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LED BASED ALTERNATIVE LIGHTING SYSTEM FOR LOW ENERGY CONSUMPTION IN ELECTRICALLY CHALLENGED ENVIRONMENTS

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ABSTRACT

The paper reviews the properties of light emitting diode (LED) as a lighting element which makes it a better choice, as compared to other light sources in use today, for low energy consumption lighting systems. LEDs use direct current (D.C) electric energy sources, and consumes small amount of energy in terms of voltage and current to produce a proportionate light output. They are small in size but produce high output light efficacy and are highly efficient. They are dimmable, can be switched ON and OFF millions of times, easily controllable, withstand mechanical stress, and live longer than other light sources. With its current-to-output light linearity, the transistor current gain characteristic is used to provide a simple intelligent control for an LED lamp through a light dependent resistor. To further explore the controllability property of the LED, a more advanced microcontroller control system is also presented.

Keywords:energy, LED, controllability, intelligent, microcontroller control

INTRODUCTION

As our society grows, the need for more energy is on the increase and the cost of this energy as well. Much demand on the available energy sources by increased population is also gradually resulting to serious scarcity of this commodity such that if not properly addressed may lead to a total short down of industries and as well as city blackouts.

One of the most available usages of energy is in lightning of homes and cities. The end user at home will need to light his\her environment at increased cost, and the government will also need to allocate more funds to lightning of our cities - this is not favorable.

A proper management of our lightning systems both at home and within the city can greatly reduce the cost of energy consumption. The use of conventional incandescent and fluorescent lamp have not helped in this matter since they need a lot of energy to be powered wasting most of this energy in form of heat and unwanted light. Therefore, we must look for an alternative lighting system to reduce energy consumption and cost. The new system must be able to save wasted energy in terms of heat loss and light. Different technologies have been deployed to produce energy saving bulbs; and what is the cost implication of using these bulbs? Do they really satisfy the end user? What is their life-span like? Are they easily controllable?

In this paper, we shall be looking into the use of light emitting diodes (LED) as an alternative to the existing lighting elements, as well as exploring its controllability for the production of intelligent energy saving lamps that are capable of reducing energy consumption while still giving adequatelight to the environment.

THE NEW LIGHTING ELEMENT

A light emitting diode (LED) is a semiconductor device which converts electricity to light. As a diode, when current is passed through the LED in the forward direction, it emits light, but blocks the flow of current in the reverse direction and does not emit light (Robert & Louis, 1999), (Henry, 2004). The color of the emitted light depends on the material and construction of the diode. The amount of light varies roughly linearly with the amount of current passing through the LED, which provides us a convenient way to efficiently change the light output (Henry, 2004).

Introduced as a practical electronic component in 1962, early LEDS emitted low-intensity red light, but modern versions are available across the visible, ultraviolet and infrared wavelengths with very high brightness (Wikipedia, 2004).

Colors of LED

LEDs are available in red, orange, amber, yellow, green, blue, and white. The blue and white types are much more expensive than the other colors due to the technology used in their production. The color of an LED is determined by the semi-conductor material used not by the package. Hence a single LED can be made to produce more than one color as can be seen in RGB LED which combines red, green and blue colors in different proportions to produce multiple colors.

Efficiency and Life-spam

Typical indicator LEDs are designed to operate with no more than 30 to 60milliwatts (mW) of electrical power. Around 1999, Philips Lumileds introduced power LEDs capable of continuous use at one watt. These LEDs used much larger semiconductor die sizes to handle the larger power inputs. Also, the semiconductor dies were mounted onto metal slug to allow for heat removal from the LED die. Today, several high power LEDs with very high brightness exist. As a measure of its light output per unit power input, LED has high efficiency (Rajbeer, n.d) and this is a key advantage for LED-based lighting. The efficacy of LED can even be improved if it is properly used in terms of its specifications. LEDs are semiconductor devices and are subject to very limited wear and tear if operated within the specified current and temperature, and are not physically mal-handled. LEDs can last for very long time if properly used. Many of the LEDs produced in the 1970s and 1980s are still in service today. Typical life-span are 25,000 to over 100,000hours of operation but heat and current specification settings can extend or shorten the life-spam significantly. LEDs are more reliable than the incandescent lights that are commonly found in our environment. LEDs can also tolerate shock and vibration loads than other common light sources including incandescent light bulbs, florescent light bulbs, and other are light sources.

