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Authentic User Light Intensity Control for Outdoor Application

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Abstract: Outdoor lighting accounts for 75% of total demand and 19% of total energy consumption worldwide. The primary goal of this work is to control intensity of outdoor luminary system using Timer control, authentic user control (AUC) and hybrid control mode (HCM). The light intensity (LI) is regulated in different time zones based on the traffic on the road. In timer mode, the LI can be controlled based on the time zones. In AUC, the LI can be controlled by the authentic user by pressing a valid key from mobile. The AUC facilitates LI control (LIC) at midnight and on special occasions. In hybrid control mode, the LI of the luminaries can be controlled by timer and AUC. When authentic user presses the valid key, it overwrites the timer control, and based the key the LI is controlled. The luminaries operate in four different LIC modes. The LI may vary by 100%, 50%, 25%, and 0% (OFF). Three different modes are proposed in this work. They are: (i) auto-run self-test mode (ARSTM), (ii) normal mode (NM), and (iii) HCM. The luminaire working condition is tested using ARSTM. The NM has two operating modes: Timer mode (TM) and AUC mode (AUCM). In HCM, depending on the control inputs, the designed module operates based on timer and AUC inputs. The operation of the developed module is verified in ARSTM, NM, and HCM. Simple logic circuits are used in the proposed modules. This module used in rural, urban, other outdoor lighting applications and saves energy with LIC. It can be employed in outdoor LIC applications that rely on motion detection.

Keywords: DTMF Decoder, GSM, LED, Luminary, Mobile phone.

Introduction

A Smart street lighting (SSL) management system reduces the energy consumption of outdoor lights. It saves energy, reduces carbon footprints, and lowers maintenance costs.

Outdoor lighting accounts for 75% of total load demand and consumes 19% of total energy consumption worldwide.[1,2] The cost of outdoor lighting electricity in a European country ranges between 1-3 million dollars per one lac people. Outdoor lighting in India consumes 3,400MW (18% of total energy) and contributes 1.6 billion tons of carbon footprints per year.[3] Every country is looking for a possible solution for energy-efficient outdoor lighting system implementation. Recently, India's honorable Prime Minister announced that outdoor luminaries will be replaced with LEDs, saving 9000 million kWh of energy worth $850 million per year. The majority of the world's outdoor street lighting has yet to adopt new technologies. Few countries have already implemented advanced outdoor lighting control methods such as LED luminary and motion detection-based lighting control. However, every country in the world should focus on energy-efficient advanced outdoor lighting control management system and their implementation for a healthy environment.

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Significance of the proposed work

Outdoor luminary intensity management through Wi-Fi or the internet is not viable to install on most highways due to the absence of internet availability on remote roads. Nowadays, streetlights are being replaced with Light Emitting Diodes (LED), LED arrays that consume significantly less energy. These lights are on all night and require energy-saving techniques to save energy. In low traffic hours at night, intensity dimming can reduce energy waste by 50%. Because of safety concerns, dimming is not allowed on highways or in other high-traffic areas.

In tracking high-speed vehicles, the sensors' base LIC based on motion detection is inefficient. Furthermore, the central server or network-based architectures are expensive to implement across an entire country. As a result, to support high-speed vehicles on highways, one should prioritize energy-efficient adaptive motion detection-based LIC.

We primarily developed a luminary intensity control based on time zone or AUC module with autorun self-test mode provision as part of the adaptive motion detection-based light intensity control project. The primary goal of this work is to create an energy-efficient LIC system. The selected LED luminary has intensity variations of 25%, 50%, and 100%. The LI varied by time or AUC. It enables LIC through the use of timer and authorized user control using hybrid control mode.

This contribution's highlights are listed below.

i. Integrating a solar panel into an LED array luminary with intensity control
ii. development of ARSTM, NM, and HMC modules for LIC
iii. In the field, test light intensity control in various modes using the designed modules.

The significance of the proposed work, is it save energy by controlling the intensity of the outdoor luminaries based on the time zones, and also provides flexibility of intensity control based on authentic user control inputs. The proposed module can be used in rural and urban street lighting, saves lots of energy.

Outdoor Lighting Management System and Current Status in Literature

Review Stage

On highways, streetlights employ high-intensity discharge (HID), LEDs, etc.[4,5] Several methods like LIC of sodium light by Latin[6] *et al*, central control-based LIC of HID light utilizing magnetic ballast, and LIC via ballast described in Rueda[7] *et al* were used for light intensity control. LEDs are more energy-efficient than incandescent bulbs.[8] As a result, outdoor luminaires were replaced with LEDs to save 65-85% energy.

