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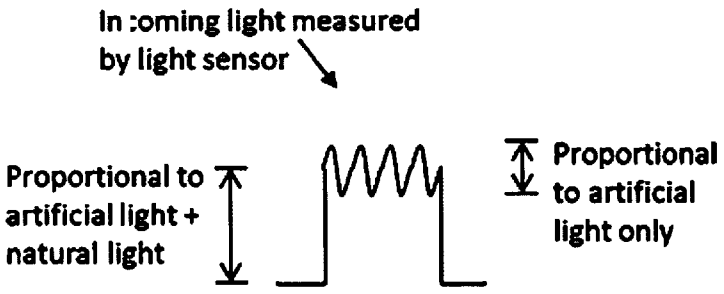
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[Continued on next page]

(54) Title: SENSING LIGHT FROM DIFFERENT SOURCES

Figure 4



(57) Abstract: An input signal is received from a light sensor based on a level of light comprising a first contribution from one or more electric lighting devices and a second contribution from another source, e.g. daylight. Both a DC component and an AC component are determined from the input signal. For example the AC component may be noise resulting from the electric lighting. Information on a relative proportion of the first and second contributions is determined in dependence on a magnitude of the DC component and of the AC component, e.g. a proportion of artificial light relative to daylight. The information may be used in a lighting system to control the level of light. In one application, this enables the system to distinguish between an apparent change light level due to reflection, and actual change in light level due to a change in the amount of daylight, and to react accordingly.

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Sensing light from different sources

FIELD OF THE INVENTION

The present invention relates to sensing light in an environment where the light comprises contributions from one or more electric lighting devices and also from an additional light source, such as daylight entering a room through a window. For instance this may be used as part of a lighting control system to regulate the level of light in the room or other space.

BACKGROUND

Daylight harvesting refers to the use of natural daylight to supplement the artificial light in an environment such as an interior space of a building, e.g. an office or other room. The idea can be used to reduce the amount of artificial light needed to illuminate the space and so reduce energy consumption. Nonetheless, in certain environments such as an office workspace a certain standardized or recommend light level may be required, e.g. 500 Lux at desk height. Even in non-regulated environments the end-user may require a certain light level as matter of preference. Hence to conserve energy consumption whilst still meeting the relevant light level requirement, a modern lighting system may comprise a controller which adjusts the artificial light output by one or more electric lighting devices depending on the amount of daylight present.

A closed-loop control system uses feedback of the quantity it is controlling (as opposed to an open-loop system which does not use feedback). In the case of a lighting control system, a photosensor detects the total photometric amount of light from both daylight and electric sources in the space. The sensed level is then used to control the amount of light. Some systems may use “active daylighting” whereby a suitable device is controlled to admit or direct varying amounts of daylight into the space in question, e.g. by means of automatic window blinds, windows comprising “smart glass” with controllable opacity, or a heliostat comprising a movable reflector arranged to direct a controllable amount of light through a window or other opening. In addition artificial light from one or more electric lights may be adjusted to make up any requirement for overall light level that cannot be met using the natural daylight alone. Other systems may passively collect natural light though

regular windows or skylights and adjust the electric light sources to meet the required light level.

One lighting control system is disclosed in "Daylight Integrated Illumination Control of LED Systems Based on Enhanced Presence Sensing", by Ashish Pandharipande and David Caicedo, Energy and Buildings No. "Daylight Integrated Illumination Control of LED Systems Based on Enhanced Presence Sensing", by Ashish Pandharipande and David Caicedo, Energy and Buildings Vol. 43, pp 994-950. This paper considers an energy-efficient illumination control design of LED based lighting systems in office spaces, with the goal of determining the optimum dimming levels of the LED sources so as to minimize the power consumption while rendering uniform illumination at a given illumination level in occupied workspace regions, and a minimum illumination level of lower value in unoccupied regions. The method takes into account illumination contributions, at the workspace plane, both from daylight and from the different LED sources. The LED sources are identified by information coded into the light they emit, and the information is used to produce a mapping table which is mathematically optimized to set the dimming levels of the LEDs.

SUMMARY

When sensing light it may be useful for various reasons to distinguish between artificial light and other sources of light such as daylight. Further, the inventors have recognized that it would be useful not just to make a simple yes/no determination as to whether artificial light is present, but to provide some information on the relative proportion of the different types of light. For example such information could be used by an automatic controller of a lighting system to determine when and/or how to adjust the level of light.

For instance in many systems a light sensor may be arranged to detect light via its reflection from a surface being illuminated, e.g. a ceiling mounted sensor may be mounted above a desk or other work surface. In this case it may be useful to distinguish between artificial and natural light because different surfaces may reflect light in different ways. It may not be desirable just to measure the overall amount of light arriving at a ceiling mounted sensor, as it may not be known how much of the different contributions from artificial and natural light are being reflected to the ceiling.

Another use could be to a human surveyor of a room or building, or to a designer or installer of lighting system to determine what contribution the two types of light are making to the overall light level.

One way to distinguish between light from different sources would be using coded light, whereby an information signal is coded into the light from an artificial source using a deliberate modulation of the light at a frequency unnoticeable to the human eye. However, systems for encoding information into light and for decoding the coded light can be undesirably complex. Further, not all existing lighting systems are capable of encoding information into light, and not all control systems are capable of decoding the coded information from the coded light. At least, it may be an onerous or expensive task to install such a system or modify an existing lighting system to accommodate such techniques. It may therefore be desirable to provide an alternative way of distinguishing between light from an electric lighting device and light from another source such as natural daylight. Even if coded light is available or complexity is not an issue, it may still be desirable to provide another form of detection to supplement the coded light or as an alternative option.

According to one aspect of the present invention there is provided an apparatus comprising an input for receiving an input signal from a light sensor, based on a level of light comprising a first contribution from one or more electric lighting devices and a second contribution from one or more further light sources. The apparatus also comprises a signal level detector configured to determine a DC component of said input signal, to further determine an AC component of said input signal, and to determine information on a relative proportion of the first and second contributions in dependence on a magnitude of the DC component and an amplitude of the AC component.

