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Two Step Algorithm Implementation for Intelligent Street Light System

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Abstract—This paper presents an algorithm for the automation of street lights for existing urban roads in India. In thiscase study a two kilometre lane in Chennai, India is taken under consideration. The paper proposes replacing the existingHigh Pressure Sodium VapourLamps (HPS) with Light Emitting Diodes (LED). A smart algorithm is fed into the system design incorporating phototransistor and Infrared sensors. The opera- tion time of the street lights can be categorised as High Passerby Frequency(HPF)andLowPasserbyFrequency(LPF)period.The Dynamic Intensity Modification (DIM) system operates during LPF duration hence, when passerby is detected the street is illuminated to maximal intensity which otherwise is maintained at low intensity consuming low power resulting in low cost.For the 2 km stretch, the results highlight that replacing all existing lamps with LEDs and dimming light intensity in the absence of users in the vicinity of the lamp-post is convenient and provides minimum of 65.74% and a maximum of 72.9% relative reduction in cost for a period of twenty years for this specific case study. However, the DIM algorithm is generic and can be implemented across any Indianroadway.

Keywords—Urban Roads, Infrared Sensors, Phototransistors, Intensity Modulation, Automated Switching, Street Lights.

I. INTRODUCTION

Street lighting is considered vital for the development of countries worldwide. Lighting can account for 10-38total energy bill in typical cities[1]. The features of street lights indirectly have assisted the public and government in reduction of crime rate and accidents in the area. Poor lighting creates unsafe conditions. According to a study by the New York City Police department, installation of outdoor lighting inpreviously unlit areas, has resulted in 39% reduction in index crimes duringnight[2].

However, conservation of electrical energy is a major concern of the 21st century, given the rapid speed in burning of fossil fuels. If fossils are burned at the present rate, it is predictedthat fossil fuels would be exhausted by the year 2060[3]. Though, street lights are considered essential, it is highly expensive, energyconsumingandposesashighpriorityloadsduetosafety concerns. This can be changed by automating the switching operationsanddecreasingtheilluminanceofthelightswhen passerby is not present on the streets, thereby reducing the load significantly and eliminating the need for manpower.

II. RELATED WORK

Revathy et al[4] has proposed the idea of using Light Dependent Resistors (LDR) for the purpose of vehicle move- ment detection. The recommended system is operated at 20% light illuminance when no vehicle movement is detected and escalates to 100% when vehicle movement is detected. The author has not taken into account the safety of the pedestrians which is highly vital, furthermore LDR has a high response time of about 5-50 ms. for the case of a vehicle moving at a speed of 60 km/hr would cross a metre in 60ms, the street light would lit up in a delay which would cause more of nuisance to the driver with improper lighting.

Preethika et al[5] has proposed the idea of integrating IR sensors to sense vehicle movement and glow whenever the sensor senses vehicle right in front of the lamp-post. This causes vision disturbance to driver, to witness flickering of lights throughout the travel.

Sharath et al[6] has suggested that the entire lighting system can be made self sustainable by the use of solar panels. Though, the use of solar panels indirectly reduces the environmental impact for power generation, it is considered as a high cost alternative to conventional electricity. The break even of cost happens at around 18.6 years and the solar panels need to be replaced every twenty years. Very negligible cost reduction is observed for the proposed system.

III. PROBLEM STATEMENT

Shanthi colony, a two kilometre stretch in Chennai, India shown in Fig 1 is switching from conventional HPS lamps to LED to save energy and cost. Replacement of HPS with LED lamps paves way to automate the switching and decrease the load resulting from street lighting by reducing the intensity with which the light glows. However, the 12 hour ON - OFF cycle is followed for switching purposes. Implementing the the system of switching ON LEDs only when natural light is absent along with decreasing the illuminance of light during low passerby frequency can be performed with ease by installing the required components along with the installation of LEDs. The additional cost incurred to interface the system with the street lights and implement the algorithm is absorbed in Capital Cost.