At first, the streets of Estonia Street used LED Luminaries. Later in Budapest, Hungary's capital, and in India's Nashik Municipal Corporation, among other locations.

BIS-1981 contains the outdoor lighting standards.[9] Smart street lighting (SSL) or automated smart outdoor lighting (ASOL) has several advantages, including energy efficiency, bright illumination with uniform distribution, longer life, and low cost. The quantity of LEDs in an LED array increases the likelihood of luminary failure and presents a high-reliability LED module array design for streetlight applications.[10] Solar PV integrated outdoor LED luminaire automated intensity control from 0-100 percent, which is cost-effective and ideal for airports, parking lots, and rural roads.[9,11-13] As described in Shahzad[14] *et al*, smart scheduling with traffic-based intelligent drives can save 50% energy, while LED arrays with dimming can save 70% energy. It poses a security risk even if every other light in the row turns off. Light dimming, often known as LIC, is an energy-saving technique. Dimming based on time zones proposed in Joshi[15] *et al*. Luminary intensity control using fuzzy logic proposed in Shafer[16] *et al*.

The Lee[17] *et al* was proposed fault detection with automobiles using lighting maps and data collection. Outdoor light intensity control using ZigBee demonstrated by Kaleem[18] *et al*. The outdoor LIC can control by traffic density.[19] The Bai & Ku[20] described a microcontroller-based home automated light intensity control system with PIR sensors and an RF module. Various sensors are used for light intensity control applications.[21-23] The light intensity can be controlled by sensors using Internet of Things (IoT).[24,25] The light intensity control using RISC processor was described by Hong[26] et al. The Muhendra & Arzi[27] proposed light intensity control using Wi-Fi. Various intensity control strategies like adaptive control method, other intelligent techniques, distributed sensor networks, piezoelectric sensor networks, vehicle motion detection, etc., can be used to control light intensity.[28-34] A centralized LIC in the ISM band has been experimented with using GPRS, gateway, central node with RF communication. The use of motion detection sensors to adjust intensity saves 20% of energy, etc., described by Lavric[8] *et al* and Lau[34] *et al*. Mullner and Riener[3] describes smart outdoor lighting management using IP networking. It provided a centralized luminary intensity control system with Wi-Fi. The use of IP networking for smart outdoor lighting management was described by Mullner and Riener[3]. Recently, S.-T. Shih and I.-C. Li[35] proposed LIC using a mobile with MIT APP.

The majority of the world's street lighting systems have yet to incorporate modern technologies. Internet-connected or network-controlled lights are expensive and not suited for many roadways. LED luminary has replaced outside luminaries; however, they remain on at night during non-traffic hours. Even though dimming saves energy, it is not suitable for usage in high-traffic areas.

To support high-speed vehicles, motion detection-based IC modules should be designed properly. Many designs are available online, but how feasible they are in reality remains an open issue (?). For various types of roads, adjust the sensor's range and uniform light distribution. When designing a motion detection-based lighting system, consider the slope of the street, the amount of traffic, and the location of the luminary. Real-time problems are to be managed effectively with a simple design. Designing a central control street LIC system without networking is complex. Another concern is granting access to legitimate users.

The designed modules used for motion detection-based centralized LIC using simple circuits to handle the above difficulties. We built a module to adjust luminary intensity based on time zone and authorized user control with an auto self-check facility as part of our project.

System Model and Implementation

The main goal is to create a low-energy, low-cost outdoor lighting control system. The design and implementation of a LIC module is the first step toward achieving this goal. Fig. 1 illustrates the proposed LIC module and its components.[36]

The AC is initially converted to 5V DC using a rectification circuit and the IC 7805. A mode selection switch uses to choose between the ARSTM and NM modes. The DS1307 Real Time Clock (RTC) and DTMF decoder HT9170 connected to ATMEGAA8 produce T1, T2, T3 and C1, C2, C3, C4 in positive logic (PL) or negative logic (NL). RTC divides a day's total time into four slots. T1: 6.00-9.00 p.m. and 4.00-6:00 a.m.; T2: 9.00-11.00 p.m.; T3: 11.00 p.m.-4.00 a.m.; T4: 6.00 a.m.-6.00 p.m.

In AUC, the transmitter is a mobile phone, and the receiver is an HT9170 DTMF decoder with a GSM module SIM800L (as depicted in Fig. 2) or another mobile phone. Control outputs C1, C2, C3, and C4 are produced according to the control key pressed by the user mobile.