To succeed in an LED lamp design for good use of its efficiency, three major conditions must be carefully managed. These are the electrical drive in terms of current and voltage, thermal management and the optics (Chris, 2008). A good balance of these three pieces on the solid state devices (LEDs) will result to long life, high electrical efficiency, high luminous efficacy and pure color.

The Electrical Drive

The first thing to be considered in terms of the electrical drive in the design of an LED lamp is the drive current, and the second is to determine the voltage range of the LED. Careful review of the manufacturer's specification will yield a recommended drive current and voltage necessary for proper usage of the device.

Thermal Management

Heat is a strong barrier to the efficient use of LEDs in order to efficiently use an LED for any application in terms of its efficacy and life-span, a proper heat management must be put in place. Heat sinks must be use when necessary to remove (conduct) excess heat away from the LED. Again the avoidance of excessive current through the LED will reduce heat produce at the LED device. A proper use of resistive elements that allow the flow of specified current is a good idea.

The Optics

The LED chip emits light in all direction. An optical system is used to gather the light and shape it into a beam. The LED itself has a built-in lens. This lens is limited in its ability to gather and shape the light into an acceptable beam and the LED manufacturers only offer a limited number of lens options. An LED lamp optical system consisting of just the built in lens in the LED may produce acceptable result for inexpensive lamps, but for higher quality results, a more advanced optical system is required.

This additional optical system will majorly be reflectors which will help throw the light from the LED. In a real reflector you have imperfections that tend to scatter the light beam. First, your light source is never a point source - it is always a complex 3-dimensional surface. Second, the reflector's surface is never perfectly smooth or exactly in the correct shape. This leads to angular errors that tend to spread the beam. By designing and controlling the angular errors you can shape the light distribution (beam pattern) to suit your purposes. Reflectors tend to provide the highest quality beams and the highest overall efficiency.

Controllability

LEDs are semiconductor devices and as with many semiconductor devices posses a good switching speed. LED are fast switching devices. However, it should be noted that as switching speed increased, the amount of current allowed to pass through it reduces, hence reducing the brightness. This process can as well be harnessed for power saving. LED are easily controllable, they can be dimmed by merely reducing the amount of current passing through them or voltage across them and this can be done in a very simple way bearing in mind that LEDs operates with very small D.C voltages and current range.

COMPARISON OF LED TO OTHER LIGHT SOURCES

LEDs as a light sources have several advantages over conventional light sources like the incandescent and fluorescent light bulbs ("Solid-State Lighting", 2010). At this instance we shall be comparing the brightness of LED light as a choice over other types of lights sources.

Are LED really bright?

LEDs are smaller in size when compared with the conventional bulbs or tubes. Hence their light output generally covers a smaller surface area. In terms of unit area illumination, LEDs do better than match the convectional bulbs and tubes.

Again because of the lens system used in the production of LEDs, they tend to produce light in some angular direction unlike the incandescent lamp for example whose output light is Omni-directional. Therefore more than one LED (probably spread in different direction) will be needed if the goal is to light a space formerly occupied by the light bulb. Placing these LEDs in series guarantees that the same current flows through each device and is the best way to ensure uniform light output from a group of devices.

In general as many LEDs are placed in series as possible and then further series chains are added in parallel until the total light output reaches the desired level. The number of LEDs that can be placed in series depends upon several factors but is primarily dominated by the input voltage, electrical codes and safety standards (Chris, 2008). Typically, the efficacy of a residential application LED is approximately 20lumens per watt (LPW), though efficacies of up to 100 LPW have been created in laboratory settings. Incandescent bulbs have an efficacy of about 15 LPW and qualified compact fluorescents are about 60LPW, depending on the wattage and lamp type (NAHB, 2010).

