chromaticity denoted by the reference

parameter set (i.e. the substantially constant chromaticity that is maintained up to that point may match the reference chromaticity).

As noted, "actual" brightness (B) in the context of the present invention means the luminous intensity of the emitted light, i.e. a photometric measure of a perceived total power (i.e. energy per unit time) of the emitted light per unit of solid angle. That is, the total radiometric power (energy per unit time) of the emitted light in all directions weighted to account for varying sensitivities of a human visual system to different wavelengths according to the standard and well-established luminosity function. It is closely related to luminance, commonly denoted "Y" in the art, in that the luminance Y is the luminous intensity emitted per unit area. Despite this photometric weighting, it is still the case that decreasing the saturation at constant hue and brightness (i.e. luminous intensity) is perceived by the human visual system as creating "more" light. Brightness can be fully represented using a single parameter.

A distinction is drawn herein between "actual" brightness in this sense, i.e. luminous intensity which is an objectively measurable flux output of the at least one luminaire (e.g. in units of candela), and what is sometimes referred to as "perceived brightness" herein, which refers to an impression created by desaturation at constant luminous intensity even when the actual brightness (i.e. luminous intensity) is unchanged, from the perspective of the user.

Unless otherwise indicated, all references to "brightness" below mean the actual brightness i.e. the luminous intensity.

"Chromaticity" is a color measure of the emitted light defined independently of the brightness B (i.e. independently of its luminous intensity). Chromaticity can be fully defined using two independent parameters, such as hue and saturation values (hs), CIE chromaticity values "xy", CIE tristimulus values "XZ". Broadly speaking, "hue" corresponds to a peak wavelength of the emitted light, and "saturation" to a spread of wavelengths about that peak (lower saturation corresponding to a wider spread). Maximum-saturation corresponds the outer-boundary of a CIE color space (42, figure 4A/4B), wherein a reduction in the saturation corresponds to a movement away from the outer-boundary 42 towards the white region of the CIE color space.

As such, the brightness and chromaticity characteristics of emitted light can be fully defined using three independent parameters – such as hsB; xyB; XBZ; RGB (red, green, blue), yellow/cyan/magenta etc. – often referred as a color vector or simply a color by those skilled in the art. As such, the term "color" sometimes can sometimes refers to a three-

dimensional color vector in this sense (covering both brightness and chromaticity), and at other times refers to just chromaticity (not brightness). Where the term "color" is used herein, it will be clear in context what is meant.

For the avoidance of doubt, it is noted that the terms "chromaticity", "hue" and "saturation" refer to physical characteristics of the emitted light itself, and are not limited to any particular representation of color data used by the dimming controller or any other component of the lighting system. For example, whilst the control signal generated by the control unit may encode a given saturation, hue and brightness "directly" as respective hue, saturation and brightness values (hsB) embedded in the control signal, the invention is not limited to this: for example, the hue and saturation may be conveyed by "xy" or "XZ" values embedded in the signal, or all three of the brightness, hue and saturation may be conveyed by, say, an RGB or yellow/cyan/magenta triplet of values embedded in the control signal; or, in certain circumstances, it may be possible to represent, say, the chromaticity using a single value, such as a color temperature where the distribution of the emitted light is approximately a black-body distribution. In general, the information needed to cause the initial increase in brightness followed by de-saturation after reaching the maximum brightness can be represented in any suitable form (analogue or digital) and embedded in the control signal in any suitable manner.

It is also noted that "maximum brightness" in the context of the present invention does not necessarily mean an absolute maximum brightness achievable by the luminaire for a given chromaticity; the maximum brightness may also be a brightness below this absolute maximum that is deliberately imposed by the control unit. For example, in preferred embodiments, the control unit is configured to determine the maximum luminous intensity based on the reference chromaticity denoted by the reference color parameter set. That is, the maximum luminous intensity is set according to the reference chromaticity, and may be varied by the control unit in response to changes in the reference chromaticity denoted by the reference parameter set.

Moreover, the maximum brightness can in some cases vary depending on the chromaticity of the emitted light itself.

"Substantially constant chromaticity" means constant enough that the user cannot perceive a change in color saturation and hue. "Substantially maximum brightness" means constant enough that the user cannot perceive a brightness drop as he continues to increase the dimming level, i.e. it means no or perceptually negligible deviation from the maximum brightness during the desaturation.

The control unit may be configured to determine the non-linear function using the reference parameter set.

The control unit may be configured to reduce the saturation as a function of the dimming level, the control unit being configured to determine the function by retrieving a set of chromaticity values held in a data store in association with the reference color parameter set.

The control unit may be configured to decrease the saturation to no less than a minimum saturation, at which a hue of the chromaticity of the emitted light is still perceptible to the user.

The control unit may be configured, when the dimming level is adjusted to a predetermined value, to set the chromaticity and luminous intensity of the emitted light to match the reference chromaticity and a reference luminous intensity denoted by the reference color parameter set, whereby the chromaticity and luminous intensity of the emitted light when the dimming level is at the predetermined value is changeable by changing the reference parameter set.

The control unit may be configured reduce the saturation after reaching the maximum luminous intensity towards a point on a Planckian locus, wherein the point is selected based on the substantially constant chromaticity of the emitted light.

A lighting control system may comprise: a scene controller configured to generate a set of one or more reference color parameters based on at least one color selection input received from a user; and a dimming controller according to the preferred embodiments of the first aspect, wherein the dimming controller comprises a reference input configured to receive the reference parameter set, and the control unit is configured to control the chromaticity of the emitted light based on a reference chromaticity denoted by the reference parameter set.

A second aspect of the present invention is directed to a method of controlling a lighting system based on a dimming level, the method implementing by a dimming controller the following steps: receiving from a user a dimming level that is adjustable by the user; and generating a control signal for controlling a luminous intensity and a chromaticity of light emitted by at least one luminaire of the lighting system; wherein in response to successive increases in the dimming level, the luminous intensity of the emitted light is successively increased whilst maintaining a substantially constant chromaticity of the emitted light until reaching a maximum luminous intensity for that chromaticity, and thereafter a

saturation of the chromaticity of the emitted light is successively reduced whilst maintaining at least the maximum luminous intensity.

In embodiments of the second aspect, any feature of any embodiment of the first aspect may be implemented.

5 A third aspect of the present invention is directed to a computer program product comprising code stored on a computer readable storage medium and configured when executed to implement the method of the second aspect or any embodiment thereof.

BRIEF DESCRIPTION OF FIGURES

10 For a better understanding of the present invention, and to show how the same may be carried into effect, reference is made to the following figures, in which:

Fig. 1 shows a perspective view of an exemplary environment illuminated by a lighting system;

15 Fig. 2 illustrates cooperation between a dimming controller and a scene controller of a lighting system;

Fig. 3 shows a graph illustrating an example of how a dimming controller can modify reference color parameters based on a received dimming level for rendering by at least one luminaire of a lighting system;

Fig. 4A shows a graph illustrating a CIE color space;

20 Fig. 4B shows a graph representing color modification by a dimming controller in a CIE color space;

Figs. 5A-5D show various examples of how a dimming controller can be incorporated in a lighting system;

25 Fig. 6A shows a first example, in which a dimming level is adjusted using a control mechanism incorporated in a luminaire;

Fig. 6B shows a second example, in which a dimming level is adjusted using a graphical user interface displayed on a user device.