The apparatus may be provided as a stand-alone detector or more preferably as component for use in a lighting control system. Hence in a preferred application of the present invention, the apparatus comprises an output for supplying a control signal to at least one light level control element, and the signal level detector is configured to generate the control signal to control the level of light based on said information.

In one particularly advantageous application of the present invention, the information on the relative proportion of the two types of light is used to distinguish between an apparent change light level due to reflection, and an actual change in light level due to a change in the amount of natural light entering the space in question. For instance, in certain situations, there may be no substantial change to the amount of natural light entering a space and no substantial change in the output of the one or more electric lighting devices. However, if there is a change in reflection within the space, more light may be reflected into the light sensor. In a conventional arrangement this might trick the system into wrongly adjusting the light level even though the total quantity of light in the space has not changed.

A realization exploited in embodiments of the present invention is that if there is an increase or decrease in reflection, artificial light and natural light will be reflected in approximately the same proportion. Hence if there is a change in the input signal but no substantial change in the relative proportion is identified, there is no real change to the overall amount of light in the space and no adjustment should be made.

On the other hand, if there is an actual increase or decrease in natural light (e.g. more daylight entering through the window), the proportion of natural light relative to artificial light will also increase or decrease. So if there is a change in the input signal and also a change in the relative proportion of the two types of light, an adjustment should be made to compensate for the overall change caused by the natural light.

Therefore in embodiments of the present invention, the signal level detector is configured to control the level of light by adjusting the level of light on condition of identifying a change in the relative proportion of the first and second contributions.

The condition prevents the signal level detector from adjusting the level of light on one or more occasions when a variation in the input signal occurs due to reflection, rather than due to an actual change in the level of light (e.g. due to more daylight entering the space). If it appears based on the input signal that the first contribution has changed but in substantially the same proportion as the second contribution, the signal level detector refrains from adjusting the light level.

In further embodiments of the invention, the signal level detector may be configured to identify said change on condition of the relative proportion varying beyond a threshold amount.

The signal level detector may be configured to adjust the level of light to compensate for a change in the second contribution.

Said information on the relative proportion may comprise an indication of whether the first contribution changes when the second contribution changes.

Said information on the relative proportion may comprise a quantitative measure of said relative proportion.

The AC component may be an AC noise component resulting from operation of the one or more electric lighting devices, and/or of one or more other electric devices.

The AC noise component may comprise an AC ripple resulting from a power supply of the one or more lighting devices. The AC ripple may oscillate at 50Hz or 60Hz.

The amplitude of the AC component may be proportional to light intensity sensed by the light sensor.

The light level control element may comprise a dimmer of at least one of the one or more electric lighting devices, and the signal level detector may be configured to control the level of light by controlling the dimmer.

The light level control element may comprise an actuator of a device controlling admission or direction of natural light into an interior space, the signal level detector may be configured to control the level of light by controlling the actuator.

According to another aspect of the present invention, there may be provided a lighting system comprising an apparatus having any of the above features, and further comprising the one or more electric light sources, the light sensor coupled to the signal level detector via said input, and the at least one light level control element coupled to the signal level detector via said output.

According to another aspect of the present invention, there is provided a method comprising: receiving an input signal from a light sensor based on a level of light comprising a first contribution from one or more electric lighting devices and a second contribution from one or more further light sources; determining a DC component and an AC component of said input signal; determining information on a relative proportion of the first and second contributions in dependence on a magnitude of the DC component and an amplitude of the AC component; and generating an output signal based on said information.

In embodiments, the method may further comprise operations in accordance with any of the above apparatus features.

According to another aspect of the present invention, there is provided may be computer program product embodied on a computer-readable medium and comprising code configured so as when executed on a processing apparatus of a lighting system to perform operations of: receiving an input signal from a light sensor based on a level of light comprising a first contribution from one or more electric lighting devices and a second contribution from one or more further light sources; determining a DC component and an AC component of said input signal; and determining information on a relative proportion of the first and second contributions in dependence on a magnitude of the DC component and an amplitude of the AC component.

The computer readable-medium may be a computer readable storage medium. In embodiments the code may be further configured so as when executed to perform operations in accordance with any of the above apparatus or method features.

According to another aspect of the present invention, the method or apparatus of the present invention may be implemented wholly or partly in dedicated hardware circuitry.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the present invention and to show how it may be put into effect, reference is made by way of example to the accompanying drawings in which:

Fig. 1 is a schematic illustration of a lighting system installed in a room of a building,

Fig. 2 is a schematic illustration of another lighting system installed in a room,

Fig. 3 is a schematic block diagram of a lighting system including a control system,

Fig. 4 is a sketch of a input signal from a light sensor, and

Fig. 5 is a flow chart of a lighting control method.

DESCRIPTION OF PREFERRED EMBODIMENTS

Figure 1 is a schematic representation of an environment such as an interior space of a building, e.g. an office or other room 100, installed with an example lighting system according to one embodiment of the present invention. The lighting system comprises one or more electric lighting devices 102 which may take the form of integrated fixtures of the room or free-standing units. Each lighting device 102 comprises an electric lighting element such as an LED (light emitting diode) or electric filament, along with any associated fixture or fitting (sometimes referred to as a luminaire). For example the electric lighting devices 102 may be mounted on a ceiling 104 of the room 100. Each electric lighting device 102 emits artificially generated light. The room 100 also comprises one or more openings such as a window 108, e.g. a window in a side wall of the room and/or a skylight. The window 108 admits other light into the room 100 from the exterior, principally natural light comprising daylight from the sun.