As mentioned before, LED are better at placing light in a single direction than incandescent or fluorescent bulbs. Because of their directional output, they have unique design features that can be exploited by clever designs. LED strip lights can be installed under counters, in hallways, in staircases, and all sort of difficult places where conventional light bulbs cannot be used.

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How much light do we really need?

One would ask how many of these LEDs do we really need to wire together to give a good brightness enough to cover a required space and possibly to pick a grain of sand in the flour? But rather ask, how much light do we really need?

If you look at typical LED marketing literature, you might think that brighter is always better. But that may not be the case. Your eyes can adapt to a wide range of light intensities. At noon on a sunny day the sun can illuminate a surface to about 120,000lux while an overhead full moon might illuminate the same surface to only 0.1lux (Henry, 2004). Your eyes use three main methods when adapting to changing light level. Under bright conditions, your eyes exclude excess light by closing the pupils. As the light level falls below the point where the pupils are fully open, the eyes undergo a chemical change to increase the cone (color) cell sensitivity. Finally, as the light levels falls below the capability of the cone cells, the rods (no color) cells take over and become mainly sensitive. It takes about 20 minutes after you leave a brightly illuminated area to become fully dark adapted.

So how much light do you actually need to perform a task? 1000 to 2000lux is recommended for fine detail work where maximum visual acuity and color recognitions is required. 100 to 200lux is appropriate for most office work. By 10lux colors are less vibrant while visual acuity is good. By 1lux, unsaturated colors cannot be distinguished and visual acuity is only acceptable. By 0.1lux, no colors are visible and visual acuity is poor. By 0.01lux, visual acuity is lousy and you can see objects better if you do not look directly at them.

So far, we can see that the number of these LED devices we will need for a lamp in a lighting area will really depend on the amount of light we need in that area.

ENERGY CONSUMPTION

Two features set LEDs apart from lighting sources; first LEDs are driven by current sources and secondly the forward voltage across an LED is low and is D.C (NAHB, 2010). Typical forward voltage for LED ranges from 2V to 4V, but its light intensity is proportional to the forward current.

Due to their D.C operation, LEDs consume very small amount of energy to give appropriate brightness in an area when compared to most other light sources (Ton, Foster, &Calwell, 2003). In this respect, power supplied to LEDs must be converted from the general alternating current (A.C) sources to a direct current (D.C) source before it is applied. It also made it possible for us to have high mobility miniature support lighting systems, this is because battery sources are D.C and need not be converted, and presently are made as small as possible for various operations which highly support the use of LEDs for lighting.

Power Supply for LED

The purpose of the power supply is to regulate power to the LEDs and ensure a stable operating environment. The power supply can vary in sophistication from a voltage source in series with a resistor – such as a battery with or without an additional resistor – to a fully regulated constant power system with thermal regulation.

LEDs have a negative thermal coefficient (Robert & Louis, 1999). This means that its forward voltage decreases with increasing temperature. With a constant voltage power supply, increasing the temperature slightly decreases the forward voltage and increases the current by a relatively large amount – causing a net increase in power and a further increase in temperature for any given thermal path, there is a power level at which the heat transfer can no longer keep up the increasing power and falling forward voltage. Thermal runway results and will destroy the LED if the power is not limited to a safe level in some way.

The best thing is to prevent thermal runway by regulating the current or power through the LED device. Regulating power through an LED has added benefit that it tends to provide better brightness regulation over a temperature range. A good regulating circuit keeps the LED lamp’s brightness the same throughout the life of the battery when a battery is used. Switch mode power supply offer very unique option for powering LED lamps. These power supplies, apart from being light in weight and in small sizes, have output that are easily controllable. They also provide good amount of current output for these LEDs.