DETAILED DESCRIPTION OF EXAMPLE EMBODIMENTS

30 Figure 1 illustrates an example lighting system 1 in which embodiments of the present invention can be implemented. The lighting system 1 comprises one or more luminaires 4 installed in an environment 2, arranged to emit light in order to illuminate that environment 2. The environment 2 may be an indoor space such as one or more rooms and/or corridors, or an outdoor space such as a park or garden, or a partially covered space such as a

stadium or gazebo, or any other space such as an interior of a vehicle, or any combination of these. Each of the luminaires 4 comprises at least one respective light emitting device such as an LED-based lamp, gas-discharge lamp or filament bulb, plus any associated housing or support. Each of the luminaires 4 may take any suitable form such as a ceiling or wall
5 mounted luminaire, a free standing luminaire (e.g. table lamp, desk lamp or floor lamp etc.), a wall washer, or a less conventional form such as an LED strip, a luminaire built into a surface or an item of furniture, or any other type of illumination device for emitting illumination into the environment 2 so as to illuminate the environment 2.

Each luminaire 4 has both a controllable brightness (i.e. luminous intensity)
10 and chromaticity. It may for example comprise three light emitting elements (red, green, blue; yellow, cyan, magenta etc.) which can be independently controlled to adjust the overall brightness and chromaticity of the composite light. The lighting emitting elements may be different colored LEDs incorporated in to a single light bulb, or three separately replaceable lighting bulbs etc.

15 The lighting system 1 also comprises an interface device 10, sometimes referred to as a bridge. The bridge 10 is connected to each of the luminaires 4 such that it can transmit control data to that luminaire in order to change not only a brightness of its emitted light, but also its chromaticity such that it can vary both its saturation and hue. A lighting system providing advanced control such as this is sometimes referred to as a "connected
20 lighting" system. In this manner, the luminaires 4 form a lighting network, to which the bridge 10 is a gateway. One example of a suitable bridge 10 is the Philips Hue Bridge.

Figure 2 is a functional block diagram, in which a scene controller 16 and a dimming controller 12 are shown. The scene controller 16 and dimming controller 12 are functional modules, representing different functionalities that are implemented by the
25 lighting system 1. The scene controller 16 and the dimming controller 12 provide different but complementary mechanisms by which a user 8 occupying the environment 2 can adjust the illumination as he desires.

The scene controller 16 generates a set of one or more reference color parameters 22 ("reference parameter set"), based on one or more color selection inputs by the
30 user 8. The reference parameter set 22 denotes (i.e. conveys) at least one reference color vector i.e. at least one reference hue, saturation (h0,s0,B0 respectively).

The scene controller 16 may provide "advanced" control, in the sense that the user 8 has as much freedom as he likes to set reference color vector(s) for individual luminaires (or groups of luminaires). For example, the user can manually input one or more

individual color selections 18 for one or more of the luminaires to the scene controller, or the user can select at least one image 20 which is received and processed by the scene controller 16 in order to determine color characteristics of the selected image for rendering by one or more of the luminaires 4. This image-based color selection may be entirely automatic or the selected image may be displayed by the scene controller 16 to the user 8 so that the user can manually select one or more colors within the image 20 to be rendered by the luminaires 4 (e.g. by placing one or more color pickers on the displayed image), i.e. the color selections 18 may be made by the user from the image 20. Alternatively, the color selections 18 may be made, for example, using a color palette, color wheel, a voice command, or other color selector that is displayed by the scene controller 16.

Alternatively, the scene controller 16 may simply function as a hue selector, by which the user 8 simply selects the reference hue h_0 for the illumination of the lighting system (or multiple reference hues, for different luminaires) with all control over brightness and saturation being provided by the dimming controller 12 (see below). In this case, the scene controller may determine a reference saturation s_0 and brightness automatically B_0 (e.g. based on one or more capabilities of the lighting system 1), or pre-determined (e.g. default, or user-specified) reference saturation and brightness values may be used to apply the techniques set out below.

Alternatively, the scene controller 16 may offer different levels of control which the user can choose between e.g. to provide the user 8 with a basic option of providing a simple, quick and easy hue selection, and also more advanced selection options should he wish to take advantage of them.

Based on the user's one or more color selections 18 (which may be a simple hue selection, or a more advanced selection conveying additional reference brightness and/or hue information) and/or the selected image 20, the scene controller 16 generates the reference parameter set 22. As noted above, whilst it may be the case that the reference parameter set conveys these directly (i.e. it may comprise at least one brightness value, at least one hue value and at least one saturation value), this is not essential e.g. the reference hue h_0 and saturation s_0 may be represented by "xy" or "XZ" values (neither of which necessarily corresponds to a hue or saturation value directly, but which nonetheless fully define the desired hue and saturation when taken together); as another example, the reference brightness B_0 , hue h_0 and saturation s_0 may be conveyed by a triplet of RGB values, or yellow/cyan/magenta values in the parameter set 22, based on a color temperature, or using any other suitable combination of parameters in the reference parameter set 22.

The reference parameter set 22 is provided to the dimming controller 12 by the scene controller 16. The dimming controller 12 has an input connected to receive a dimming level D (i.e. one dimensional control value) set by the user 8, according to which the dimming controller 12 modifies the reference parameter set 22, thereby generating a modified set of color parameters 22'. The modified parameter set 22; denotes at least one hue "h", saturation "s", and brightness "B" to be rendered by at least one of the luminaires 4. As for the unmodified reference parameter set 22, the modified parameter set 22' may convey these using any suitable combination of parameters that need not be hue, saturation or brightness values *per se*. Moreover, the modified parameter set 22' need not represent hsB in the same form as the original parameter set 22 represents h_0, s_0, B_0 . For example, h_0 and s_0 may be represented by xy values in the original parameter set 22, whereas hsB may be represented by a triplet of RGB or yellow/cyan/magenta values in the modified parameter set 22'.

The modified parameter set 22' is what sets the actually illumination emitted by at least one of the luminaires 4, such that the illumination can be adjusted both by modifying the underlying reference parameters 22 but also by adjusting the dimming level D . The modified parameter set 22' is embedded in a control signal 22', which controls the at least one luminaire to render the color vector hsB in its illumination.

The modified parameter set 22' is generated by a control unit 12a applying a lighting control algorithm to the reference parameter set 22' and the dimming level D , as described below.

A simple example of the algorithm is illustrated in the graph of figure 3, which shows how the brightness B and saturation s of the modified parameter set 22 vary as respective functions of the dimming level D , as it is varied between a minimum $D_{\min}$ and maximum $D_{\max}$ value.

