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Energy Efficient Smart Street Lighting System

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Abstract - Modern Street lighting systems utilize a significant amount of power because of their outdated, inefficient architecture. Energy-efficient systems that are simple to maintain and have good administration become a primary concern for smart cities. We set building a smart street lighting system as our primary goal in order to achieve these goals, notably with solutions like dynamic delay of sensing mechanisms, the combinations of sensors (LDR, IR, and PIR) with adaptive control agents, and web technologies with cloud-based solutions. And also, it makes sure the power consumption is reduced to maximum feasible solutions without affecting street lamp experience. This system supports automation to its core encouraging routine things to get auto done from software solutions. The prototype system's results were found to be encouraging, and sample data and statistics indicated potential. Using street lighting technologies can expand potential for the future. When used in conjunction with appropriate sensors, the technology enables remote streetlight output monitoring, fault detection, energy performance monitoring, and, in the future, real-time notifications for city-wide issues.

Index Terms: Automated lighting, Energy efficiency, Intelligent street-lighting, Smart-street lighting, Light dependent resistor (LDR), infrared sensor (IR), Passive infrared sensor (PIR).

I. INTRODUCTION

Urbanization and population growth have been increasing over the years. The rapid influx of people into cities has meant increased infrastructure costs and energy consumption. Local governments and municipalities have to meet the cost and demand posed by the growth scenario. Currently about half of the world's population lives in cities and it is estimated that this number will continue to grow up to 70% by 2050 [1]. Water, energy and land resources in demand by citizens will also grow at least linearly with the population; Since the scarcity of fossil fuelsis a major concern and due to the continuous rise in their price, better power management, and a strategy needs to be implementedfor energy-efficient system.

City lighting [2] has historically been a serious issue because it accounts for 10% to 20% of the electricity used in most nations. Municipalities frequently replace emission devices with ones based on LED technology [3–5]. A large amount of energy can be saved through more intelligent lighting system control, nevertheless, even without spending money to replace inefficient appliances [6–10]. This is a rapidly spreading trend toward extremely sustainable systems. One of the city's most significant and costly obligations is providing street lighting. Street lighting expenses can be reduced by 35 to 70% using energy-efficient findings and design, with street lighting accounting for 15 to 40% of the total energy used in normal cities around the world [11]. Savings like these enable the provision of alternate energy options for those who live in distant places. Municipalities could be able to increase the availability of illumination in suburban regions byexpanding street lighting in additional locations thanks to these cost savings. Additionally, better illumination can raise the level of safety for pedestrians and vehicular traffic.

A well-designed, cost- and energy-effective lighting system should allow users to travel at night with good vision while using less energy. The additional needs such as poor visibility during foggy and cloudy times of day should also be addressed. The invaluable resources are being wasted due to the miscalculation of adequate lighting by overlooking some use cases mentioned above. Even though the countries have their regulation policies for street lighting but the goal of energy conservation remains the same. The conventional method is in which the lamp is turned on whenever required and turned off when not. Currently,the system in place around the globe switches on the street lights when it's dusk and turns them off when it's dawn. This is a significant energy waste, and the plan for execution needs to be changed. The proposed solution with novel techniques will presentas a prototype for such implementation.

Any device or object having sensors that can communicate information across the network (Internet)

without human involvement is considered to be part of the Internet of Things (IoT)[15-18].
One of the most revolutionary technologies in recent decades maybe the Internet of Things. It is anticipated that by 2025, there willbe 41.6 billion linked Internet of Things (IoT) devices, producing 79.4 zettabytes (ZB) of data [15]. The perception (sensing), network, and applications layers make up the general three- layered structure of the Internet of Things architecture.

II. RELATED WORK

This section contains some of the related works with **S**mart street lighting and Energy-efficient solutions.

A GSM-based strategy was suggested by Prof. K. Y. Rajput et al. [21] for an intelligent street lighting system that aims for energy-saving and autonomous operation on streets with reasonable costs. Two LDR sensors were used in the design of thissystem, one of which tracks day/night status and the other of which tracks the condition of the bulb. Through the GSM module, the status data were gathered and stored on their server.