Configuration for Optimal Power Usage

As stated earlier, one of the greatest enemies to LED light is thermal runway. This apart from destroying the LED, results to a considerable amount of power loss in the system. LED lamps are most efficient in terms of energy consumption when the LED is properly configured for optimal power usage.

One of the ways to handle this situation is to use a resistor in series with the LED (James, 2006). This will prevent passing of excessive current through the LED device, by sharing the supply voltage between the LED and the resistor.

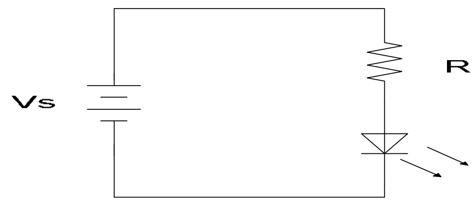


Figure 1.Limiting LED Current

An appropriate calculation of this resistor R value following the specification for the LED will ensure an efficient output result in brightness and lifetime.

As mention before now, more than one LED may be needed to develop a lamp of a required brightness. Connecting these LEDs in series will produce an equal brightness of the LEDs as well as reduce energy consumption and save cost of production of the lamp and that of running it. There is however, a trade off for this. As the number of LEDs in series increases, a higher amount of voltage will be required across the chain.

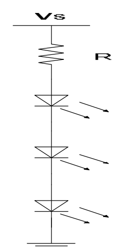


Figure 2.LED Connected in series

Hence there is a limit to the number of LEDs that may be placed in series for a particular value of supply voltage. If numerous LEDs are needed for a specific voltage value, then the best way to handle this is to connect several serial chains in parallel to each other while being supplied from the same source.

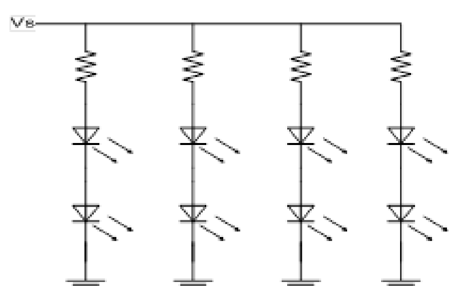


Figure 3.LED Array

This is an important way of saving power while lighting many LEDs, the current consumption of each series chain is the current due to one LED. Hence, if three LEDs made up one series chains and four chains are connected in parallel then the entire unit which consist of twelve LEDs will be using current due to only four LEDs. The serial configuration gives us optimal power management on usage if properly done.

Controllability for Power Usage

LEDs have high switching speed and this can be utilized for efficient power usage. First in dimming the light, and secondly in putting the light ON and OFF at high speed in a process of scanning such that each LED (or group of LED) is ON for a half cycle and OFF for the next half cycle of switching. In this process, large amount of current that gives required brightness can be passed through the LED at a very short interval amount of time. This means at entry interval of time, only current due to one LED (or group of LEDs) is used by the system thereby saving power.

Another aspect of using the controllability of LED for power usage is in putting off the light very easily, using circuit controls and possibly sensors, when not in use or when no lights are need. This is very much applicable as lights are needed only in the night or on run-ways that may require so much energy to power. Since LEDs can be switched ON/OFF many times without break down, they are a very good match for any of such application.

ADDING INTELLIGENCE TO YOUR LIGHT

Lucky enough, the LED is a semiconductor device and uses D.C sources for power, exactly the type of power source needed for electronic control. So why not become smart in power usage both at home and in the public. We can solve many other problems that relate to lighting in our environment by adding little intelligence to the LED light.

Several methods can be used to add intelligence to the LED lamps, ranging from simple transistorized control with light sensors to microcontroller control with infrared and/or proximity sensors.

Simple Transistor Control

As discussed before, we don't really need more light than we wanted for an area. And the fact that LEDs are easily dimmable due to their output light linearity with the amount of current passing through it, we can use a simple transistor with a light dependent resistor (LDR) to maintain the amount of light needed in an area to give the required illumination. In this process the transistor acts as a very simple amplifier to allow proportional amount of current to pass through the LEDs at a time as determine by the amount of light/darkness of the area. It uses an LDR in its base biasing arrangement.