In the embodiment of Figure 1, the lighting system further comprises a respective light sensor 110 and controller 112 for each of the electric lighting devices 102. The controller 112 is coupled to the respective lighting device 102, and the light sensor 110 is coupled to the controller 112. The light sensor 110 may also be substantially co-located with the respective lighting device 102. Each controller 112 controls the light of its respective lighting device 102 based on its respective sensor 110. The controller 112 may be calibrated to control the light emitted from the device to provide a specified target light level at a certain point or height within the room 100, such as desk height 114. I.e. the controller 112 is calibrated (e.g. by a technician at the time of installation) with the information that a certain

sensed level at the detector 110 corresponds to the specified light level at the height 114 in question, so if it detects a decrease below the sensed level it will increase the light emitted by the device 102 until the sensed level is back within range, and vice versa. For example one recommendation for an office workspace is 500 Lux at desk height. In this arrangement each of the controllers 112 may operate independently of one another.

In an alternative arrangement shown in Figure 2 the room 100 is installed with an integrated lighting system according to another embodiment of the present invention. Here a shared controller 112 is coupled to one or more lighting devices 102 and also to one or more alternative devices 202, 204 for controlling light level in the room 100. For example the one or more alternative devices may comprise a window treatment 202 for controlling the amount of natural light admitted in through the window 108 from the exterior, such as an automatic blind for covering a variable area of the window 108 or smart glass with controllable opacity. Alternatively or additionally, the one or more alternative devices may comprise a heliostat 204 with a movable reflector, operable to direct a controllable amount of natural light in through the window 108 from the exterior. One or more light sensors 110 are also provided in the room 100, e.g. mounted to the ceiling 104 though not necessarily co-located with any of the lighting devices 102. The light sensor 110 and devices 102, 202, 204 are coupled to the controller via a suitable interconnect 206.

In such embodiments the controller 112 is still calibrated to target a specified light level at desk height 114 (or such like) but has one or more alternative devices available for varying the light level, other than controlling the amount of light output from the one or more lighting devices 102. For example if the light in the room 100 needs to be increased, the controller 112 may be configured to first attempt to achieve the target light level using one or more of the alternative devices 202 and/or 204, and then resort to increasing output of the lighting devices 102 the target level cannot be met that way. Alternatively the controller 112 may be configured with an algorithm for controlling the lighting devices and one or more alternative devices together in a synergistic manner, an example of which will be given later. Another option is that the controller 112 is cony coupled to the one or more alternative devices, and does not control the light emitted by the electric lighting devices 102 at all.

Figure 3 is a schematic block diagram showing some of the components of Figures 1 and 2. The light sensor 110 is coupled to the controller 112 and arranged to supply it with an input signal that is representative of the level of light arriving at the light sensor 110 (the sensed level). The controller 112 takes the form of a signal level detector configured to control the light based information derived from the input signal. The controller 112 is

coupled to one or more of the electric lighting devices 102 and alternative devices 202, 204, and arranged to supply each of them with a respective control signal which controls the amount of light in the room 100 via a respective control element 302,304 of the device. In the case of an electric lighting device 102, the control element comprises a dimmer 302 operable to increase and decrease the amount of artificial light emitted by that lighting device 102 in dependence on the respective control signal from the controller 112. In the case of one of the alternative devices 202, 204, the control element comprises an actuator 304 operable to increase and decrease the amount of natural light admitted or directed into the room 100 in dependence on the respective control signal from the controller 112. E.g. in an automatic window blind or heliostat the actuator 304 may comprises a motor for moving the blind or reflector, and in a smart glass system the actuator may comprise circuitry for controlling the opacity of the glass.

In embodiments any one, some or all of the devices 102, 202 and 204 may be present as part of the system. The controller 112 may be implemented in the form of software stored on a storage device and arranged for execution on a processor of the lighting system, or in the form of dedicated hardware circuitry, or a combination of these. In the case of a software implementation the storage device may comprise any suitable medium or media such as magnetic or electronic storage. The processor may comprise one or more processing cores or units.

In a basic system the controller would simply act based on the total sensed amount of light, calibrated to the target level at desk height 114 (or such like). However, rather than just detecting the total overall amount of light in the room 100, the following embodiments of the present invention seek to distinguish between natural light and artificial light.

It may be useful to be able to distinguish natural light from artificial light in a system where a light source is controlled in dependence on measured light levels. In systems with daylight regulation or daylight harvesting, light sensors are used to measure the amount of light in a room. The light level measured by the sensor depends on the reflections of the light. When the interior of the environment changes the reflection coefficient also changes, influencing the amount of light that reaches the sensor (note that the artificial light level from the lighting devices and daylight level have remained constant, and only the reflection of light from the desk, floor or other such surface will have changed). Some root causes of changes in reflection factors may comprise:

- changing carpets;

- changing curtains;
- changing furniture;
- change of wallpaper or paint;
- change of ceiling color;
- fading of various surfaces due to aging; and/or
- particular reflection changes, such as a large white paper being placed on a table or someone entering the environment wearing a white shirt.

Any such factors may have an impact on the measured light level, even though the actual overall amount of light in the room has not changed.

For example, the system might be arranged to increase or decrease the output intensity of the light source in response to a decrease or increase in natural light levels as measured by a light sensor (as in daylight harvesting). However, if less or more of the light source's own light is reflected onto the light sensor, e.g. due to foreign objects arriving in the vicinity of the light sensor, this may be perceived as a decrease or increase in natural light levels. Consequently, without taking measure to address the problem, the system might increase or decrease the output intensity of the light source when it shouldn't.

Coded light techniques could be used to differentiate between natural light and artificial light based on the information coded into the light. However, embodiments of the present invention are directed to a less complex approach.

As illustrated schematically in Figure 4, embodiments of the invention make use of an inherent modulation that already exists in the system, preferably either the AC ripple from the mains voltage or the HF modulation of the driver. This inherent noise present in artificial light can be used to determine a change in the ratio of natural light to artificial light as measured by a light sensor. The approach takes advantage of the fact that the amplitude of the noise will be proportional to the output intensity of the light source, i.e. that the light from a light source is inherently modulated with a value indicative of the output intensity.