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Fig. 1. Shanthi colony, Anna Nagar, Chennai

IV. METHODOLOGY

A. Load Modelling

The prevailing system's load is reduced by the replacement of HPS with LED. The LED equivalent of a 250 watt HPS lamp is identified as 95 watt, based on lumen count and S/P ratio[7]. The power rating of the LED is obtained to calculate the total load per hour TL_h as given in Equation 1.

$$TL_h = \sum \frac{SL}{ISD} L_i \times 95 \qquad (1)$$

where, SL - Street length in metres ISD - Inter Streetlight Distance L_i - No of lanes (1,2)

A. System Design

I. Phototransistor Integrated System (PIS)

Phototransistor is a bipolar junction transistor which can be used as a light sensor. The collector is kept at a higher potential than the emitter hence, the collector - base junction of the NPN transistor is reverse biased exposing it to a light source. The base is not electrically connected but the base current is generated by light falling on the collector - base junction. In the absence of light, a faint normal leakage current flows, in the presence of sunlight on the base terminal, beam of photons hits the collector - base junction. When a photon of adequate energy is incident on the junction, an electron is liberated and if this electron holds sufficient energy, it may pass over the energy barrier causing an increase in flow of base current. Below saturation the transistor implements Equation 2.

$$I_C = \beta I_B \qquad (2)$$

where, I_C - Collector current

I_B - Base current

β - Current gain β is typically 100 and hence a phototransistor has a higher gain from light to current than a photodiode. The magnitude of the collector current is directly proportional to the extent of illumination of the junction. The phototransistor is fixed to the foremost street light in the street. During sunrise the sun emits a little less than 400 luminous flux per unit area (lux). The collector current corresponding to measure of illuminance is inferred from Figure2

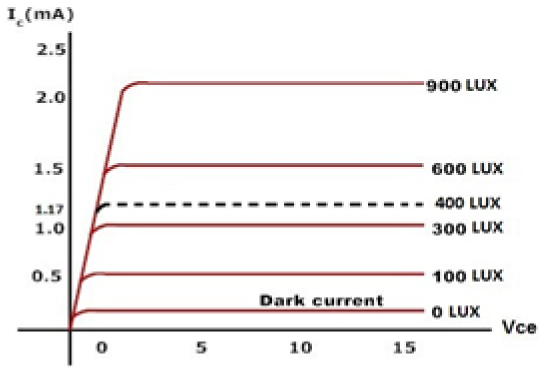

Fig. 2. Collector current corresponding to Illumination

From Figure2 collector current of approximately 1.17 mA corresponds to 400 lux. The phototransistor - LED interface is set such that when the collector current transcends above 1.17 mA the street lights are switched OFF. Naturally , the system is designed such that when the current reduces below 1.17 mA the street lights are switched OFF.

Algorithm 1 Automated Switching with Photodiode

1: **if** PT == HIGH **then**
2: $LED_{1 \to n} \leftarrow ON$
3: **if** PT == LOW **then**
4: $LED_{1 \to n} \leftarrow OFF$
5: **end if**
6: **end if**

The switching of street lights is thus, fully automated and avoids burning of street lights in the presence of sunlight. During summer this significantly reduces the operation time for more than 40 hours a year which increases the lifetime of the led and thus the replacements in long term. The phototransistors tend to decrease in

I. Dynamic Intensity Modulation (DIM)

The two foremost street lights on either ends of both lanes are switched ON to 100% intensity once the phototransistor exceeds 1.17 mA. Rest of the street lights burn at only 40% intensity at normal conditions.