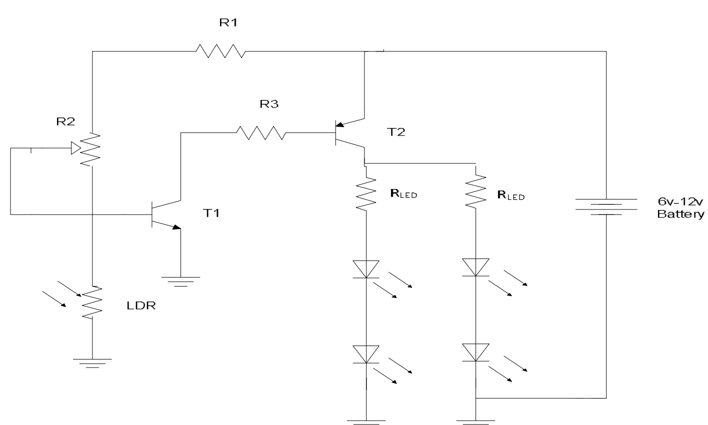


Figure 4.Simple LED light Regulation intelligent control

The circuit shown in fig 4 utilizes the controllability of the LED to put the lamp ON, increase or decrease the brightness with respect to the amount of light in the area.

R1, R2, and LDR form a voltage divider network to share the source (battery) in proportion to give a required base voltage to the base of the transistor T1. R2 is made variable to enable pre-setting of the bias voltage.

When light falls on the LDR, (whose resistance is dependent on the amount of light falling on it), The voltage at the base of the transistor T1, is proportional to the amount of light on the LDR surface allowing a proportional amount of current to flow. The current at the base of T1 (I_b) gives rise to a current flow (I_c) from collector to emitter of T1 determine by;

$I_c = \beta I_b$

Where β is the current gain for T1

T1 is a small signal transistor and its collector cannot handle large amount of current required to drive the number LEDs is used. Therefore T2, a power (or medium power) transistor capable of handling larger amount of current is added. The operation of T2 is exactly like that of T1, only that it is controlled by T1's output.

Therefore, the amount of light falling on the LDR, produce a proportional amount of current at T2 to give the required brightness, on the LED.

The system can be powered by battery and non-battery D.C sources. When battery powered, it supports mobile lighting sources (such as rechargeable mobile lamps) and the lamp is observed to be automatically increasing and reducing in brightness as the unit is moved from place to place within the environment. In areas with high reflective walls, its brightness is reduced and in less reflective areas, its brightness is increased. When other sources of light are introduced, the lamp shuts down totally and automatically provided such sources are bright enough.

When used in fixed lighting systems, it ensures that the lights are OFF during the day and comes ON only at night. Since the transition from day to night is not sudden (discrete), the circuit gradually increases its brightness as the day goes darker and darker until full darkness falls. In bad weather conditions resulting to darkness at day time, these lights provide alternative lighting to the environment. The circuit has a very high sensitivity and because LEDs are high speed devices, there is no noticeable delay to the output light of the system, the output production is quite automatic and it is intelligently calculated. The component count is low and the components are inexpensive, production cost is very minimal as compared to other lighting system that may be made to possess such capability.

Limitations

The only limitation to this control is in the constant maintenance of the LDR light sensitive surface. Whenever there is coverage of the LDR surface, the light will come ON regardless whether it is day or night. This could be a serious drawback when the system is used for outdoor lighting in dusty or snow prone environments.

However, there is a mild solution to this. Placing the LDR in a downward (i.e. facing down) position during installation greatly reduce the accumulation of dust and/or snow on its surface, and will therefore require little cleaning maintenance from time to time.

