IoT Based Automated Street Lighting: A Systematic Survey

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***Abstract*—The integration of the Internet of Things (IoT) in automated street lighting systems offers many benefits, such as dynamic lighting control and motion sensors, leading to increased energy efficiency and cost savings. IoT also enables remote monitoring and management of street lights, predictive maintenance, and accurate energy metering for each light. Moreover, IoT sensors can monitor air quality and weather conditions, adjust lighting levels accordingly, and provide valuable data insights for traffic flow analysis and urban planning. By implementing IoT in automated street lighting, cities can create sustainable and intelligent lighting systems that can respond to real-time conditions, promote energy efficiency, and improve overall urban livability. This paper discussed various methods used for the automation of public lighting systems. The control and monitoring system is a crucial component of the implementation of Public Street Lighting. However, over time, several techniques have been discovered to identify significant challenges. This survey paper describes and compares various identification techniques and components.**

***Index Terms*—Smart Street Lighting, Internet of Things, Wireless Smart Poles, Zigbee, Energy Saving, Low-cost monitoring system.**

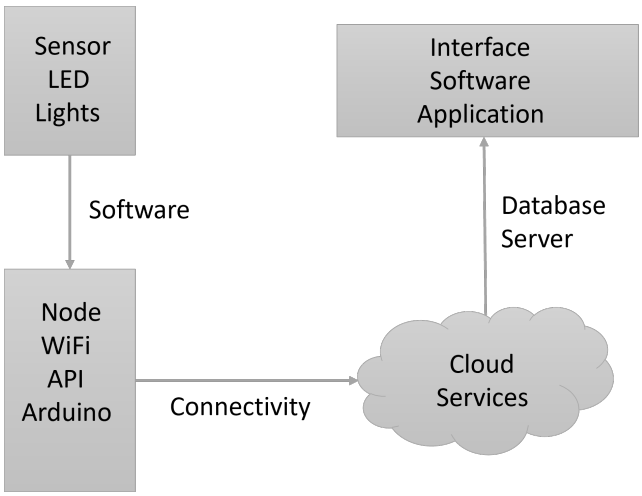

Fig. 1. SSL configuration

I. Introduction

An automated public lighting system operates without human intervention. It turns on automatically when there is a need for light, and it turns off when there is sufficient natural light. This is made possible by a sensor circuit that detects the level of darkness and activates the system accordingly. [1] So, when darkness rises to a certain level, the system switches on, and when there is enough natural light during the day, the system switches off. Public lighting plays a vital role in both urban and rural settings as it provides safety, and security, and improves the overall quality of life. Public lighting systems have been a part of our daily lives for many years. However, these systems have several issues such as high energy consumption, uneven light distribution, frequent maintenance, and a shorter lifespan. To address these issues, this paper proposes a detailed analysis of an automated public lighting system.

Intelligent lighting systems play a crucial role in the successful implementation of smart cities. Intelligent streetlight management systems have enabled the development of smart cities by leveraging advancements in the fields of the internet of things, mobile computing, wireless networking, and remote sensing. Automated public lighting offers a wide range of benefits that make it the smartest option for modern urban and public space management. [2] It provides significant cost savings, energy efficiency, and environmental benefits while enhancing safety and reducing light pollution. With remote monitoring and control, adaptive lighting, data collection, IoT integration, and improved aesthetics, automated public lighting is the ultimate solution for smart city systems. Municipalities can customize lighting schedules and profiles based on community needs and preferences, and automated lighting can respond to emergency situations. Therefore, it is an assertive and