Each street light is interfaced with an Infrared transmitter and receiver pair which are fixed to the pole. The IR transmitter and receiver placed adjacent to each other are located at a 95 cm height above the ground. The IR transmitter (Infrared Source) emits infrared rays. When the infrared rays are hindered by an obstacle, it is reflected back which are then captured by the IR receiver (Infrared detection). Thus, the moving vehicle is detected by the IR sensors as shown in Figure3. The range of

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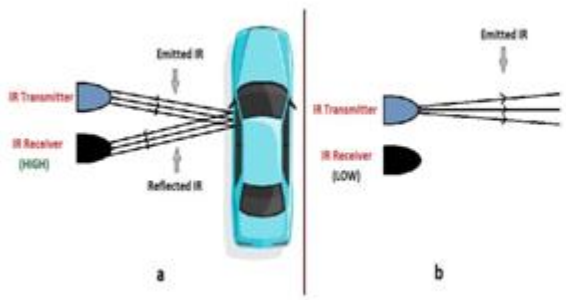

Fig. 3. Operation of IR sensor in presence(a) and absence(b) of an obstacle

the IR sensor is fixed as in Equation3

$$Range_{IR} = \{Width\ of\ lane + Width\ of\ Sidewalk\} \quad (3)$$

The width of the lane is 7.5m and the sidewalk is 2m, hence the range of the IR sensor is fixed at $7.5m + 2m = 9.5m$. This is done to ensure that even a person walking at the far end of the sidewalk would not go undetected. The IR pair in the foremost lights on the either end of the lane record the average time the vehicle or human takes to move from one pole to another. A vehicle enters to street with the initial two street lights illuminated. Once the IR sensor from the initial pole detects the vehicle, the DIM technique ensures that a distance of 90m ahead of the driver is always illuminated.

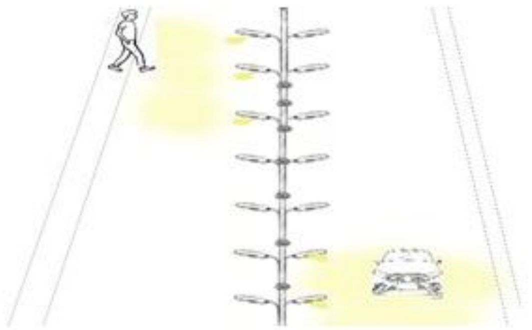

Fig. 4. Pedestrian walking on right lane (3 lights glowing) and car parked on left lane (2 lights glowing)

The DIM mentioned in 2 is implemented from 11:15pm to 4:30am which is considered as LPF period as when passerby frequency is high the cost savings is not significant , also frequent fluctuations in input voltage decreases the lifetime of the LED. When the vehicle crosses the first and second pole the third LED from the respective pole is consecutively switched ON to ensure the 90m forward illumination for passerby is present. The average time taken to cross the distance between two poles is stored in AT. When IR_x is HIGH, corresponding LED is switched to Maximum Intensity for a duration of AT. A counter for each IR keeps track of the number of passerby which had went across. When the counter variable

Algorithm 2 Implementation of DIM

if $(Hour \geq 11:15pm) \cup (Hour \leq 4:30pm)$ **then**
  $LED_1, LED_2 \leftarrow ON[MaxIntensity]$
  $LED_{3\rightarrow n} \leftarrow ON[0.4 \, MaxIntensity]$
  if IR_1 == $HIttH$ **then**
    $LED_3 \leftarrow ON[MaxIntensity]$
  end if
  if IR_2 == $HIttH$ **then**
    $LED_4 \leftarrow ON[MaxIntensity]$
  end if
  $x \leftarrow POS[IR]$
  AT= Time[IR_2 - IR_1]
  if IR_x == HIGH **then**
    $Count[LED_x] \leftarrow Count[LED_x] + 1$
    for $I \leq Seconds$ **do**
      $LED_x, LED_{x+1}, LED_{x+2} \leftarrow ON[MaxIntensity]$
    end for
    if Count$[LED_X]$ > Count$[LED_{X+1}]$ **then**
      $LED_x, LED_{X+1} \leftarrow ON[MaxIntensity]$
    end if
  end if
end if

of $IR_x > IR_{x+1}$ after a period of AT, it denotes that the passerby had halted in between the two poles.