One or both of these functions may be linear, i.e.:

- for B , such that an increase in the dimming level from D_1 to $D_1 + \Delta D$ before reaching $B_{\max}$ causes a brightness increase $\Delta B(\Delta D)$ that depends on ΔD but is independent of D_1 ;
- for s , such that an increase in the dimming level from D_2 to $D_2 + \Delta D$ when at $B_{\max}$ causes a saturation decrease of $\Delta s(\Delta D)$ that depends on ΔD but is independent of D_2 .

Alternatively, one or both of these functions may be non-linear, i.e.:

- for B, such that an increase in the dimming level from D_1 to $D_1 + \Delta D$ before reaching $B_{\max}$ causes a brightness increase $\Delta B(D_1, \Delta D)$ that depends on both ΔD and D_1 ; and

- for s, such that an increase in the dimming level from D_2 to $D_2 + \Delta D$ when at $B_{\max}$ causes a saturation decrease of $\Delta s(\Delta D, D_2)$ that depends on both ΔD and D_2 .

An advantage of using linear functions is that they are simple to implement. An advantage of using non-linear functions is that they can provide perceptually smoother changes in the brightness or saturation as applicable (the human visual system is such that linear changes in brightness and saturation are not necessarily those which are perceived as the smoothest changes).

These respective functions are determined by the control unit 12a based on the reference parameter set 22, e.g. based on an electronically stored lookup table (see below).

In the examples described below, the saturation s is decreased as the dimming level is increased above D_{int} substantially as shown in figure 4D (see below).

As can be seen in figure 3, as the one-dimensional control value D is successively increased from $D_{\min}$, the control unit 12a responds by successively increasing the brightness B from a minimum brightness (substantially zero lumens in this example), to a maximum brightness $B_{\max}$, which is reached before the dimming level D reached $D_{\max}$ and an intermediate value D_{int} . For the range of dimming levels up to between $D_{\min}$ and D_{int} , $s = s_0$ i.e. the saturation remains substantially constant and substantially matches the reference saturation.

The maximum brightness $B_{\max}$ is set by the control unit 12 based on the reference hue h_0 and saturation s_0 . That is, the maximum brightness $B_{\max}$ is determined by the reference chromaticity h_0, s_0 , and may vary depending on the reference chromaticity to provide a maximum brightness $B_{\max}$ that is perceptually optimized for the user 8.

As D is increased above D_{int} , the brightness B remains substantially constant at $B_{\max}$ in this example, whereas the saturation s is gradually decreased, until reaching a minimum saturation $s_{\min}$ at $D_{\max}$. The minimum saturation $s_{\min}$ is set based on at least the reference hue h_0 .

Alternatively, as noted above, the brightness $B_{\max}$ may continue to increase as D is increased above D_{int} whilst the de-saturation is performed ($B_{\max}$ is not necessarily an absolute maximum, but rather the highest brightness that is achieved for as long as the hue and saturation remain constant at h_0 and s_0).

In this example, $h=h_0$ for all values of D i.e. the hue of the modified parameter set is substantially independent of the dimming level D , and substantially matches the reference hue h_0 , though in other cases the hue may also be varies as the dimming level is increased.

5 When the dimming level D is set to a predetermined reference value D_0 , which in this example lies in the middle of the range $[D_{\min}, D_{\max}]$ and is equal to zero (though this choice of value is purely arbitrary), $h=h_0$, $s=s_0$ and $B=B_0$ i.e. the reference hue, saturation and brightness are unmodified, such that the illumination is set according to the original reference parameters 22'.

10 This method can be applied to single luminaire or multiple luminaires, collectively or individually. The range of the control parameter for multiple lights can be defined as follows:

- Range minimum = - MAX (B0)
- Range maximum = MAX ((1-B0)+f(x0, y0)) ; here f(x0, y0) is a function of

15 x0,y0 (i.e. the reference chromaticity) that depends on saturation level of the color. Alternatively a function of h_0 , s_0 can be used $f(h_0, s_0)$, or more generally any function $f(c_0)$ of the reference chromaticity c_0 however it is represented.

Different lights 4 can be set to different brightness and saturation levels. When the control parameter D is equal to 0 all lights are set to their "original" value, i.e. the B_0 , h_0 ,
 20 s_0 for that light (which can be different for different lights). When the control parameter D is less than 0, then all lights start to dim down. When reaching a minimum brightness value, the control parameter D has a negative value that equals the maximum brightness of all lights (brightness of the light = original brightness of the light + control parameter value), denoted MAX(B). For the upper bound, increasing the control parameter value D will first increase
 25 brightness of the lights and then start de-saturating them. Each light first has to increase brightness to the maximum value. Thus lights have a "room" equal to 1 –corresponding to the original brightness B_0 . Secondly, lights have a certain saturation level. White light cannot be de-saturated, pink requires some de-saturation while red light requires a lot of de-saturation. This is represented with $f(c_0)$. Thus, the full swing of current color to the maximum
 30 brightness and de-saturated color requires a change of the control parameter that is equal to $(1-B_0) + f(c_0)$. When working with multiple lights, the upper limit of the control parameter is maximum of individual control parameter values i.e. MAX(1-B0+f(c0))

Based on experiments, the inventors have devised the following principles by which the desaturation from D_{int} to D_{max} can be optimized. These are explained with reference to Figures 4A and 4B.

Figure 4A is a schematic illustration of a well-known CIE color space 40, defined by CIE chromaticity parameters x and y , which together fully define the hue h and saturation s , and are independent of the brightness B . The color space has an outer-boundary 40, bounding an area in the xy plane that corresponds to the gamut of a human visual system i.e. all of the different combinations of hue and saturation that are perceptible to it. Points on the boundary 42 itself correspond to "pure" hues, i.e. maximum saturation. The gamut is shown divided into regions that approximately correspond to different groups of colors including white, i.e. completely unsaturated light.

Broadly speaking, changes in hue h correspond to rotations about the white region (such as movement along the outer boundary 42), whereas decreases in saturation correspond to movement in a direction away from the outer boundary 42 towards the white region.

Figure 4B also illustrates the principles by which the desaturation may be optimized by the control unit 12a. A line 41 is shown, which is a portion of the "Planckian locus" corresponding to colors that can be rendered by a perfect black-body emitter at different temperatures, referred to as "color temperatures". If a light emitting device is emitting light with a spectrum that approximately matches that of a perfect black-body emitter, the saturation and hue of that light can be characterized approximately by a color temperature corresponding to the temperature of the black body. Each color temperature corresponds to a respective point 46 on the Planckian locus 41.

An inner boundary 48 is shown within the outer boundary 42 of the gamut, which represents the lower limit on the saturation s i.e. s_{min} for different reference hues h_0 . The inner boundary 48 is set so as not reach actual whites for any reference hue h_0 , i.e. so as to produce pastel colors on the luminaires 4 so the reference hue h_0 is still recognizable to the user 8. This helps maintain a recognizable lighting scene and prevents the user 8 from getting "lost in white".

For greenish, cyan, bluish, and purplish reference colors, the control unit 12a de-saturates towards a cool white point (e.g. a color temperature of about 6500K). For yellowish reference colors, the control unit 12a de-saturates towards a warm white point (e.g. about 3000-4000 K). For orange, it de-saturates towards a warm white point (e.g. about 2700-3000 K). For red reference colors, it de-saturates towards pinkish white (e.g. about 5000K-

5500K). This will provide an aesthetically pleasing result and logical behavior of controls in the perception of users.