The ULN 2003 driver module receives T1, T2, T3 timer outputs or legitimate user DTMF decoder outputs C1, C2, C3, which regulates the intensity of the LED array with 5V Relays J1, J2, J3 as shown in Fig. 3 & Fig. 4 shows a complete laboratory test model of the luminary with a control module and solar panel

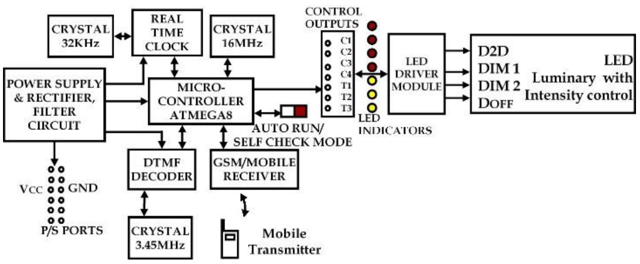

Fig. 1 — Proposed LIC module

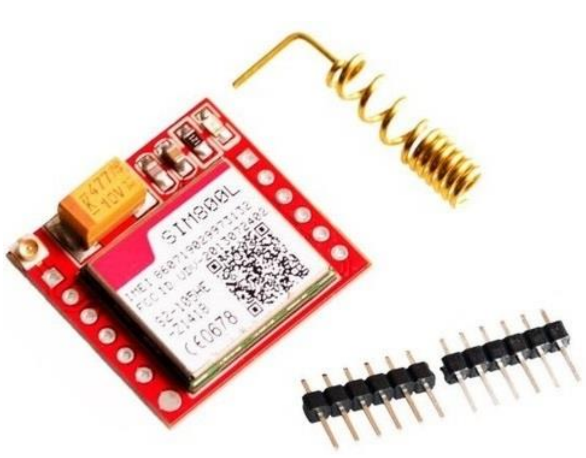

Fig. 2 — GSM module SIM800L integrated.

Hybrid Control Modes Operation

The LI control by either TM or AUCM, depending on the application. The control module is usually in timer mode and can control by AU depending on the situation. When the AU dials and presses the correct control key, the intensity of the LED array changes to match the external authentic user's valid key pressed.

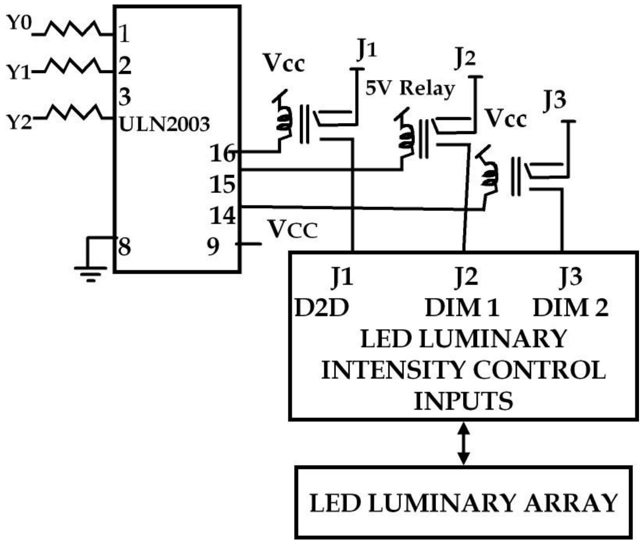

Fig. 3 — Logic switching module (LSM) or LED luminary driver module

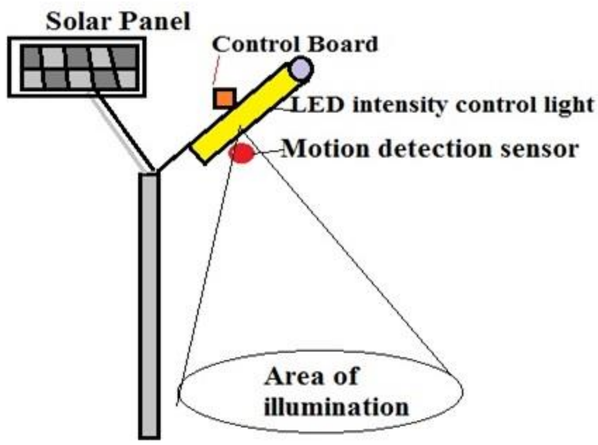

Fig. 4 — Complete laboratory test model: luminary and control module integrated with solar panel