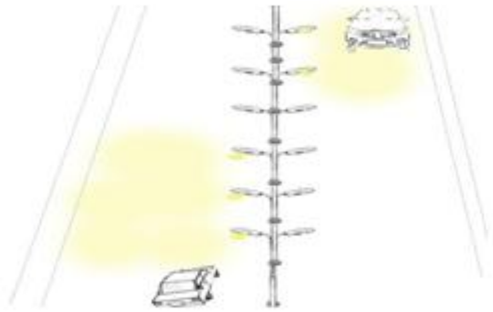

Fig. 5. Car moving forward in left lane (3 glowing lights) and car parked in right lane(2 glowing lights)

For safety concerns, the adjacent LEDs are switched to Maximum Intensity and rest all reduced to 40% of Maximum Intensity.

B. System Simulation

The proposed algorithm is fed into an AT89C52 to develop a working prototype which can later be expanded into a fully functional working system. The DIM system is simulated in Proteus software. A 11.0592MHz quartz crystal is connected to XTAL1 and XTAL2 pins in order to use the on chip oscillator. The reset circuit of the microcontroller consists of a 10K resistor, 10uF capacitor and a push button. Port 0 is used as IØport for IR receivers by connecting the pins to external pull up resistors. IR transmitter is not a part of the microcontroller connections as the only job of the IR transmitter is to continuously emit infrared rays.

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Hence they are separately connected to power supply with corresponding current limiting resistors. The IR transmitter and receivers are placed facing each other to reduce the design complexity of the circuit. LEDs are connected to port 2 of the microcontroller

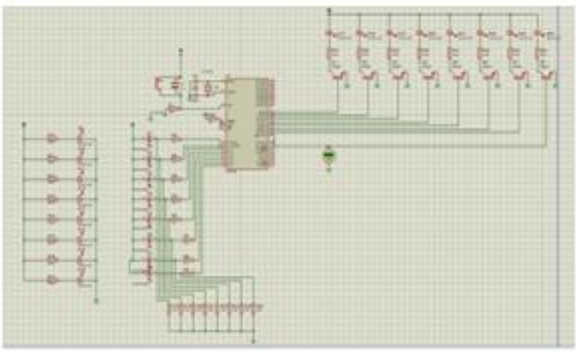

Fig. 6. DIM hardware simulation

through 2N2222 transistors which act as switch. As mentioned in section IV-B at the beginning, when there is no obstacle, the IR Receiver is on Logic 0 as it does not receive IR light transmitted by the IR Transmitter. When a car or any other vehicle blocks any of the IR sensor, the IR Receiver changes to Logic 1 and the microcontroller turns ON the immediate three LEDs. If the car blocks the first IR sensor, the first three LEDs are turned ON by the microcontroller. As the car moves forward and blocks the second IR sensor, the corresponding next three LEDs will be turned ON and the first LED of the previous set is turned OFF. The process continues this way for all the IR Sensors and LEDs.

C. *Cost Analysis*

The system is modelled for twenty years and the cost over this span of time can be categorised as follows.

- Capital Cost
- Operation and Maintenance Cost
- Replacement Cost

I. Capital Cost

The set up cost includes purchasing of LEDs, IR sensor pairs and Phototransistor.The HPS are replaced with LEDs of rating 95Kw. The two kilo meter road stretch has 69 poles. Each pole has two LEDs attached on either side. Totalling to 138 LEDs. A single phototransistor is fixed in pole number 35 which is interfaced with the entire circuit. IR transmitter and receiver are purchased for either side of each pole for the two lane road, totalling to 138 IR sensor pairs.The total cost is given by Equation4

$$C_I = \{N_{LED} * C_{LED} + C_{PT} + N_{IR} * C_{IR}\} \quad (4)$$

where, C_I - Initial Cost

N_{LED}, N_{IR} - No of LED , No of IR

C_{LED}, C_{PT} , C_{IR} - Cost per unit of LED, phototran- sistor and IR sensor respectively.