By way of example, a line 44 between a point on the outer boundary 42 and a point 46 on the Planckian locus 41 is shown. A point on the line 44 is shown, which corresponds to the chromaticity h_s . As D is increased above D_{int} (ΔD), the point chromaticity of the emitted light is changes such that the point moves along the line 44 away from the outer-boundary 43 towards the point 46 on the Planckian locus 46, terminating on the inner boundary 48. The reference chromaticity s_0, h_0 defines the starting point on the line 44, which may or may not be on the outer boundary 42 (i.e. which may or may not be maximally saturated).

The control unit 12a of the dimming controller can use a pre-calculated and electronically stored lookup table that contains, for example, one or more of the following in association with different reference colors:

- target "white" xy or hs values, corresponding to points 46 on the Plankian locus 41, towards which the light is de-saturated;
- segment definitions (e.g. in xy space or hs space), i.e. corresponding to the line 44 to follow through the color space 40 during the de-saturation;
- an optimal distance from the target white, i.e. where ideal pastel color is reached and de-saturation should stop – corresponding to the internal boundary 48;
- the sensitivity of the de-saturation, i.e. an incremental distance (step size) to move along the line 44 in response to an incremental increase in the dimming level D . The step size may vary with D to compensate for a perceptual non-uniformity of the color space 40 i.e. to make perceptually optimal step sizes (corresponding to a non-linear de-saturation function).

The values in the lookup table are preferably predetermined and specified by a lighting expert, but some values might be configurable by the user 8 himself.

The control unit 12a interpolates in-between the values specified in the table to calculate:

- de-saturation white targets for any specified reference color;
- and optimal distance towards the white (e.g. an ideal pastel color), and
- a sensitivity of de-saturation.

If the starting color value is already inside the range of the target pastel color, the control unit 12a does not de-saturate the color any further even as the dimming level is increased above D_{int} .

Embodiments of the invention can be applied to a single color lighting device (i.e. luminaire), to a multi-node color lighting device such as a pixelated light strip or Hue Beyond luminaire or to multiple individual color lighting devices. For instance, a group of color lighting devices can be associated with a one-dimensional UI element or UI device, or they may be logically grouped into a room, zone, or light scene, whereby each lighting device creates its own color or color pattern.

The reference parameters 22 are preferably stored in the bridge 10, but can also be stored at a user device (e.g. smartphone), in a luminaire, or in a dedicated control device.

An overall dimming level can be set which is applied to all luminaires 4, or an individual dimming level may be set of each luminaire.

The algorithm can be executed at different locations in a smart lighting system, e.g. on the bridge, in the app, lights or in the control device. That is, the dimming controller 12 can be incorporated into the lighting system in a variety of different ways, some examples of which will be described with reference to figures 5A-D.

Figure 5A shows a first example, in which the dimming controller 12 and scene controller 16 form part of a dedicated, standalone user input device 26 of the lighting system 1, such as a wall panel or remote control. The dimming level D is set using a one-dimensional user input element 26 of the stand-alone device, such as a rotary dimmer, slider, or a pair of function buttons (one to increase the dimming level, one to decrease it). The dimming controller 12 embeds the modified parameter set 22' in control signal 28, which is transmitted to the bridge 10 and causes the bridge 10 set the illumination of the luminaires 4 accordingly.

Figure 5B shows a second example, in which the dimming controller 12 is part of the bridge 10 itself. In this case, the bridge 10 receives the dimming level D set by the user 8, for example from the dedicated user input device 26 (as shown) or alternatively from a general purpose user device 30 (e.g. smartphone, tablet device, laptop or desktop computer etc.). The scene controller 16 is a component of the user device 30 in this example, for example it may be a code module executed on a processor of the user device, though it could alternatively be a component of the dedicated user input device 26.

In the examples of figures 5A and 5B, when the user 8 rotates, say, a wall dimmer of the dedicated user input device 26 counter clockwise, the lights 4 may decrease in brightness B whilst maintaining the original color point h_0, s_0 defined by the reference parameters 22. If users 8 rotates the wall dimer clockwise, the lights 4 get brighter

maintaining the original color point, until the maximum brightness $B_{\max}$ is reached. Further rotation in clockwise direction will de-saturate the light and thereby perceptually increase the brightness further, even though the actual brightness B is constant.

Figure 5C shows a third example, in which both the scene controller 12 and dimming controller 16 are components of the user device 30. As shown on the right-hand side, the user device 30 comprises a processor 31 on which a lighting control application 15 is executed. The dimming controller 12 and scene controller 16 are both software modules of the lighting control application 15. That is, the dimming controller 12 and scene controller 16 are part of the same application 15. The user device comprises display apparatus 27b (comprising one or more display devices) and user input apparatus 27a (comprising one or more user input devices, such as a touch screen) connected to the processor 31. The display apparatus 27b and user input apparatus 27a may comprise one or more components that are integrated in the user device and/or one or more external, peripheral components connected to the processor 31 via an external interface.

Figure 6B shows an example of graphical user interface (GUI) generated and displayed by the control application 15. In this example, the user 8 can select an image 20 via the GUI which the scene controller 16 uses to generate a respective set reference parameters for each luminaire 4 being used to render the scene (i.e. so that different luminaires 4 may render different colors). At least part of the selected image 20 is displayed simultaneously with a dimming control element 29. In this example, the dimming control element 29 is a rotary selector, which the user can use to adjust the dimming level D across of the luminaires, e.g. via a touchscreen of the user device 30. Thus, using the app 15, the user 8 can select a multi-colored light scene based on the image 20 and subsequently tune the scene using a single rotary element 29. The dimming control method described above is applied separately for each of the luminaires 4, to its respective reference parameter set, so as to provide a coherent, intuitive, and aesthetically pleasing way to tune each of the luminaires 4 using a single GUI element 29 whilst still preserving the essence of the lighting scene.

Figure 5D shows a fourth example, in which the lighting system comprises multiple luminaires 4 and a respective dimming controller 12 is incorporated into each of these luminaires 4. In this example, the scene controller 16 is incorporated in the user device 30, which communicates the reference parameters 22 to the bridge via connection 29. The bridge 10 relays the reference parameters 22 (possibly after processing them, e.g. to apply format conversion) to each of the luminaires for use by its dimming controller. In this case, the control signal 28 is internal to that luminaire 4.

The dimming level D may also be communicated to the bridge 10 e.g. from a dedicated user input device 26 (as shown) or alternatively, the dimming level D may also be set at the user device 30 and communicated to the bridge from there. In this case, the bridge 10 relays the received dimming level to at least one of the luminaires 4. Alternatively or in addition, a dimming level can be set at one of the luminaires itself, e.g. figure 5D shows one of the luminaires comprising an individual in control mechanism 40, which can be used to set the dimming level for that luminaire.