Using Motion Detection and Dimming, Wireless connection, and other techniques, Roxana Alexandru et al. [22] investigated various approaches to smart lighting, including variable lighting, part night lighting, and light trimming. Dimmingis the process of lowering the brightness of Light Emitting Device(LEDs) such that lowerbrightness levels are used when there are no vehicles or pedestrians on the streets.

Using motion detection, Sindhu. A.M. et. Al [23] presented a smart street light system to reduce energy use when vehicle movements on the road is not found.

An energy-efficient Smart Street Lighting (SSL) system was presented by Reinhard Mu liner et al [24]. It mainly used for dynamic switching of street lamps. This device allows pedestriansto set up safety zones and track their location using their smartphones. Such systems will lower CO2 emissions. The noted drawback of this method is that trees and other such objects interfere with wireless transmission between lampposts, leading to inaccurate position recognition using the global positioning system.

An intelligent street lighting system was described by Chetna Badgaiyan et al. [25] using a wireless sensor network, pyroelectric infrared sensor (PIR), and Zigbee. PIR is used to trackthe movement of vehicles and pedestrians, and the intensity of light is altered as a result. If there is no movement, the brightnessof the street lights decreases.

The smart embedded system, which Parkash et al [26] built, regulates the street lights based on the detection of automobiles or other obstructions on the street. The light will automatically turn on or off depending on the obstacle detection whenever it is detected on the street in the allotted time, and the same information can be viewed online. The PIR and LDR sensorsdetect the presence of people and the level of light in a certain area,and they use Zigbee to wirelessly relay that information to the EBsection.

For automatic On/Off and light intensity adjustment, Deepak Kumar Rath [27] proposed an LDR-based smart street lighting system.

B. K. Subramanyaml and colleagues in article [28]. Intelligent wireless street light management and monitoring systems are proposed, offering easy maintenance and energy savings through the integration of modern technology. Installing solar panels on the street lamp A Graphical User Interface(GUI) application that displays the state of the lights in the street or highway lighting systems allows us to monitor and manage the street lights as well as conserve some additional power and energy by using LDR
Ricardo Alvarez et al. [29] discussed real challenges this smart transformation in street lighting system entails in implementation perspective in Sensing Lights: The Challenges of Transforming Street Lights into an Urban Intelligence Platform.
Baozhu Zhou et al 2021 [30] discusses the power of IoT in integrating varieties of people's livelihood services with smart lighting infrastructure. Their theoretical framework of application of feasible technologies has expanded scope for future discussion.

Previous work done by other researchers have many issues or problems like excess dependence on sensors, poor feasibility and implementation, uneconomical for scalability, vague efficiency techniques based on sensor signals, controlling and monitoring using third party platform with limited flexibility, dealing with delay in sensor communication and finally producing a system which has certain impact on energy efficiency by wider margin than traditional unoptimized system. We have discussed and identified barriers in picture and implemented system with which we have overcome energy challenges. According to Decrolux [31] sodium lights need time to warm up before reaching maximum output of around fifteen to twenty minutes, while LEDs can get total output instantaneously. In proposed method we have exposed how these challenges were dealt,

III. PROPOSED METHOD

Many convenient techniques have been proposed for monitoring, controlling, and mainly automating outdoor street lamps. Those techniques fall short when energy efficiency is in question.

The proposed system integrates Motion sensors, LDR sensors, Wireless communication, Dynamic delay, and a custom- designed centralized management application to achieve a significant reduction in energy consumption.

The sensing redundancy is one of the most energy- consuming aspects of IoT systems. The sensing frequency is optimized and redundancy is eliminated by designing a solution based on environmental conditions. The frequency of the sensor reading the immediate environment is scheduled such that sensingis reduced in closer time frames in day and night time and increased in dusk and dawn. With the technique of *Dynamic delayof sensing* the schedule will stop redundant sensing in the LDR.