Microcontroller Based Control

A more advanced intelligent LED light control system is realizable through the use of a microcontroller (microcomputer) with a software algorithm embedded in it for a multi-functional intelligence. This intelligent control through an in-built (or added) analogue to digital converter (ADC), converts light intensity to its equivalent binary bits used by the microcontroller to make several decision with respect to light output brightness, ON/OFF time, delays, color of lights when multicolor LEDs are used. Infrared and proximity sensors (which are LED based) can equally be added to the control system to make moving objects (such as human) detection and presence decision (Thomas, 2009).

One of the basic advantages of this intelligent control system over the simple transistor based system is its ability to put OFF the light automatically when the light is not needed, such as when no one is crossing a corridor or no one is present in a room. This can be used to control multipoint, multicolor lighting system. Hence a simple control that is microcontroller based can be used for a household.

The sensor unit in fig. 5, serves as a feedback from the lighted environment to tell the microcontroller the present amount of light and this light is converted to its binary equivalent through an ADC before being applied to the controller (since the controller only understands digital values) for decision making.

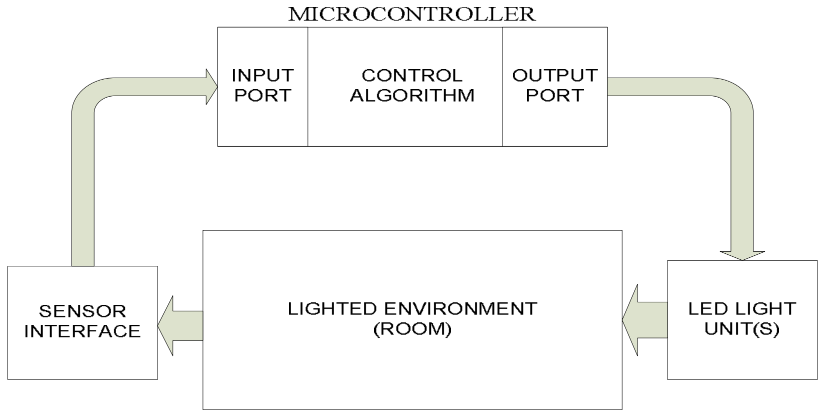
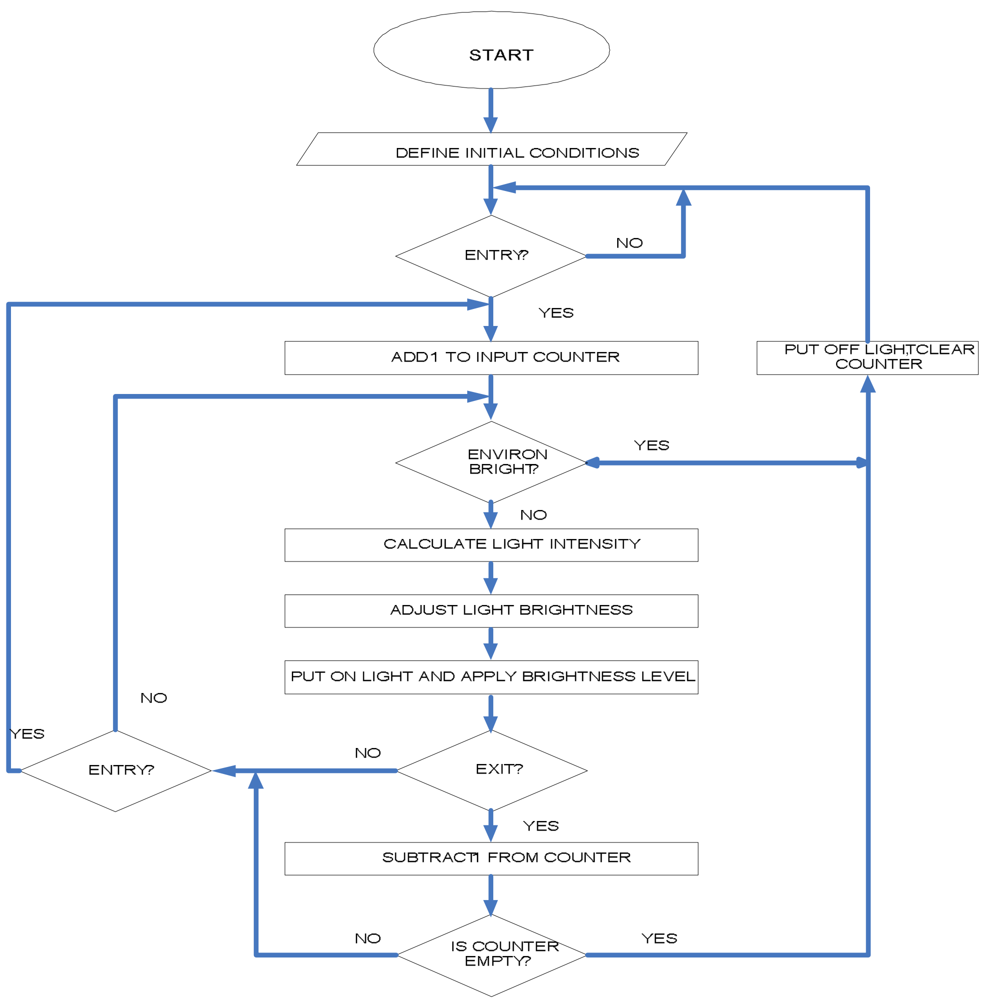