For example, as illustrated in figure 6A, the luminaire 4 may be a table-lamp with a touch sensitive housing, which can be tapped by the user to set the dimming level for that lamp at least, to adjust the dimming level for that luminaire 4 or for all luminaires 4 (in which case the dimming level can relayed to the other luminaires via the bridge 10, or directly between luminaires 4 in a mesh network).

Alternatively, a connected luminaire (such as a Hue Beyond) may be equipped with, say, a touch slider, which can be used to set the dimming level for that luminaire or for all luminaires 4, by communicating it to the other luminaire(s) via the bridge 10 or by relaying it directly between the luminaires 4.

The terms "luminaire", "light source" and "illumination source" are used interchangeably, to refer to a device which emits not just any light, but specifically light that provides illumination, i.e. light on a scale suitable for contributing to the illuminating of an environment occupied by one or more humans (so that the human occupants can see within the physical space as a consequence). A basic luminaire may consist simply of a light bulb or bulbs (e.g. LED, a filament bulb or gas-discharge lamp) and any associated support structure. Other luminaires may also comprise, for example, an associated casing or housing though others may not. A luminaire can take the form of a traditional ceiling or wall mounted room luminaire, or free standing luminaire (such as a floor or table lamp); or it may take a less traditional form such as an LED-strip embedded in a surface or item of furniture, a wall washer, or any other form of illumination device adapted to provide illumination specifically. Components for communicating with the controller (e.g. dedicated circuitry, FPGA, processors and accompanying software (e.g. firmware) as applicable) may be incorporated in a light bulb with a standard fitting, to allow easy retrofitting of connected lighting functionality into existing, non-specialized lighting systems. However, this is not essential and in general these communication components can be incorporated at any suitable location in the lighting system to allow communication between the luminaires and the controller.

The above examples have been described by reference to a bridge 10, which is a gateway to the lighting network, in the sense that it functions as an interface between the lighting network and other devices (e.g. a smartphone, or other user device). Communication between the luminaires 4 and the gateway 10 can be effected in a number of different ways.

5 For example, data transmitted and received between the gateway 10 and one or more of the luminaires 4 may be relayed via one or more other of the luminaires 4, i.e. the lighting network may have a mesh topology. Alternatively, data may be communicated directly between the luminaires 4 and gateway 10 (i.e. not relayed via other luminaires), i.e. the lighting network may have a star topology. In general, the lighting network can have any
10 suitable network topology, e.g. based on any suitable combination of direct and indirect (i.e. relayed) connections. The data can be communicated between the gateway 10 and the luminaires 4 wirelessly, for example using ZigBee, Wi-Fi or Bluetooth, via wired connections, such as Ethernet or DMX connections, or a combination of two or more such technologies (wired and/or wireless). Communication between the other devices and the
15 gateway 10 can also be effected in a number of different ways, such as via Wi-Fi or Bluetooth, or via a wired connection. It is also noted that the present invention can also be applied in lighting systems which do not have a gateway of this kind – for example, in a lighting system in which the luminaires can be controlled directly from a user device using Wi-Fi or Blue Tooth. In this case, the dimming controller 12 can, for example, be
20 incorporated in the user device (e.g. it may be implemented as code executed on a processor of the user device), or it may be an external component that communicates with the user device.

In general, the control unit 12a of the dimming controller 12, and the scene controller 16, can be implemented in any suitable manner, using software, hardware or any
25 combination of both. Software refers to code (i.e. executable instructions) executed on a processor or distributed across multiple processors, at any level or levels of software architecture, including low-level firmware and higher-level application software. Hardware includes both application-specific circuitry and also programmable hardware, such as FPGAs. The dimming controller 12 and scene controller 16 may be integrated in the same
30 device, or in different devices; or one or both of them may be distributed across multiple interconnected devices, which may or may not be collocated in space. In general, the terms "module" and "controller" may refer to software, hardware, or any combination thereof.

Where it refers herein to "increases" in the dimming level, this refers to the information that is conveyed to the dimming controller and the way in which the dimming

controller interprets it, rather than to any particular signal or physical medium that happens to convey that information (e.g. it is quite feasible for an increase in a dimming level to be conveyed to the dimming controller by a decrease in a voltage, current or electrical resistance; or by a reduction in a binary or other value).

5 It will be appreciated that the above embodiments have been described by way of example only. Other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims. In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a
10 plurality. A single processor or other unit may fulfil the functions of several items recited in the claims. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage. A computer program may be stored/distributed on a suitable medium, such as an optical storage medium or a solid-state medium supplied together with or as part of other hardware, but may
15 also be distributed in other forms, such as via the Internet or other wired or wireless telecommunication systems. Any reference signs in the claims should not be construed as limiting the scope.

CLAIMS:

1. A dimming controller (12) for a lighting system, the dimming controller comprising:

- a dimming input configured to receive from a user (8) a dimming level (D) that is adjustable by the user;

5 - a control unit (12a) configured to generate a control signal (28) for controlling a luminous intensity (B) and a chromaticity of light emitted by at least one luminaire of the lighting system; and

- a reference input configured to receive a set of one or more reference color parameters (22), wherein the control unit is configured to control the chromaticity of the emitted light based on a reference chromaticity denoted by the reference parameter set;

10 - wherein the control unit is configured to respond to successive increases in the dimming level by successively increasing the luminous intensity of the emitted light whilst maintaining a substantially constant chromaticity of the emitted light until reaching a maximum luminous intensity for that chromaticity (B_max), and thereafter by successively reducing a saturation (s) of the chromaticity of the emitted light whilst maintaining at least the maximum luminous intensity.

2. A dimming controller according to claim 1, wherein the control unit is configured to set a hue (h) of the chromaticity independently of the dimming level during said reduction of the saturation.

3. A dimming controller according to claim 1, wherein the control unit is configured to set the chromaticity of the emitted light to match the reference chromaticity when below the maximum luminous intensity.

25

4. A dimming controller according to claim 1 or 3, wherein the control unit is configured to determine the maximum luminous intensity based on the reference chromaticity.

5. A dimming controller according to any preceding claim, wherein the control unit is configured to reduce the saturation as a non-linear function of the dimming level.

6. A dimming controller according to claims 1 and 5, wherein the control unit is configured to determine the non-linear function using the reference parameter set.

7. A dimming controller according to claim 1, wherein the control unit is configured to reduce the saturation as a function of the dimming level, the control unit being configured to determine the function by retrieving a set of chromaticity values held in a data store in association with the reference color parameter set.

8. A dimming controller according to any preceding claim, wherein the control unit is configured to decrease the saturation to no less than a minimum saturation ($s_{\min}$), at which a hue of the chromaticity of the emitted light is still perceptible to the user.

9. A dimming controller according to claim 1, wherein the control unit is configured, when the dimming level is adjusted to a predetermined value (D_0), to set the chromaticity and luminous intensity of the emitted light to match the reference chromaticity (h_0, s_0) and a reference luminous intensity (b_0) denoted by the reference color parameter set, whereby the chromaticity and luminous intensity of the emitted light when the dimming level is at the predetermined value is changeable by changing the reference parameter set.