The AC (alternating) component of the signal is a time-varying component of the signal level, e.g. a ripple which oscillates at a frequency of the order of tens of hertz or greater, while the DC (direct) component is an offset in the signal level. Together they form a signal with time-varying undulations in level offset by the magnitude of the DC component. The sensor signal level (typically taken as the voltage level of the signal) is representative of an amount of light at the sensor, the voltage typically being linear with the illuminance (lux) sensed at the sensor. For example an amplitude of an envelope of the AC ripple may be taken

as a measure of the AC component and an average height of the signal can be taken as a measure the DC component.

Thus this ripple can be measured with a light sensor and will be constant when the light output of the luminaire is constant. When the reflection coefficient changes the light sensor's output will change but so will the measured ripple. The change in the measured ripple is a value for the change in reflectivity. When the amount of daylight changes the measured sensor light output will change only in DC value. The measured ripple caused by the artificial light source will not change.

To elaborate, if the DC value of the light sensor's output increases but the amplitude of the noise stays the same, this will be interpreted as meaning natural light levels have increased. As a result, the light source will be dimmed. Conversely, if the DC value of the light sensor's output increases and the amplitude of the noise increases by a corresponding amount, this will be interpreted as meaning that natural light levels have not changed but for some reason more light is being reflected onto the sensor. In this case, the light source's output will not be changed. So when the reflection changes in a way that the sensor measures a higher task light level, the task light level will be adjusted into an unwanted lower light level. When the reflection changes in the other direction and the sensor measures a lower task light level, the task light level will be adjusted into a higher light level what will result in an unwanted lower energy saving.

Further, when using the artificial light source as reference one can calibrate the light sensor. To discriminate the difference between artificial light and natural daylight the AC modulation can be used.

Advantageously compared with the possibility of using coded light, there is no need to modulate a signal into the light. Instead the invention can use inherent modulation that is already present in the system due to noise. That is, unlike coded light information does not need to be encoded into the signal, but rather inherent properties of the signal itself are be exploited. Therefore the technique can be used with simpler light sources (i.e. those not enabled to communicate via coded light), or to save bandwidth for other purposes in systems that are enabled to communicate via coded light.

Further, the invention is not limited only to distinguishing whether artificial light is present, but can also use the relative levels of the DC component and the AC noise component to determine information concerning the relative proportion of artificial and natural light. In embodiments, this in turn can be used to prevent the system reacting to changes in the sensed level of light that occur due to changes of reflection in the environment,

rather than an actual change in overall light level due to a change in natural light entering the environment.

An example method that may be implemented in the controller 112 is discussed with reference to the flow chart Figure 5.

At step S10 the controller 112 monitors the input signal from the light sensor 110. The DC level of the input signal represents the total sensed level of light at the light sensor 110, which will be related to the total level of light at the point or height within the room 100 that is of interest (e.g. desk height 114 at a particular point in the room), taking into account the contributions from both artificial and natural light. The controller 112 monitors the DC component of the input signal for apparent changes to the total light level. If there is a change to the DC level, this is potentially but not necessarily due to an increase in natural light entering the room 100. To check whether this is the case, upon detecting a change in the DC level the controller 112 then proceeds to step S20.

Note that in embodiments, the controller 112 may be configured to apply a threshold interval to this monitoring in order to prevent being triggered in response to negligible fluctuations. So the controller 112 proceeds to step S20 on condition that the DC level of the input signal does vary (either increases or decreases) beyond the threshold amount, i.e. outside of the threshold interval.

As mentioned, instead of only measuring the DC value of the incoming light, the controller 112 is also configured to measure an AC noise component, e.g. the AC ripple caused by the mains is measured. Usually the ripple from the mains is a sinusoid. In the UK, elsewhere in Europe and most of Asia the mains frequency is 50Hz; and in the USA and elsewhere in the Americas it is 60Hz. Hence in embodiments the controller 112 is configured to detect a sinusoidal AC component oscillating at 50Hz or 60Hz. These measurements may be implemented for example in a microcontroller that already measures the light level by the use of an ADC (analogue to digital converter).

At step S20 the AC value is compared with the previous measured value (e.g. the last time a change in the DC value was detected, or the last measurement cycle if the method is performed in discrete cycles). If the AC value is equal to the previous one this means the light level change was caused by a change in the daylight. Accordingly upon detecting this condition, the controller 112 proceeds to step S30 where it makes an adjustment affecting the light level in the room 100. On the other hand, if the DC light level decreases and the AC value is lower than the previous value, this means the change is caused by a lower reflection coefficient and no adjustment should be made. This is also the case

when the DC light level and AC value both rise. Accordingly upon detecting this condition, the controller does not make any adjustment to the light level and instead returns to monitoring the input signal at step S10.

Note that again, the controller 112 may be configured to apply a threshold interval to this condition (not necessarily the same interval as applied at step S10) in order to prevent negligible fluctuations in the proportion of natural and artificial light triggering unnecessary adjustments. So the controller proceeds to make the adjustment at step S30 on condition that the AC component varies beyond the relevant threshold amount, i.e. outside of the threshold interval.

According to the above scheme, the determination as to whether the AC value changes when the DC value changes provides information on the relative proportion of the artificial light compared to the natural light in the room 100 (or other such environment) – specifically an indication as to whether the relative proportion has changed (beyond a threshold) or whether it remains substantially the same.

In alternative embodiments, steps S10 and S20 can be combined if the controller 112 is configured to directly monitor a numerical measure of the proportion of artificial light to natural light, e.g. monitoring the ratio of the two types of light. In this case the controller 112 may be configured to detect the condition for adjustment when it detects a change in the ratio, e.g. the ratio has changed beyond a threshold amount.

Whatever calculation is used, when the controller 112 determines that a real change in the amount of natural light has occurred (as opposed to an apparent change due to reflection), it proceeds to instigate an adjustment as represented by step S30 in Figure 5.