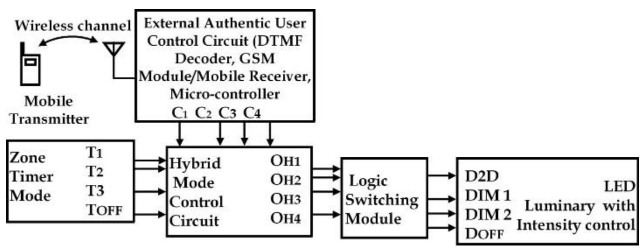

Fig. 5 — HMC operation

Fig. 5 depicts the basic block diagram for HMC. Hybrid mode uses positive logic. Time control and AUC outputs link to the HMC circuit of Fig. 6 in HM. The HCM circuit uses simple logic gates. An inverter complements the output.

The HMC outputs are generated according to the control inputs, as shown in Table 1. Fig. 6 shows an HMC circuit in positive logic mode. As illustrated in Fig. 3, the outputs of the HMC circuit apply to the LSM. LSM controls the LIC jumpers linked to D2D, DIM-1, and DIM-2.

The hybrid control outputs can express as

$$E_C = (C_1 + C_2 + C_3 + C_4)' \quad \ldots (1)$$

$$O_{H1} = C_1 + E_C T_1 \quad \ldots (2)$$

$$O_{H2} = C_2 + E_C T_2 \quad \ldots (3)$$

$$O_{H3} = C_3 + E_C T_3 \quad \ldots (4)$$

$$O_{H4} = C_4 + (T_1 + T_2 + T_3)' \quad \ldots (5)$$

Table 2 shows the experimental results obtained with a hybrid mode controller. It is explained in the subsequent sections.

Results

The test cases evaluated in the laboratory for designing and testing the proposed module are described in the following section.

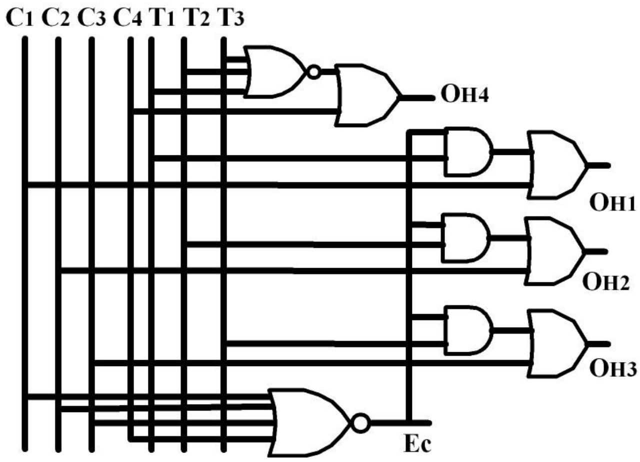

Fig. 6 — HMC circuit

Table 1 — HM control operation

Sel	MKP	C1	C2	C3	C4	T1	T2	T3	HM	O_{H1}	O_{H2}	O_{H3}	O_{H4}	L I %
		Control module outputs: AUC				TM				Hybrid CM				
PL	1	0	0	0	1	d	d	d	AUC	0	0	0	1	0
	8	1	0	0	0	d	d	d		1	0	0	0	100
	4	0	1	0	0	d	d	d		0	1	0	0	50
	2	0	0	1	0	d	d	d		0	0	1	0	25
	0,3,5, 6,7	NC				d	d	d		0	0	0	0	NC
	IA	0	0	0	0	1	0	0	TM	1	0	0	0	100
		0	0	0	0	0	1	0		0	1	0	0	50
		0	0	0	0	0	0	1		0	0	1	0	25
		0	0	0	0	0	0	0		0	0	0	0	0

MKP-Mobile key pressed NC-No Change, d-don't care, IA-inactive

Luminary

A LED array with LI fluctuations of 25% and 50% is chosen, as well as a delay provision. It is designed to run from dusk until dawn (D2D). The luminary can be powered by AC, DC, or both, depending on the intended application and cost.

Testing LED luminary working condition

Two switches (SW1, SW2) connect to the LED luminary, solar panel, and 15 V battery. Table 3 lists the primary verification of luminary. The LED panel has six control inputs, each having a 100% LIC, a 50% LIC, and a 25% LIC with delay. At first, test the operation of LED luminary with intensity controls in the laboratory. Only three luminaire controls, DIM1, DIM2, and D2D, were considered in the proposed study. The timer outputs T1, T2, T3, or the DTMF decoder outputs C1, C2, C3 are given to the LED Array LIC inputs D2D, DIM1, DIM2.