10. A dimming controller according to any preceding claim, wherein the control unit is configured reduce the saturation after reaching the maximum luminous intensity towards a point (46) on a Planckian locus (41), wherein the point is selected based on the substantially constant chromaticity of the emitted light.

11. A lighting control system comprising:

- a scene controller (16) configured to generated a set of one or more reference color parameters based on at least one color selection input received from a user; and
- a dimming controller (12) according to claim 1, connected to receive the one or more reference parameters.

12. A method of controlling a lighting system (1) based on a dimming level, the method implementing by a dimming controller the following steps:

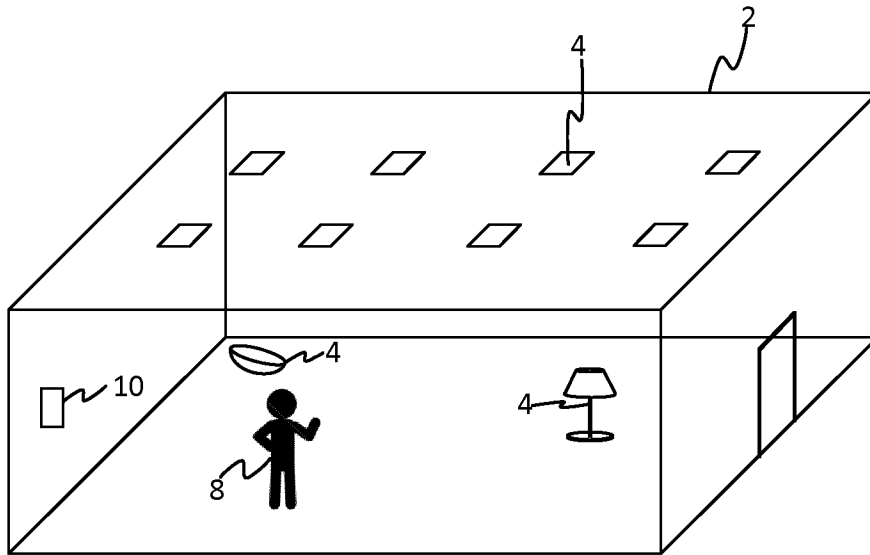
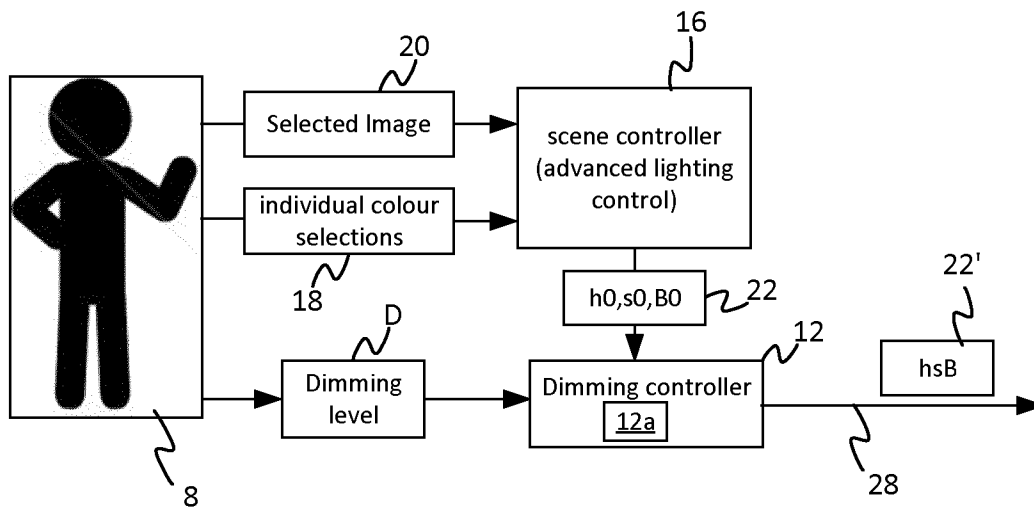
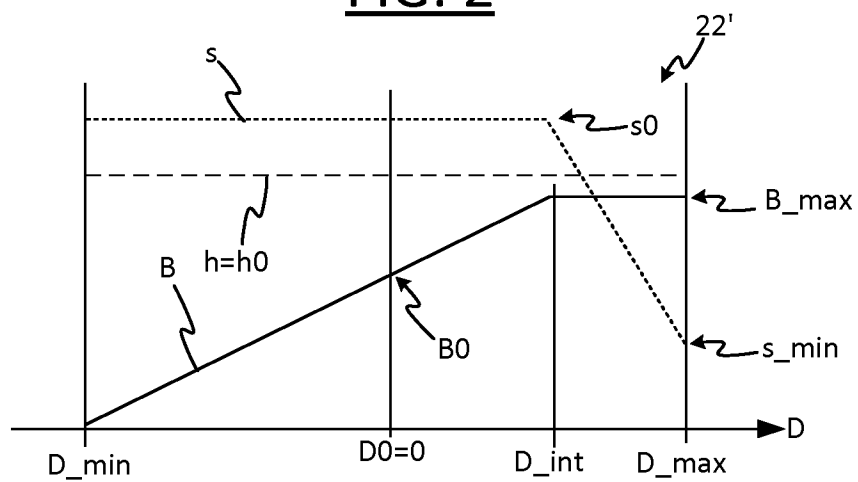
- receiving a set of one or more reference color parameters (22), wherein the chromaticity of the emitted light is controlled based on a reference chromaticity denoted by the reference parameter set,

- receiving from a user (8) a dimming level (D) that is adjustable by the user; and

- generating a control signal (28) for controlling a luminous intensity (B) and a chromaticity of light emitted by at least one luminaire of the lighting system;

- wherein in response to successive increases in the dimming level, the luminous intensity (B) of the emitted light is successively increased whilst maintaining a substantially constant chromaticity of the emitted light until reaching a maximum luminous intensity for that chromaticity (B_max), and thereafter a saturation (s) of the chromaticity of the emitted light is successively reduced whilst maintaining at least the maximum luminous intensity.

13. A computer program product comprising code stored on a computer readable storage medium and configured when executed to implement the method of claim 12.