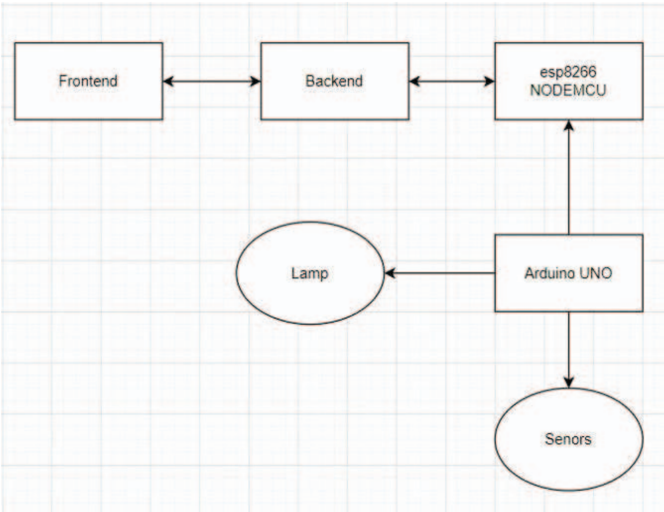

Fig 3.1 System Diagram with prominent components

Thus, with the *cloud connection*, the status of lamps can be made available to users based on the data acquired by the IoT devices in place. Fault detection in the circuit or LED is detected and notified to the UI and once the main lamp fails low-cost backup lamp glows.

The *back-end system* consists of a server responsible for receiving sensor data from the IoT system, storing the data in a database system and processing the data according to programs, and sending optimized data to the front end for presentation. A non-relational database is for data operation for faster queries overchanging data.

The front-end otherwise called the client-side is designedwith the downstream software process in the picture. But the usercan access the status of the lamp and get technicians to work for emergency manual work. GPS coordinates help locate the street lamps, in case of emergency repair or replacements, whereas the lamp status alert is displayed in the user interface.

Burning of the street lamps in empty streets, especially atnight time causes prominent energy loss. When no one is nearby during off-peak hours, a motion sensor is used to automatically switch off the lights. The unique combination of IR and PIR sensors can increase the accuracy of detection. The day and nighthours and visibility of the street are decided based on readings from LDR sensors. Additionally, adaptive dynamic lighting powered by motion sensors can cut energy use by up to 80% without sacrificing occupant comfort or public safety. [science daily].

Another prominent feature is a management system withcloud access and UI. It consists of three components IoT, back- end, and front-end systems. The IoT system consists of hardware components with the controller, GPS module, Wi-Fi module, sensors, and LED lights. The back-end for collecting, monitoring, and processing sensor data for making inferences, and the front- end for user interaction and displaying lighting system status.

New Concepts which have been proposed in this system is to control and monitor street lamp which helps to maintain efficiency. Proposed system has been developed using various sensors helps us to reduce power consumption compare to existing system. Created a User Interface so that admin will be able to access system, control lamps and monitor. Introduced GPS system where admin can access the street lamp coordinates if there is any problem with street lamp. Developed a technique of dynamic delay of sensing where it increases efficiency and reduces number of iterations.

IV. SYSTEM ARCHITECTURE

The entire system is split up into IoT components (hardware components), front-end, and back-end. IoT hardware components such the Arduino Uno, LDR, IR, PIR, LEDs, and ESP8266 are utilised to create the system. The Arduino IDE programming environment is also employed.

A microcontroller board called the Arduino Uno is based on the ATmega328 (datasheet). It contains 6 analogue inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It also has 14 digital input/output pins, six of which can be used as PWM outputs. Power source both an external power supply and a USB connection are options for powering the Arduino Uno. The power source is automatically chosen. Either a battery or an AC-to-DC adapter (wall wart) can provide external (non-USB) power. The pinMode(), digitalWrite(), and digitalRead()

routines allow you to use any oneof the Uno's 14 digital pins as an input or output.

How does **LDR** operate? Use of suitable Light Dependent Resistors, such as Cadmium Sulphide (CdS) LDR, allows the microcontroller to turn the system on and off dependent on the lighting conditions of the surrounding area. Under full darkness, an LDR typically has a resistance of 300k ohms, whichdecreases to 3k ohms in bright light. An analogue sensor was utilised in this LDR, and Arduino-UNO received analogue inputs from it.

A sensor that employs infrared technology, chips, and a transmitter to identify whether the light coming from the transmitter is coming from an object or a human is known as an **IR** sensor.

The term "**PIR**" refers to a sensor that uses infrared technology to remember the infrared image of the immediate region and detect any changes that might be brought on by motion.Pyroelectric sensors used in PIRs are used to measure infrared radiation output from objects.