Testing autorun self-test mode operation

The mode selector is kept in ARSTM. All combinations of control output C1, C2, C3, C4, and T1, T2, T3 in ARSTM are automatically generated with a 2s delay, as shown in Table 4. ARSTM checks the luminary's working status in the field.

Testing normal mode operation

Keep the mode selector switch in NM and the jumper in PL after ARSTM. The two modes of operation for an NM are (i) TM and (ii) AUCM. In NM, the LIC is managed in the field by a timer or an AUC over the phone.

TESTING TIMER MODE

The time adjustment of the time zones option is provided in the kit. The luminary intensity controls by RTC with the control module are tested and given in Table 5. The timer mode is used to test lights in the field. To control LI, RTC generates several time slots in TM. T1 has a LI of 100 percent; T2 has a LI of 50 percent; T3 has a LI of 25 percent, and T4 has a LI of zero percent. The kits allow the user to change the time zones. The results of the luminary intensity control using RTC with a control module are shown in Table 5.

TESTING AUCM

The LI can be controlled in AUCM by pressing the mobile key button, receiving via the receiver mobile or GSM module, and decoded as C1, C2, C3, C4 by the DTMF decoder. C1, C2, C3, C4 produce when a legitimate user dials and presses a valid key (8,4,2,1), which controls the LIC inputs D2D, DIM1, and DIM2.

A code word (CW) C1 C2 C3 C4 - 1000 (equivalent to binary code) is generated when AU presses key button 8. The CWs 0100, 0010, and 0001 are generated when key buttons 4, 2, 1 are pressed in PL mode. When C4 equals 1, the LED array is turned off. Table 5 summarizes the LIC in AUCM that employs NM.

NM allows the user to access the same control module for timer control, AUC control, or both timer and external user control. The proposed model can be used on a variety of roads and for different purposes in the field. As a result, control outputs for the timer and an external legitimate user with LED indication are available.

This feature allows the luminaire to be operated in several modes depending on the infield application. The same control module can be utilized for multiple applications by simply changing the plug-in connections of the control outputs.

HM

The logic selector in HM is kept in PL by a jumper.

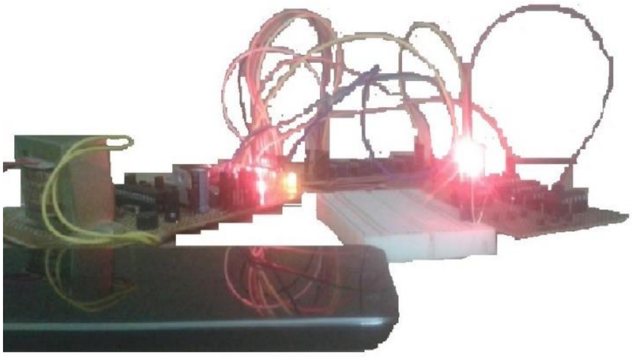

Fig. 7 — HM operation when mobile key 4 pressed, produce control output 0100001 and Hybrid CM outputs 010

Fig. 8 — Setup of external AUCM

As shown in Fig. 6, the timer and AUC inputs are given to the HMC circuit. Based on control inputs, the HMC circuit generates OH1, OH2, OH3, and OH4. After being inverted with NOT gates, these outputs are directed to the luminary control inputs. The outputs from the hybrid control circuit are used to control the light intensity. A list of HM control operations can be found in Table 1.

The HM provides more versatility and comfort for rural and urban street lighting. Autorun self-test mode used for luminary test clearance. Various modes, external authentic user control mode, timer mode, hybrid modes of a proposed module used infield applications. Only authentic users can alter the light intensity in external control/hybrid modes, which helps with privacy concerns. Table 6 lists the various components used in this project.

HM operation when the number 4 pressed given in Fig. 7. It generates Hybrid CM outputs 010 from T1 T2 T3 C1 C2 C3 C4 0100001 control module outputs. Fig. 8 shows the external AUCM test case setup. The LIC using AUC with 100%, 50% intensity when buttons eight, four, and two pressed given in Fig. 9 and Fig. 10.

Designed module and future expansion

As detailed above, the proposed circuit controls LI in TM, AUC, or HM. It helps for outdoor LIC with motion detection. During the night, this saves an additional 75% of energy.