**FIG. 1****FIG. 2****FIG. 3**

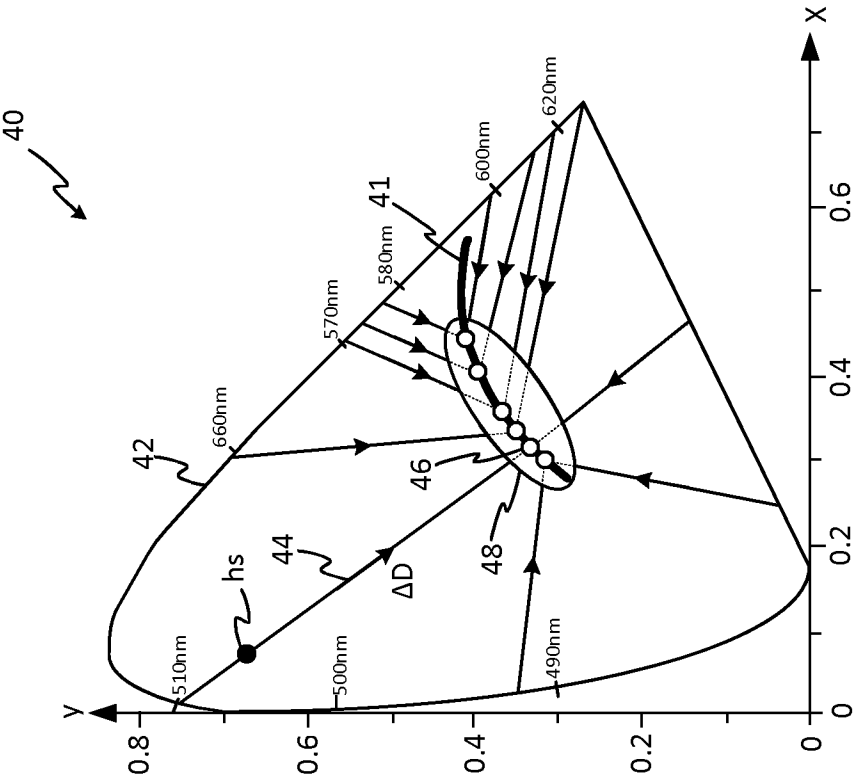


FIG. 4B

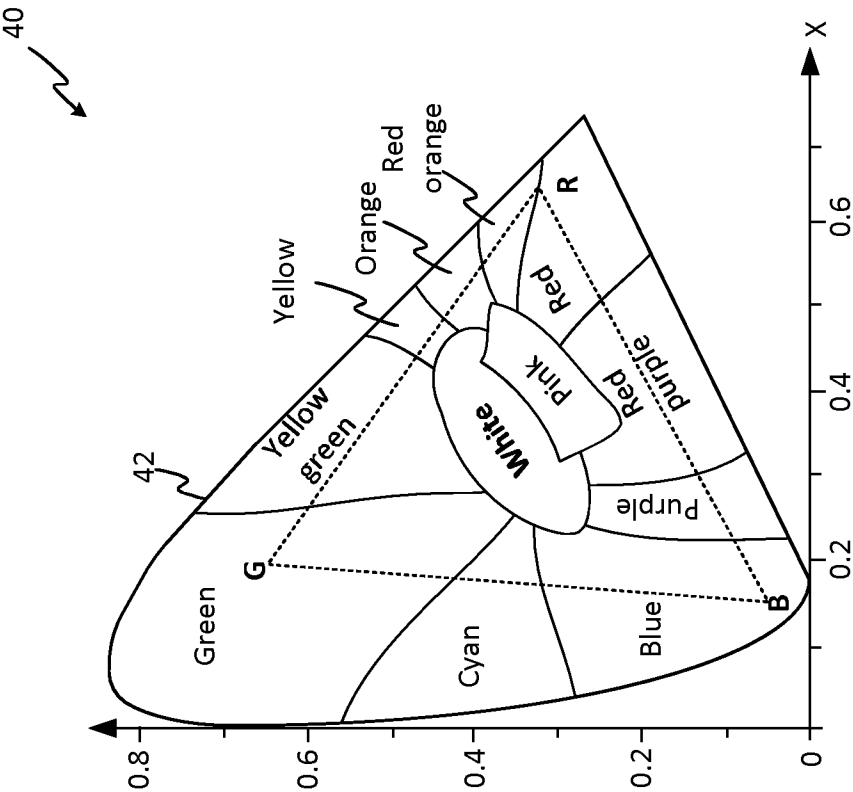
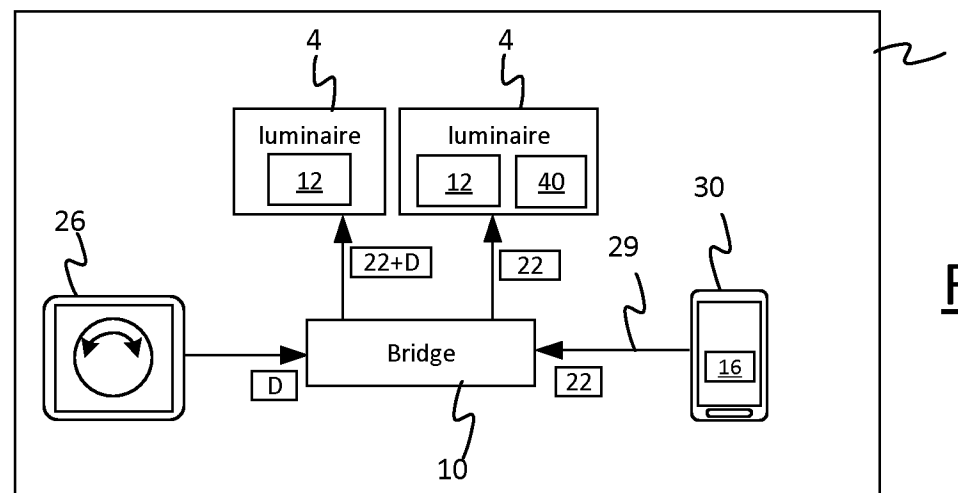
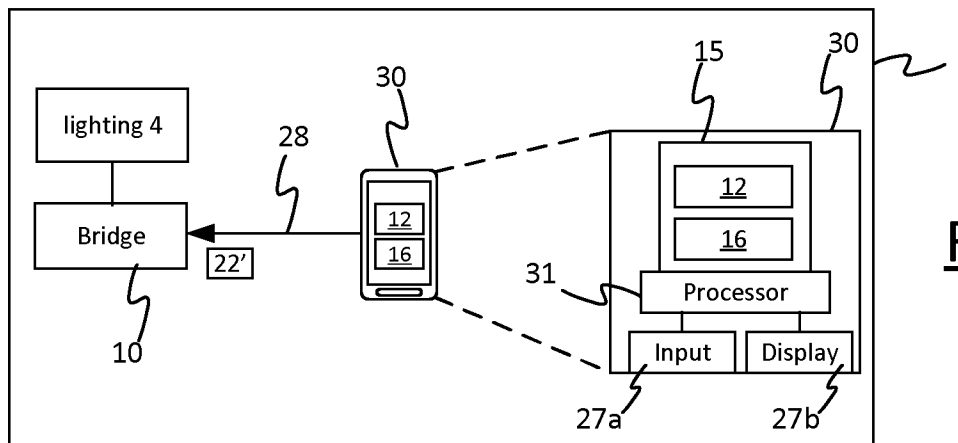
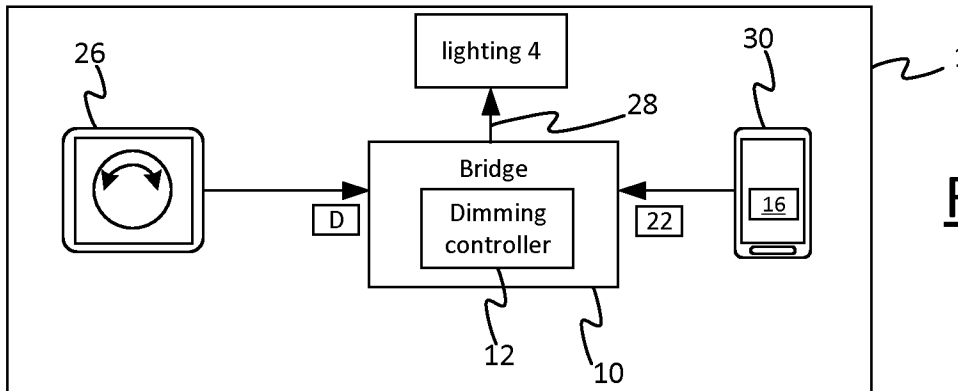
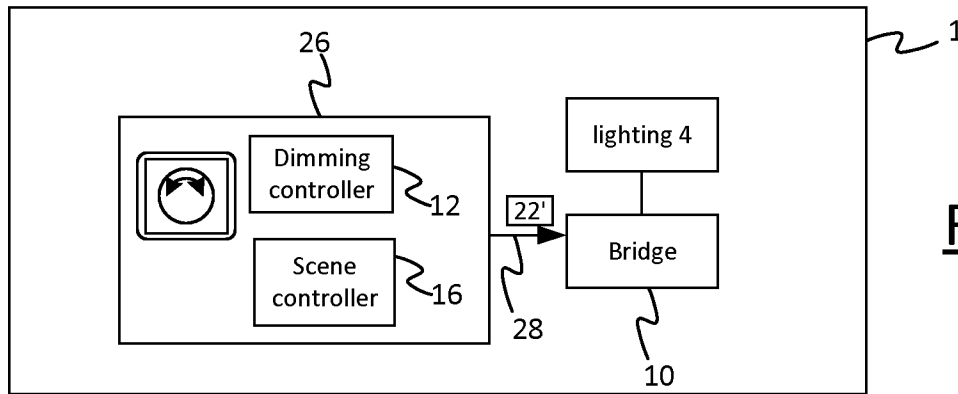