For end-point IoT projects, the **ESP8266 Wi-Fi module** is a cheap standalone wireless transceiver. Internet access for embedded applications is made possible by the ESP8266 Wi-Fi module. It connects to the server or client using the TCP/UDP communication protocol. When Arduino provides a HIGH signalto an LED's pin, the simple semiconductor device illuminates when current flows through it, and it turns off when Arduino sends a Low signal.

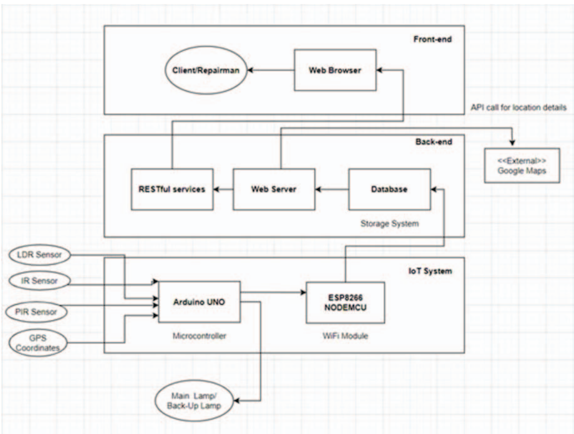

Fig. 4.1 Proposed solution system diagram

The backend architecture of the system is built with logicfor various purposes such as deduction of logs from the IoT system, transmitting Street Lamp status to the front end, and sending alerts to the front end in an emergency. We have used JavaScript as a Back-end scripting language with Node.js framework and MongoDB as the database for data operation. Node.js framework with its real-time and push-based architecture helps manage event-driven operations which is optimal for street lighting systems where events need to be addressed quickly. MongoDB database in the same way is optimal since its queries are faster than its counterpart relational database.

The front-end otherwise called the client-side is designedwith the downstream software process in the picture. Because the direct commands or instructions from clients are not necessary asthe IoT devices run on automated agents which handle multiple scenarios. Thus, the user can access the status of the lamp and get technicians to work for emergency manual work. Maps feature helps to locate the street lamps in case of emergency repair or replacements, whereas the lamp status is displayed in the user interface. The front-end is designed with Hyper Text Markup Language (HTML), Cascade Style Sheet (CSS), and JavaScript with Vue.js as the framework

V. METHODS

This section consists of methods followed in the implementation of the project to achieve the energy goals. Here starting from the implementation of hardware components, we build the layout for discussing the methods such as dynamic delayof sensing for LDR sensor, Combination of sensors to decide lighting requirement, fault detection, and location services on the client-side.

a. Dynamic delay through scheduling of sensing mechanism

Table. 5.1 Energy efficiency with 200 division LDR with time scheduling. The time that the LDR sensor is scheduled to check the light intensity and determine the delay based on it, which in turn. if the LDR value is higher than the threshold value and left on otherwise. As the difference between the LDR value and threshold value increases the delay in checking the sensor also gets increased. The results of this method were efficient in terms of computational energy-saving and acceptable with picture accuracy.

Table. 5.1 Dynamic delay based on LDR value

Time in HH:MM	LDR Value (0-200)	Delay in min
0:00	0	60
1:00	0	60
2:00	0	60
3:00	0	60
4:00	0	60
5:00	40	36
5:36	70	18
5:54	90	6
6:00	95	3
6:03	98	1
6:04	99	1
6:05	100	1
6:06	101	1
6:07	102	1
6:08	105	3
6:11	110	6
6:18	130	18
6:36	160	36
7:20	200	60
8:20	200	60

b. Algorithm

```
Algorithm: Smart-Lamp () {

If  LDR_VALUE is not less than Threshold {
        Delay = (LDR_VALUE – Threshold) * 60
        Add Sleep for Delay seconds
} else {
        Object present and object is in motion
        If then {
                Turn the
                Lamp ON
                Update to the
                cloud
                Check the Voltage across the
        Lamp
        If Voltage not Dropping
        Then Lamp Defected and, ON the
        Backup, and Update to Cloud
        Else do Nothing
} else {
        Do Nothing and Check Frequently
}
}
}
```

c. Sensor logic for the street lighting system

Here we discuss how sensor combination helps in intelligent decision-making. After registering the lamp on the cloud LDR sensor is scheduled to sense the surrounding around the clock for determining the day and night time. A scheduling technique calleddynamic delay is used to conserve energy by reducing wastage dueto continuous reading of surrounding in closer time frames. Following the data read, the switching ON/OFF of the street lamp is decided i.e. switch off the lamp in the daytime within the absenceof fog or rain and switch it on in night hours or on foggy/rainy days.