In embodiments the controller 112 makes the adjustment by changing the light output set-point of one or more of the lighting devices 102 (via the output signal which it supplies to the control element 302). For example in the arrangement of Figure 1 each controller is responsible for controlling its own respective lighting device.

One way of adjusting the light level is to make a change ΔL to the light output L of the lighting device 102. If the change is purely (or at least mainly) due to a change in natural light entering the room, the adjustment can be approximated as:

$$\Delta L = - C \cdot \Delta S$$

where ΔS is the difference between the sensed DC level and the target for the sensed level and C is a calibration factor, the calibration being determined empirically by a technician

with a light meter at the installation stage. For example C may be described as 1/(p·k) where p is the return path parameter (characterizing reflection of light from the desk 114 to the sensor 110) and k is the output path parameter (characterizing the path from lighting device 102 to desk 114).

In another embodiment the adjustment may be based on the change in natural light. The total sensed light level S_{tot} is determined from the DC component and the artificial light S_{art} at the sensor 110 is known from the AC component, so the amount of natural light S_{nat} at the sensor 110 can be known from the difference between the two. Then to make an adjustment the following relationship may be used:

$$\Delta L = - C \cdot \Delta S_{nat}$$

where ΔS_{nat} is the sensed change in natural light since the last measurement cycle. Alternatively ΔS_{nat} could be based on a difference between the sensed level and the target for the sensed level, e.g. $\Delta S_{nat} = \Delta S(S_{nat}/S_{tot})$. Such embodiments could be used to take into account the possibility that both the amount of natural light and the reflection changes in a given measurement cycle, so that the adjustment is made only based on the actual change due to natural light.

Other relationships between L and S are also possible and may be tuned empirically. Alternatively the controller 112 may adjust the light output of the device 102 in small steps in the relevant direction until the sensed DC level falls back within a threshold range of the target for the sensed level.

In another embodiment the controller 112 may make an approximate calculation of the light level at the desk height 114 based on the sensed readings. The total amount of light S_{tot} arriving at the sensor 110 and the amount of artificial light S_{art} at the sensor 110 may be determined from the DC and AC components of the input signal respectively, and the difference between the two gives the amount of natural light S_{nat} at the sensor. In one example it may then be approximated that $S_{nat}/S_{art} \approx I_{nat}/I_{art}$ where I_{nat} is the amount of natural light at the desk level 114 and I_{art} is the amount of artificial light at desk level, assuming that reflection of the two kinds of light from the desk 114 to the sensor 110 behaves roughly the same. Further, the artificial light at desk height can be known approximately from the relation $I_{art} \approx p \cdot L$ where p is the return path parameter (e.g. known empirically from the calibration stage) and L is the known light output level of the lighting device 102. This allows the amount of natural light at desk height 114 to be approximated as:

$$I_{nat} \approx I_{art}(S_{nat}/S_{art})$$

and the adjustment ΔL to the light output L of the lighting device may then be determined by:

$$\Delta L = - \Delta I_{nat}/p$$

or equivalently $\Delta L = - \Delta I_{tot}/p$ (I_{tot} being the total of I_{nat} and I_{art}) if it has already been determined (or it is assumed) that the change is purely due to a change in natural light. Otherwise the adjustment based on ΔI_{nat} may be preferred to accommodate for the possibility that both the amount of natural light and the reflection have both changed in the same measurement cycle (so the controller 112 only reacts in proportion to the actual change in natural light).

Referring to the arrangement of Figure 2, in further embodiments the controller 112 may instead make the adjustment by adjusting an alternative device such as the window treatment 202, e.g. varying the treatment until the sensed DC level returns to a level within a threshold range of the target for the sensed level. In one such embodiment, the controller 112 may be configured to first attempt to compensate for the change in light level using the window treatment 202 (or the like), e.g. to admit more light if the amount of natural light in the room has decreased, and then resort to adjusting the light output of the electric lighting device(s) 102 only if the difference cannot be made up using the window treatment 202 (or other alternative device such as heliostat 204).

Alternatively, the controller 112 may be configured to control both the electric lighting 102 and an alternative device such as window treatment 202 together. One scheme is to operate both window treatments and electric lights in such a way that both of them attempt to reduce the lighting error and energy consumption in the space. Such an objective leads to the following equations:

$$L(n) = L(n-1) - \mu_1 \frac{\partial \|e(n)\|^2}{\partial L} - \mu_2 \frac{\partial \|E(n)\|^2}{\partial L}, \text{ and}$$

$$W(n) = W(n-1) - \mu_3 \frac{\partial \|e(n)\|^2}{\partial L} - \mu_4 \frac{\partial \|E(n)\|^2}{\partial L}$$

where L and W are the variables being adapted, representing light output and window treatment respectively. For example the window treatment may be measured in terms of how much of the window 108 is exposed by an automatic blind. The variable e is the lighting error, i.e. the difference between user set point and measured light level, E is proportional to energy consumption, and the factors μ are small positive constants (adaptation step sizes). The last two terms are the amount by which the electric lights and window treatment will be adjusted for each adaptive control cycle. Here, n is an index of the cycle. The equations may be solved iteratively or analytically.

The above are just examples, and once it is determined at step S20 that an adjustment needs to be made then any suitable control algorithm may be applied. Whatever way the adjustment is made, the controller 112 subsequently continues to monitor the input signal for further changes, illustrated by a return to step S10 in Figure 5.

It will be understood that the above embodiments have been described only by way of example. Other variants may be appreciated by a person skilled in the art given the disclosure herein.

The above has been described in terms of an example room 100, but the invention may be applied in any environment that receives light from both electric lighting and one or more other sources, e.g. any covered structure such as a gazebo, tunnel or vehicle interior, or even an illuminated open air space such as at night time. Further, the term window need not only refer to windows on walls, but also for example to skylights. Also the height, region or point relative to which the target light level is set need not be limited to desk height.