FIG. 4A



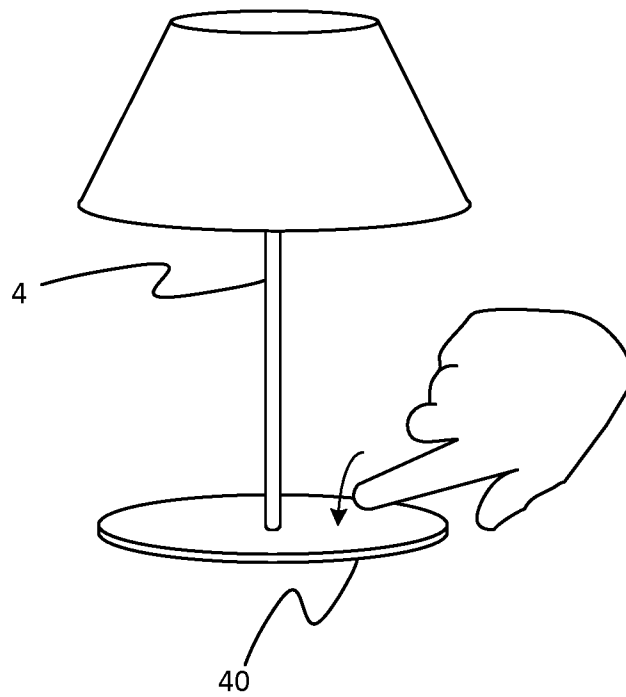


FIG. 6A

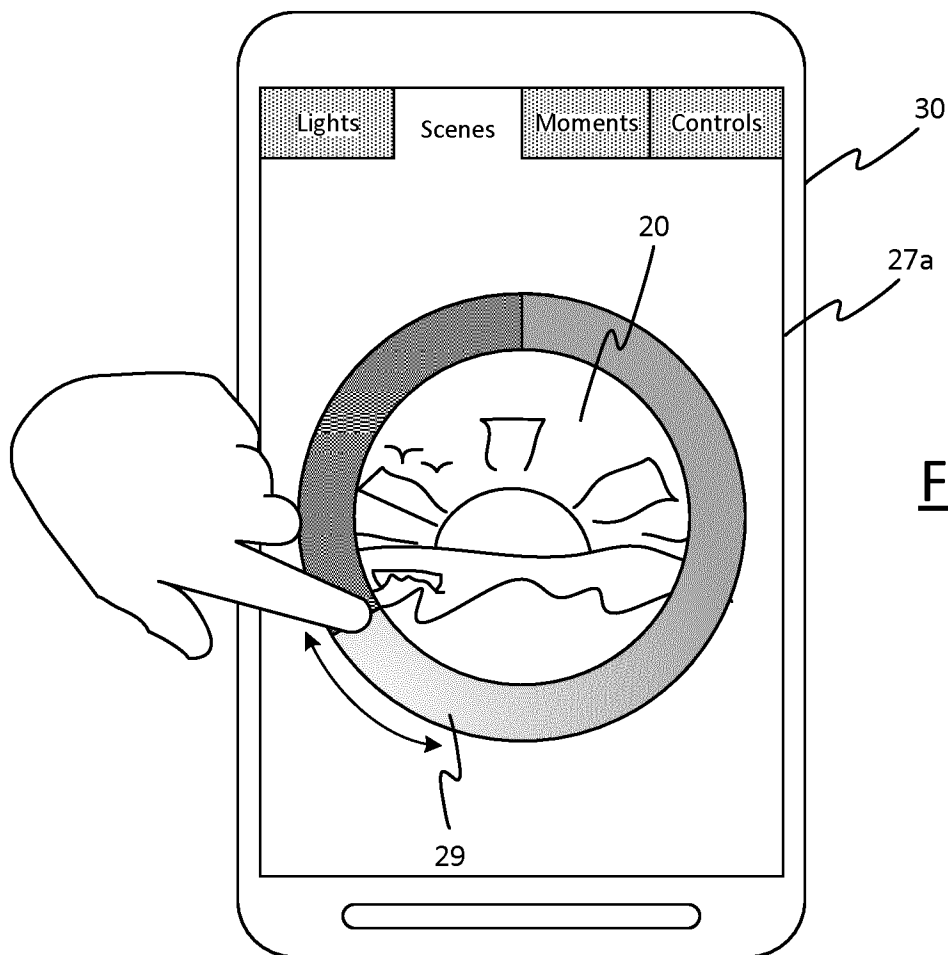


FIG. 6B

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/059792

A. CLASSIFICATION OF SUBJECT MATTER
INV. H05B33/08
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H05B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 2015/062938 A2 (KONINKL PHILIPS NV [NL]) 7 May 2015 (2015-05-07) page 5, line 32 - page 8, line 6; figures 1, 3	1-7,9, 11,12
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Y	US 2010/225241 A1 (MAEHARA MINORU [JP] ET AL) 9 September 2010 (2010-09-09) paragraph [0057] - paragraph [0063]; figure 3A paragraph [0039]	1,3,4,6, 7,9-12
	-/-	

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

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INTERNATIONAL SEARCH REPORT

International application No

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