Figure 5.Sample Block Diagram of A Microcontroller Based LED Light Control System

The controller through its embedded algorithm calculates the required environmental light to adjust the brightness of the LED lamp.



Figur 6.A Microcontroller Based Control Algorithm

The adjustment of brightness in this control process is done by adjusting the switching speed of the LED. At low speed more current is allowed for a longer time giving higher brightness, while at higher speed current is allowed for a very short time, hence reducing the light output.

Other decisions such as at what light intensity should the lamp be completely shut down, or what color should be produced, or how many of the lamps units should be put ON, could be made as defined by the driving algorithm.

The infrared/proximity sensor gives another aspect of the control decision. Imagine a house with several rooms in which the light have to be put off when no one is in any of the rooms, in other to save energy. The switching becomes boring, causes wear and tear in the manual switches, and worse is resulting constant replacement of the bulb when incandescent and fluorescent light bulbs are used.

LEDs can be switched millions of times without being destroyed. Replacing the manual switches with LED based sensors and applying them to the control unit gives a perfect switching system that helps put off the light only when there is someone in the room. The embedded algorithm in the microcontroller makes it possible to take care of the presence of more than one person in the room and only put of the light when the last person leaves the room.

Figure 6 shows a not too complex algorithm in which we control the brightness as well as detected the presence of anyone in the environment before putting on the light.

In this algorithm, the system initializes and waits for an entry into the environment. Upon entry, the presence of the person is noted and stored in form of a number. The system then enquires for the amount of light in the environment. When this light is enough, it clears the count and ensures that the lights are off, but when not enough, it calculates the environment light intensity, adjust the light brightness level accordingly, puts ON the light(s) and applies the brightness level. The system then checks for exit or more entry sequentially to know whether to off the light or note the presence of more persons, while at the same time adjusting the brightness of light at all times.

More complex algorithms can be developed depending on the complexity and requirement of the system. In all, energy is well managed and consumption is highly reduced.

DISCUSSION

Without the use of intelligent control of any kind, a good LED lamp configuration serves to reduce energy consumption to a bearable minimum. However, the addition of intelligence using the controllability characteristic of the LED reduces energy consumption to an extremely minimum amount.

Again it should be noted that the controls discussed here are not exhaustive.

CONCLUSION

Huge amount of energy is used in lighting our homes and living environments and is expected to grow with the ever growing population. To curb the possible shortage of energy as a scarce resource, the modern home and society must switch over to low energy lighting systems. LED perfectly satisfies this option and outperforms other alternative light sources. Though, the installation of LED lights may be quite expensive; their overall low running cost and long life is a pay-off. The easy use of intelligent control to the LED light systems even makes the entire lighting system more suitable for our modern smart growing society.

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