The invention could be sold as an individual control module for use in a lighting system, or as a complete lighting system, or any combination of components described above. In an alternative application the invention could be implemented as a stand-alone smart sensor for sensing natural light and outputting a signal indicative of the relative proportion of artificial light compared to natural light. For example this could be used to give a reading for use by a designer of a lighting system, or a technician calibrating a lighting system, or a surveyor of a building or other environment.

The electric lighting device or devices could comprises any source powered and/or controlled using electricity that introduces a time-varying noise component. Note that the term noise as used herein does not limit to random noise. In one embodiment the noise comprises an AC ripple from a mains supply, which is typically sinusoidal in nature. The ripple may result from operation of the electric lighting device and/or from one or more other

electric devices interfering with the electric light device. Another possibility is that the noise component results from HF (high frequency) driver of the lighting device. In alternative embodiments other noise could be exploited if it can be detected as characteristic of the light from that device.

Further, the invention may be used to distinguish between light from electric devices and any other kind of light that does not contain the same noise component. For example, the natural light could comprise moonlight (comprising reflected sunlight), firelight, bioluminescent light or light from any natural source not containing an identifiable side-effect of electric lighting. The other light could also comprise general background light even if that does contain an artificial component, e.g. electric light from a DC power source or electric light that has lost an identifiable AC signature (e.g. due to absorption and re-emission, of mixing of light from many sources).

The terms AC and DC can refer to current, voltage or any other property that can be used as a measure of signal level. The AC component can be any time-varying component of such a property and the DC component can be any offset in the level of that property. The DC component is not necessarily constant but will not regularly change to a substantial degree with a frequency or regularity on a timescale over which the AC component varies. For example the DC component may change pseudo-statically over the course of a day as the daylight changes, or suddenly but irregularly when a user switches a luminaire on or off; whereas the AC component may for example oscillate at the mains frequency, typically 50 or 60Hz.

Note that where it is referred to a relative proportion of A and B, or A compared to B or the like, this could mean determining information on A in terms of or B or vice versa, or any information allowing something about a relationship between the two to be determined. For example in embodiments of the present invention, the information may be a yes/no indication as to whether the amount of artificial light changes when the total sensed amount of light changes, or a quantitative measure (a matter of degree) of the relative proportion of artificial and natural light. Further, a measure of the proportion could mean any measure of one relative to the other, e.g. ratio or relative change.

Further, where it is said the proportion is determined in dependence on the amplitude of the signal from the light sensor, this does not necessarily limit to the proportion being determined directly from the amplitude, nor the amplitudes being directly measured. In the above described embodiments the signal amplitude is proportional to sensed light intensity, but in other embodiments other relationships between signal amplitude and light

may be possible. Generally the present invention can be used to determine the AC signature of artificial light based on any measure related to the height or size of the light sensor signal, and any relationship between this and the sensed amount of light.

In yet further embodiments, the AC component need not be a noise component. For example if the signal contains coded light information but for some different purpose (e.g. say to encode an ID of the luminaire), the amplitude of the coded light may be exploited to determine the amount of artificial light (as opposed to using information coded into the coded light explicitly specifying the amount of artificial light output by the lighting device device).

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 plurality. A single processor or other unit may fulfill 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 measured 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 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. Apparatus comprising:

an input for receiving an input signal from a light sensor (110), based on a level of light comprising a first contribution from one or more electric lighting devices (102) and a second contribution from one or more further light sources; and

a signal level detector (112) configured to determine a DC component of said input signal, to further determine an AC component of said input signal, and to determine information on a relative proportion of the first and second contributions in dependence on a magnitude of the DC component and an amplitude of the AC component.

2. The apparatus of claim 1, wherein:

the apparatus comprises an output for supplying a control signal to at least one light level control element (302, 304); and

the signal level detector (112) is configured to generate the control signal to control the level of light based on said information.

3. The apparatus of claim 2, wherein the signal level detector (112) is configured to control the level of light by adjusting the level of light on condition of identifying a change in the relative proportion of the first and second contributions.

4. The apparatus of 3, wherein the signal level detector (112) is configured to identify said change on condition of the relative proportion varying beyond a threshold amount.

5. The apparatus of claim 2, 3 or 4, wherein the signal level detector (112) is configured to adjust the level of light to compensate for a change in the second contribution.

6. The apparatus of any preceding claim, wherein said information on the relative proportion comprises one or both of:

an indication of whether the first contribution changes when the input signal

changes; and

a quantitative measure of said relative proportion.

7. The apparatus of any preceding claim, wherein the AC component is an AC noise component, the AC noise component comprising noise from operation of the one or more electric lighting devices, and/or of one or more other electric devices.

8. The apparatus of claim 7, wherein the AC noise component comprises an AC ripple resulting from a power supply of the one or more lighting devices (102).

9. The apparatus of claim 8, wherein the AC ripple oscillates at 50Hz or 60Hz.

10. The apparatus of any preceding claim, wherein the amplitude of the AC component is proportional to light intensity sensed by the light sensor.

11. The apparatus of any preceding claim, wherein the one or more further light sources comprise a natural light source and the second contribution comprises natural light.

12. The apparatus of claim 2 or any claim as dependent thereon, wherein one or both of:

the light level control element comprises a dimmer (302) of at least one of the one or more electric lighting devices (102), the signal level detector (112) being configured to control the level of light by controlling the dimmer; and

the light level control element comprises an actuator (304) of a device (202, 204) controlling admission or direction of natural light into an interior space, the signal level detector (112) being configured to control the level of light by controlling the actuator.

13. A lighting system comprising the apparatus of claim 2 or any claim as dependent thereon, and further comprising the one or more electric light sources (102), the light sensor (110) coupled to the signal level detector (112) via said input, and the at least one light level control element (302, 304) coupled to the signal level detector via said output.