Table 2 — Primary test of LED array

S1	S2	LED Array operation	Comment
1	d	0	6.00 a.m.-6.00 p.m. Light off
0	1	1	6.00 p.m.-6.00 a.m. Light on
0	0	0	Light is off

Note: ‘d’-redundant, 1-ON, 0-OFF, S1-Switch 1, S2-Switch 2

Table 3 — LED array LIC primary verification with jumper

LIC inputs						
DIM1	DIM2	DL1	DL2	DL3	D2D	LI %
0	0	0	0	0	1	100
1	0	0	0	0	0	50
0	1	0	0	0	0	25

*1-Jumper connected, 0-not connected

Table 4 — LIC using ARSTM

PL/NL Sel	AR/NM Sel	T1	T2	T3	C1	C2	C3	C4	LI%
P	AR	0	0	0	1	0	0	0	100
		0	0	0	0	1	0	0	50
		0	0	0	0	0	1	0	25
		0	0	0	0	0	0	1	0
		1	0	0	0	0	0	0	100
		0	1	0	0	0	0	0	50
		0	0	1	0	0	0	0	25
		0	0	0	0	0	0	0	0

The column group T1–C4 is headed "Control module outputs".

*P-Positive, N-Negative, Selector-Sel

Table 5 — LIC using NM

P/NL Sel	AR/NM Sel	CM TM/AUC	MKP	T1	T2	T3	C1	C2	C3	C4	LI%
PL	NM	AUC	8	0	0	0	1	0	0	0	100
			4	0	0	0	0	1	0	0	50
			2	0	0	0	0	0	1	0	25
			1	0	0	0	0	0	0	1	0
		TM	-	1	0	0	0	0	0	0	100
			-	0	1	0	0	0	0	0	50
			-	0	0	1	0	0	0	0	25

The column group T1–C4 is headed "CONTROL MODULE OUTPUTS".

*MKP-Mobile key pressed

Fig. 9 — LIC by HM when 8 is dialed with 100% intensity

APPLICATIONS

The developed modules used in outdoor lighting for regulating LI with AUC and motion detection-based applications proposed in this paper and Devi[37] *et al* can be used in commercial parking lots, educational institutes, smart cities, rural development, and other applications.

Table 6 — Various components used for the proposed work

Component	Details	Used in the block	Purpose
DTMF decoder	HT9179 with crystal frequency 3.45MHz	DTMF decoding	For external authentic user control mode operation
Mobile transceiver	Samsung mobiles		For authentic user control
GSM module	SIM800L	External authentic user control	To receive the authentic user control signal
Real time clock (RTC)	DS1307 with crystal frequency 32KHz	Timer	Timer mode operation
Microcontroller	ATMEGA8 with crystal frequency 16MHz	Programmed to generate control outputs	It generates control outputs, positive/negative logic outputs
Luminary	OSRAM LED array MCUD80	Luminary	LED luminary array with intensity control inputs
Solar panel	100W	With luminary	Charging battery for dc supply
Battery	15V	With solar panel	To provide dc supply to the luminary
Rectifier, filter and regulator	For AC to DC conversion	To supply DC 5V	5V DC supply for ICs
Lithium ion battery	5V	Timer block	Used to supply power to RTC when power is OFF.
LED lights	Red, yellow and white	Indictors	To indicate power supply, control outputs status
Relays	5V	logic switching module	Used to connect luminary jumpers
Basic Gates	NOR, OR, AND, NOT	Hybrid mode controller	To generate hybrid mode control outputs

Conclusions

In this proposed work, a luminary intensity control module was designed for outdoor streets. The proposed model uses simple circuits to create a robust, cost-effective, and energy-saving outdoor luminary intensity control system.

The module has a timer unit, authentic user module, and hybrid mode intensity control. It has selectors for auto-run self-test mode and positive or negative logic outputs. It saves 40-70 percent more energy during non-traffic hours by providing adequate lighting and ensuring citizens' safety. The current work saves energy during night times by controlling light intensity which reduces carbon footprints, reduce the maintenance cost and electricity cost, and upgrades the rural and urban outdoor lighting. Further, this module also used in motion detection based luminary intensity control applications and further enhances the energy saving up to 75-85%. The proposed module performance can be further improved effectively using artificial intelligence and machine learning techniques and Internet of Things, etc., via adaptive intensity control of outdoor luminaries.

Fig. 10 — LIC by HM when 4 is dialed with 50% intensity

Acknowledgment

Our college KITSW R&D supported this project. We filed a patent entitled "Zone Control System for Motion Detection based Light Intensity Control and Methods Employed Thereof," Patent No. 405460, Application No. 201941014850, Granted on 01/09/2022.

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