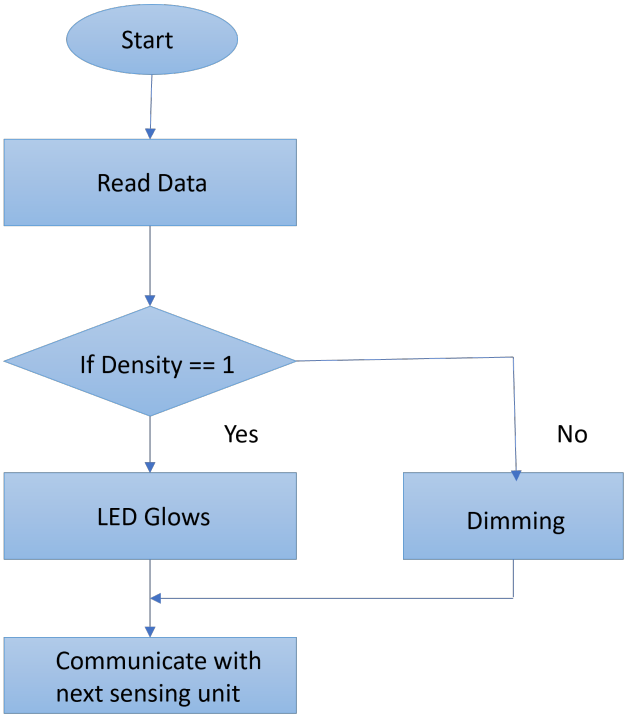

Fig. 2. Algorithm for Dimming

definitive choice for municipalities and communities seeking to optimize energy usage, reduce operational costs, and create sustainable public spaces. Automated public lighting systems have a wide range of applications in urban environments. They enhance the management and control of public lighting for various purposes. Such systems can illuminate streets, parks, recreational areas, pathways, parking lots, public transportation stops, pedestrian crosswalks, and architectural features. They can also integrate with traffic signals and other systems, such as waste collection and public safety, for smart city integration. Automated lighting is often used in event and festival lighting, environmental monitoring, and security lighting. [3] It can showcase historical and cultural sites and contribute to energy-efficient initiatives. These systems play a crucial role in creating more sustainable and efficient cities. Automated public lighting systems are flexible tools that can optimize lighting conditions, save energy, improve safety, and enhance the overall urban environment. [4] To achieve an automated and efficient public lighting system, traditional lighting can be replaced with energy-efficient LED lights. Smart lighting systems that use sensors and timers can be installed to adjust light levels based on ambient conditions. Remote monitoring can be set up to track the performance of public lighting in real-time, while energy management software can be used to optimize energy consumption. Dimming and zoning capabilities can be implemented to reduce light intensity during off-peak hours or in areas with low activity, algorithm as shown in Fig. 2. Motion sensors can also be installed in less frequented areas to activate lights only when needed. Renewable energy sources can be integrated to power streetlights, and data analytics can be used to predict maintenance needs and plan proactive repairs. Light spill and glare can be minimized to reduce light pollution. [5] It is important to involve the community in decisions regarding lighting improvements, develop a long-term budget plan for maintaining and upgrading public lighting infrastructure, and ensure compliance with local regulations and standards. In this survey paper Section II, explains Motivation, and Section III explains the Literature Survey. In Section IV, the discussion is explained. And the survey is concluded in Section V.

II. Motivation

The current scenario of street light systems is inflexible and mostly relies on manual control, with only a few automated based on environmental parameters. The biggest problem is managing remote locations where manual errors can lead to energy waste. Therefore, there is a need for an efficient street lighting system that provides wireless access for control. A server can be used to manage the entire city's street lights, and low-cost internet technology can be used for remote access. Smart street lighting is the use of connected lighting systems for public street illumination. It offers several benefits, including energy efficiency, reduced light pollution, enhanced public safety, customization, remote monitoring, data collection, reduced environmental impact, longer lifespan of LED lights, adaptive lighting, smart city integration, cost-effective upgrades, and enhanced aesthetics. [6] As technology continues to advance, smart street lighting solutions are becoming more accessible and provide cities with a range of benefits that enhance the well-being of citizens and the sustainability of urban environments.

III. Literature Survey

The concept and implementation of an autonomous street lighting system was proposed by Andi Adrian syah et al. [17] is an IoT-based framework designed to automate street lighting systems, providing efficient control, monitoring, and management of streetlights as shown in Fig 1. It consists of several components, including an energy meter, a Raspberry Pi microprocessor system, relays, a Ubidots software graphical user interface, and a USB Modem for telecommunication. The system operates in two main zones - the Device Zone and the Control Zone. The energy meter measures the energy consumption of the streetlights, which is crucial for monitoring and optimizing energy usage. The Raspberry Pi serves as the central processing unit, collecting data from the energy meter and communicating with other components. Relays are used to control the streetlights, with each relay switching individual streetlights on or off. Ubidots is a cloud-based platform that provides a user-friendly GUI for managing and visualizing IoT data. The Control Zone manages the streetlights, allowing for manual and automatic control of the lamps. Users can remotely turn the lights on or off through the Ubidots GUI. The system can also automatically adjust the lighting based on pre-defined criteria, making it essential for enhancing energy efficiency and reducing operational costs in street lighting applications.

TABLE I
COMPARISON TABLE

Ref.	Approach	Description
[7]	Cost model for a 5G smart light pole network	Total cost of 5G smart light pole network deployment including capital and operational expenses.
[8]	Based on Traffic Density	An energy-efficient power generating system is proposed that automates street lights based on traffic density.
[9]	An IoT augmented Lamp Posts	Smart Intelligent Street Lighting system provides energy-efficient lighting for cities and is monitored via Thingspeak cloud.
[10]	Operation Scale Expansion Method	ZigBee hierarchy and multi-channel clustering. Coordinator interacts with cluster heads in master-slave mode, and nodes exchange data in hidden token mode.
[11]	24GHz millimeter wave radar	Radar in the smart street light system detects pedestrians and adjusts LED lighting.
[12]	LoRaWAN based smart street lighting control system	The system is composed of motion and illuminance sensors, as well as LoRaWAN daughter modules, all located in each light pole.
[13]	Edge orchestrators based street lighting management system	The architecture combined the container-based virtualization technology, Docker, to the deployment of the cloud and edge services.
[14]	campus edge computing network	The system employs street lighting as the IoT network communication node device.
[15]	CADSDR methodology	The proposed system can be controlled automatically using IoT technology in order to reduce the power energy consumption of the street lights system.
[16]	Metro Industry 4.0 application	PELL project provides an IoT platform aims to manage and process technical and consumption data of public lighting systems.