II. Operation and Maintenance Cost

The tariff rates fixed by the Tamil Nadu government changed as follows over the so many years 7. [8] gives us the past data with which the future tariff rates are predicted by extrapolating the cost vs year Figure 7.

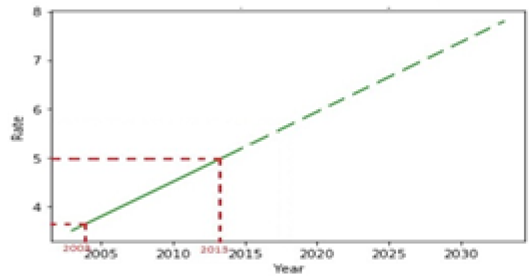

Fig. 7. Tariff rate prediction for 20 years

equation of the line can be deduced from the Figure 7 to simplify calculation.

$$R_{Year} = \{0.143 * (Year - 2000) + 3.07\} \quad (5)$$

where, R_{Year} - Tariff Rate for 5 years

R_{Year+2} is divisible by 5

The tariff rates are revised every 5 years.

The maintenance cost is negligible as LED lamps do not need maintenance.

I. Replacement Cost

An LED has a lifetime of about 50000 hours. Roughly converted to the operation time an LED lasts for about 13.5 years. The depletion region of the phototransistor widens in time and hence, the phototransistor is replaced every year to maintain negligible errors in operation. The response time of the IR sensor gradually increases on operation for a long period of time. Hence, the whole array of IR sensors are replaced every 2 years to maintain accuracy. The total replacement cost is denoted by Equation 6

$$C_R = \{N_{LED} * C_{LED} + C_{PT} * 20 + N_{IR} * C_{IR} * 10\} \quad (6)$$

where, C_R - Total Replacement Cost

The final cost analysis including Capital Cost, Replacement Cost, Operations and Maintenance Cost is showcased in Table I

From Table I it can be incurred that replacing HPS with LED and implementing PIS alone, although more than doubles the Capital Cost, it cuts down the Replacement Cost and Operations & Maintenance cost, ultimately cutting down the Total cost by 1,68,36,843.05 INR for a period of 20 years.

TABLE I TOTAL COST ANALYSIS

Cost (INR)			Capital Cost	Operations and Maintenance Cost	Replacement Cost	Total Cost
HPS			345000.00	20298263.57	4968000.00	**25611263.57**
LED			621000.00	7713442.27	621000.00	**8955442.27**
PIS			621200.00	7515220.52	638000.00	**8774420.52**
DIM	Passerby Frequency (Percentage)	50 %	669500	6502823.63	780500	**7952823.63**
		...		...		...
		40 %		6300351.51		7750351.51
		30 %		6097864.61		7547864.61
		20 %		5895387.11		7345387.11
		...		...		...
		10 %		5692919.02		7142919.02
		0%		5490442.87		**6940442.87**

Implementation of DIM further reduces the Operation Cost which varies in accordance to passerby frequency. Even for a passerby frequency of 50% a relative decrease of 9.3% in total cost to PIS is observed. For a 0% passerby frequency, a relative decrease in total cost to PIS of about 20.9% is observed.

V. CONCLUSION

The DIM algorithm implemented along with PIS gives a two step cost efficient solution for saving energy. The PIS design effectively utilises sunlight for lighting and does not light up the street when natural lighting is available. It gives a decrease in cost of **2.02%** compared to the base case of just replacing HPS with LED. Implementation of DIM further reduces the cost by **11.19%** for a 50% passerby frequency and by **22.5%** for a passerby frequency of 0% during the hours of consideration in midnight. However, the there is a cost reduction of minimum **65.74%** and maximum **72.9%** relative to the existing system of street lighting using HPS lamps. However, the system developed is not restricted to the two kilometre stretch under consideration and can be extended beyond this scope, which when implemented will yield better results in cost reduction.

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