For environment-aware monitoring, a passive infrared (PIR) motion sensor is employed to identify passing pedestrians and moving vehicles. The street lights would subsequently be adjusted based on the traffic conditions as determined by the PIR data.

Fig. 5.1. Sensor logic for illumination

Using an IR sensor, we can detect the stationary objects of importance which are in requirement of luminous surroundings orstreets. Since the PIR sensor detects moving objects the stationary pedestrians and temporarily stopped vehicles near the street lamp are ignored. This is where the IR sensor fills in. This combination of IR and PIR sensors works to provide complete coverage to the possible need of a well-lit street.

The decision made from the LDR sensor constitutes the first layer where the main decision for lighting lamps is taken based on light intensity in the environment. Whereas the second layer is formed by the combination of IR and PIR sensors, whose combination decides when in particular, the lamp is lit based on the presence of vehicles or pedestrians.

d. Fault Detection and notifications

In the situations of defected LED or damaged circuit the LED lamp doesn't glow which leads to a serious threat to vehicle and pedestrian safety. This situation is resolved by a detection mechanism.

The lamp defect is detected by checking potential across the circuit and if the potential has completely dropped then it’s founddefective. The lamp_defect() function reports the status of the lamp to the database and the database is updated, which is finallydisplayed in the user UI.

The maps feature is helpful for users to locate defective lamps. In the map area, the working lamp is identified with a bluemarker whereas defected by red. *show map for area* button can beused to view the lamps in the group based on area as in fig 5.3. The technician who acts as a client can use the location service tolocate the lamp for manual repair/replacement work depending upon the condition.

Fig 5.2 Defected lamp marker in map and major nearby landmark address

The coordinates of the location of the street lamp and IoT components are fed to the Arduino microcontroller at the time of setup which is sent to the cloud database on registering and creating the new lamp.

The latitude and longitude components of the coordinates of the location are stored in the database by addressing the combination of both as unique since one coordinate of a place canbe the same two places whereas another coordinate is different but
their combination is always unique for any position on the map.

The Google cloud API for maps is used to locate the coordinates on the map on the client-side and addressed is retrieved for the same coordinates in the backend and stored in the database.

The designed UI presents the user with options for working with the street lighting system remotely. UI holds details such as Lamp name, status, coordinates of the location, address of lamp location, and More details button to access the map locating the lamp based on coordinates.

UI also supports location marker which indicates the street lamp situated in different places. Users can use the service to identify and locate the physical location of the lamp. Thesearch bar can be used to group street lights based on location by using an element such as street name, city name, or pin code. Mainly they can be segregated based on working conditions. The defected lamps can be found by selecting the defected option.

VI. RESULTS

Efficiency and accuracy of the Dynamic delay LDR sensing

By plotting the table for the scale of changes in efficiency and accuracy of detection of lighting through LDR sensors, we aim toincrease the efficiency of LDR sensors by reducing the frequencyof sensing thereby reducing energy expenditure.

By decreasing the frequency of sensing from every 1- second check to every 10-minute delay we have derived an increase in efficiency and deduction accuracy value.

These values are compared to time-varying delay (dynamic delay logic) discussed in the methods section which provides higher accuracy and efficiency with the limited number of iterations.

Sensor Logic	Efficiency Scale (0-10000)	Accuracy Scale (0-100)	No of checks or iteration
Every 1 sec check	0	100	86400
Every 2 sec check	5,000	100	43200
Every 1 min check	8,000	100	17280
Every 2 min check	9,833	90	1440
Every 2 min check	9,916	80	720
Every 2 min check	9,966	60	288
Every 2 min check	9,983	30	144
200 division LDR with time varying delay	9,998	~100	24 - 32

Table 6.1. Efficiency and accuracy of the Dynamic delay LDR sensing

Combination of sensors:

Here we have discussed how IR and PIR sensor works individually in a different state of object condition. The LED is glowed by acquiring the total ON state as 1 by combining IR and PIR sensors. That is, the LED will glow when a moving object is detected.