14. A method comprising:

receiving an input signal from a light sensor based (110) on a level of light

comprising a first contribution from one or more electric lighting devices (102) and a second contribution from one or more further light sources;

determining a DC component and an AC component of said input signal; and

determining information on a relative proportion of the first and second contributions in dependence on a magnitude of the DC component and an amplitude of the AC component; and

generating an output signal based on said information.

15. A computer program product embodied on a computer-readable medium and comprising code configured so as when executed on a processing apparatus of a lighting system to perform operations of:

receiving an input signal from a light sensor (110) based on a level of light comprising a first contribution from one or more electric lighting devices (102) and a second contribution from one or more further light sources;

determining a DC component and an AC component of said input signal; and

determining information on a relative proportion of the first and second contributions in dependence on a magnitude of the DC component and an amplitude of the AC component.

Figure 1

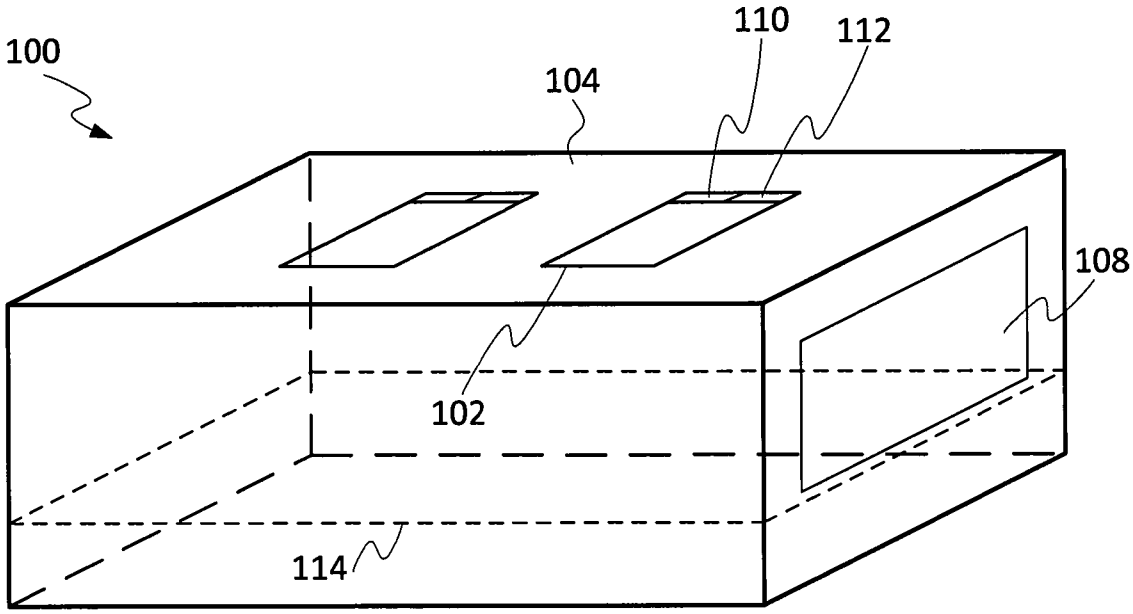


Figure 2

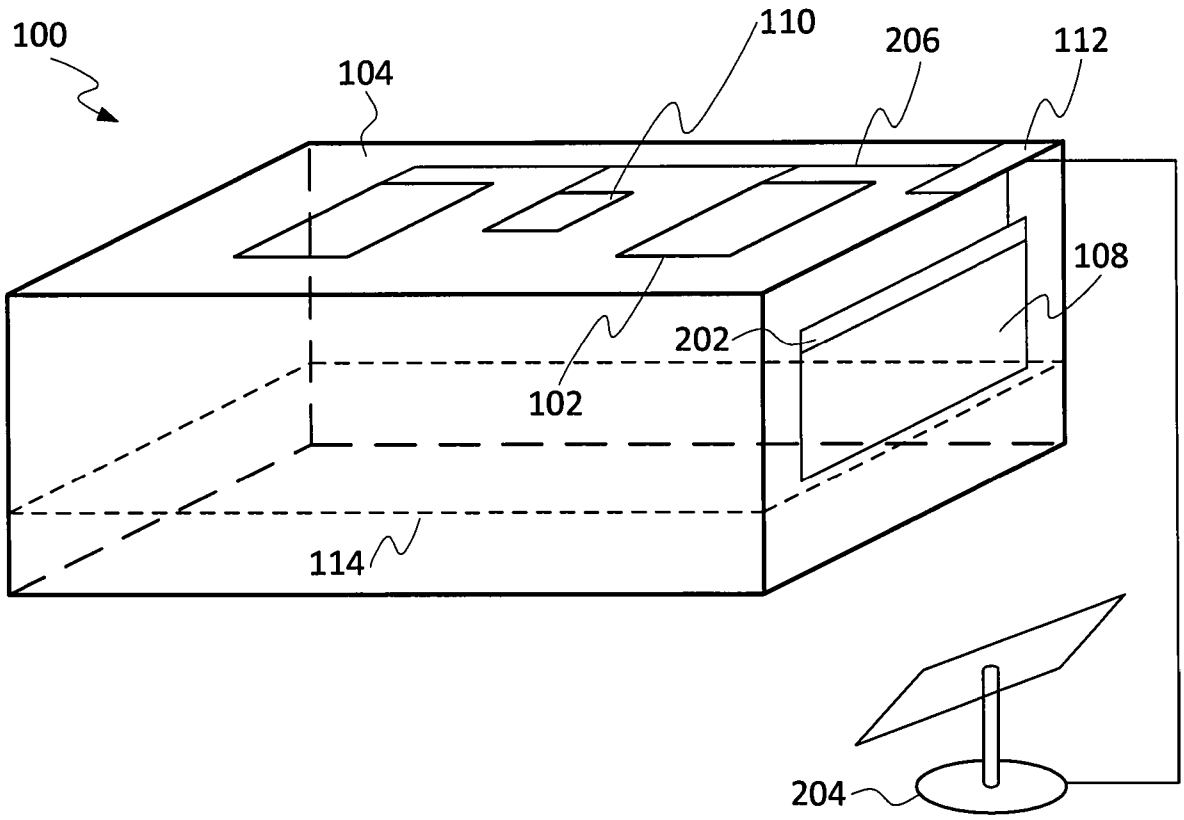


Figure 3

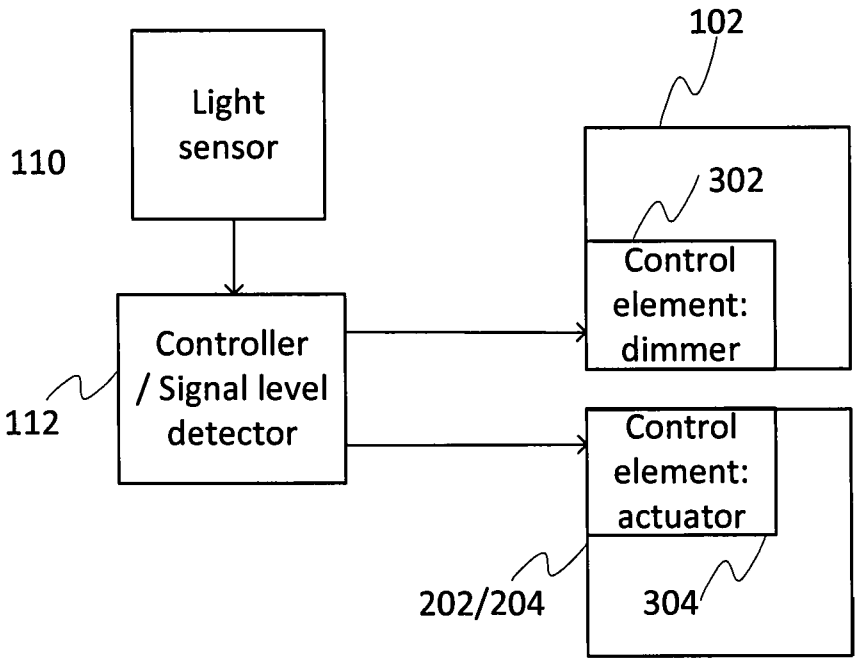


Figure 4

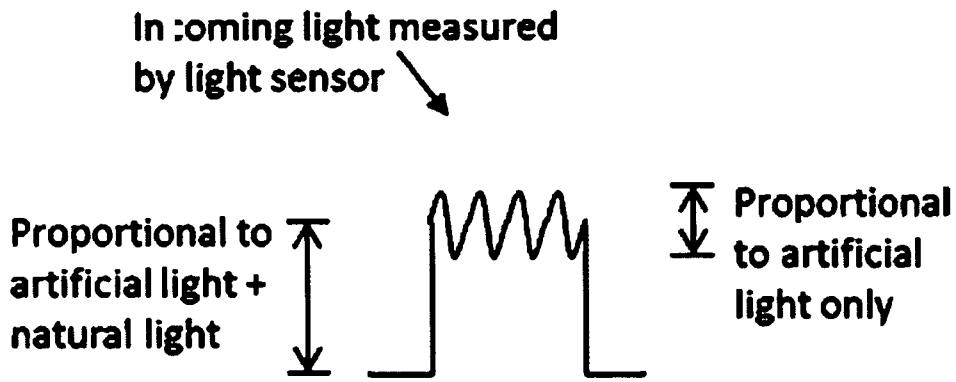
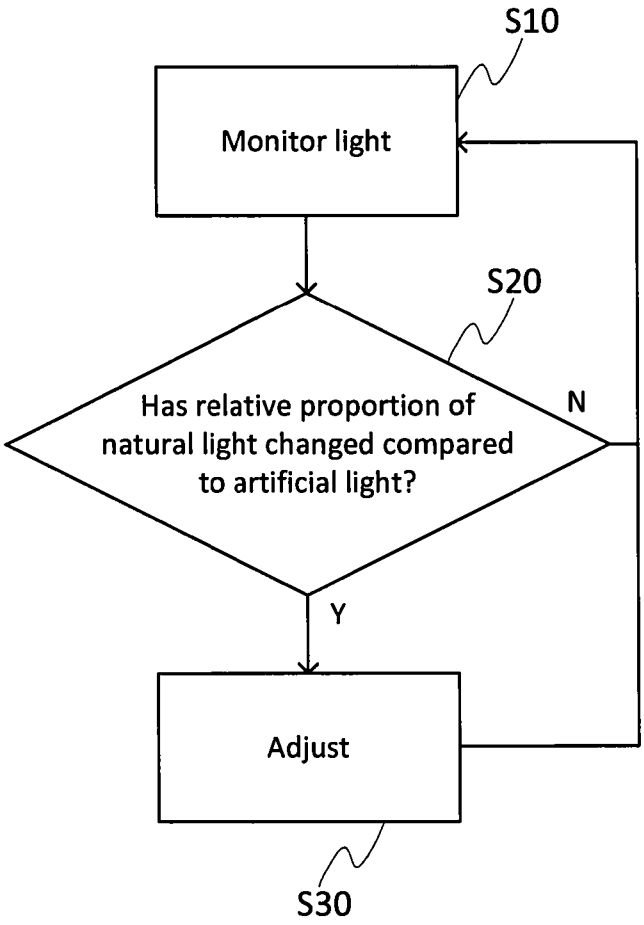


Figure 5


S10
Monitor light
S20
Has relative proportion of natural light changed compared to artificial light?
N
Y
Adjust
S30

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2013/058392

A. CLASSIFICATION OF SUBJECT MATTER
INV. H05B37/02
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 G01J H01J G03B

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

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Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
28 February 2014	06/03/2014

Name and mailing address of the ISA/	Authorized officer
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INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2013/058392

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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