PIR sensor alone can't satisfy the illumination requirement. As in the table, the PIR sensor responds only to moving objects. Whereas IR sensor can detect the objects after the motion has stopped, makes decision LED illumination for a few seconds for a stopped vehicle.

	No Cars	Moving Car	Static Car	Object Moving	Total ON State
IR Sensor	OFF	ON	ON	OFF	2
PIR Sensor	OFF	ON	OFF	ON	2
IR + PIR Sensor	OFF	ON	OFF	OFF	1

Table.6.2 Combination of sensors

Energy saving in different traffic scenarios:
Three cases were discussed.

Case 1: 50% traffic with a static object in the street
- current system saves 0 energy.
- proposed system saves 0-50%

Case 2: 0% traffic with static objects in the street
- No save in the current system
- 100% Save in the proposed system.

Case 3: 100% traffic
- 0% energy for even traffic distribution
- no save in the current and proposed system.

Here we can understand how the proposed system is more efficientin different traffic conditions.
When 50% of traffic is detected, the current system glows all the time, whereas the proposed system saves 0-50% energy based on the distribution of traffic. 0% energy for even traffic distribution 25% save for trajectory distribution.

Comparative Energy Calculations:
Street lights are turned on and off at regular intervals in order tocalculate the energy usage of the lights in real-time.

Period of lights off = 6 A.M. to 7 P.M = 13 hours
Period of lights on = 7 P.M. to 6 A.M. = 11 hours

Let 'W' be the power consumption per hour for a lamp

Power Consumption of Existing system

$$Duration\ of\ lights\ ON \times Power\ Consumption\ per\ Hour = 11\,W \times 1 = 11\,W$$

Power Consumption of Proposed system

Case 1: (0% Traffic)

$$Duration\ of\ lights\ ON \times Power\ Consumption\ per\ Hour = 11\,W \times 0 = 0$$

Case 2: (25% Traffic)

$$Duration\ of\ lights\ ON \times Power\ Consumption\ per\ Hour = 11\,W \times 0.25 = 2.75\,W$$

Case 3: (50% Traffic)

$$Duration\ of\ lights\ ON \times Power\ Consumption\ per\ Hour = 11\,W \times 0.5 = 5.5\,W$$

Case 4: (75% Traffic)

$$Duration\ of\ lights\ ON \times Power\ Consumption\ per\ Hour = 11\ W \times 0.75 = 8.25\ W$$

Case 5: (100% Traffic)

$$Duration\ of\ lights\ ON \times Power\ Consumption\ per\ Hour = 11\ W \times 1 = 11\ W$$

So, The Average power consumption of the proposed system will be the average of all the cases + 10% Tolerance in theworst-case scenario.

$$Average\ Power = \{(0 + 2.75W + 5.5W + 8.25W + 11W) \div 5\} \pm 1.1\ W = 6.6\ W$$

Average Power consumption = 6.6W

$$Proposed\ System\ will\ be\ having = (11W - 6.6W) \div 11W \times 100 \cong 40\%$$

The Proposed System is approximately 40% better than the existing system.

VII. CONCLUSION

The role of Smart-street lights in enhancing public safetyand well-being is undeniable since vehicles and people move dayand night hours and accidents are prone to happen due to poor visibility as well as street lamp failures. But conventional HPV sodium lamps with manual ON/OFF or automated during dusk anddawn are still inefficient in addressing public safety as well as energy efficiency. However, not only it is energy-draining it also poses economic challenges to local government. Thus, previous many inefficiencies were addressed in our prototype by accounting for environmental factors such as light levels and traffic flows.

Reducing energy consumption by designing an efficient system is of paramount importance for a sustainable future. The environmental sensors at the ends generate loads of data to be delivered to back-end systems for making inferences. Data received periodically are monitored and collected which providesinsights into the efficiency of the system across an entire city. Thishelps lower the electricity consumption even lower and meet sustainability targets

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