Moreover a proposed system has been designed [18] to control and automate streetlights in a cost-effective manner while monitoring environmental conditions. The system utilizes components such as the LDR, relays, a microcontroller, a temperature and humidity sensor, electronic components, an ESP-12 WiFi module, and an Arduino microcontroller. The LDR detects ambient light levels, distinguishing between daytime and nighttime, and helps the system decide when to turn the streetlights on or off. The relays are used to control the streetlights, while the microcontroller processes data from the LDR and the temperature and humidity sensor, and communicates with the ESP-12 WiFi module to send and receive data from a central database. The temperature and humidity sensor ensures that streetlights can be adjusted or controlled based on temperature and humidity levels. The system is connected, allowing for data collection and control through a web interface and central database. The system is also cost-effective, easy to implement, and designed to enhance streetlight management and promote energy efficiency.

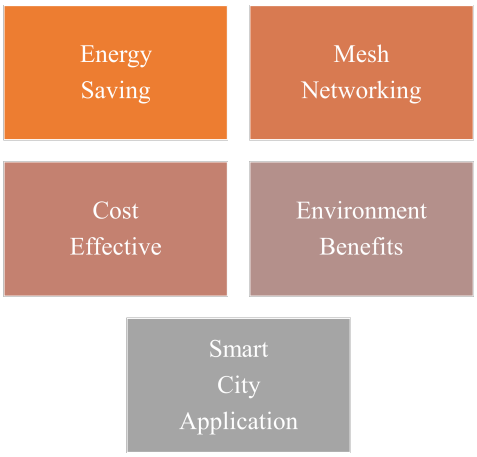

Fig. 3. Advantage of ZigBee Communication

Further Vivek G.V and Sunil M.P [19] in their paper, the authors introduced a system for enabling IoT services using a Wi-Fi ZigBee gateway in a home automation network. The system involves deploying sensors and actuators to a remote location, which communicate wirelessly with a cubieboard control unit that runs a graphical user interface (GUI) and

Fig. 4. Benefits of Smart Street Lighting

acts as a gateway, enabling access to the sensors and actuators both locally and remotely. The system uses ZigBee and Wi-Fi wireless communication protocols, with the gateway bridging the connection between them to enable local and remote access to the sensors and actuators. The system is designed to turn traditional homes into smart homes by adding various sensors and actuators to allow for automation and monitoring of home environments, including real-time monitoring of energy consumption. Overall, this system provides an integrated solution for transforming a regular home into a smart home by combining various sensors and actuators with a central control unit and a user-friendly GUI. Benefits of Zigbee communication shown in fig 3.

However the paper "Cost model for a 5G smart light pole network" by Oliver Landershamer [7] proposes a model for deploying utility poles in a city, taking into account different pole configurations, grid-based deployment, cost evolution, and associated cost estimates. The model includes four pole configurations, a grid-based deployment structure, and considers the evolution of key cost items over time, including improvements in prototype components. The Total Deployment Cost (TDC) estimates are given for both minimum and massive deployment, with potential cost decreases attributed to improvements in prototype components. The recommendations emphasize the importance of flexibility and adaptability in city infrastructure planning, suggesting that cities should begin infrastructure projects and choose pole designs that can be easily upgraded or adapted to take advantage of future cost reductions and technological advancements.

In addition a concept street lighting model and its functions by Kalaimathi B et al. [8] are based on traffic density. This model implements an IoT-based street lighting system that uses various sensors to detect the presence of vehicles or pedestrians and illuminates itself based on the requirements. As shown in Fig 5 the system is equipped with LDR to follow the switching operating, and IoT to display and control the status of the street via a web browser or a mobile application. To automate street lights based on traffic density, the model uses hardware components such as IR sensors, solar panels, LED lights, and a 16-channel analog multiplexer. Additionally, Node MCU is used as the microcontroller, and the Arduino-IDE software is used for programming. Moreover, the project employs a step-down transformer to reduce the voltage level before transferring it to the microcontroller. The Internet of Things connects different objects, and any device that is connected to the internet is called a smart device.

Further presented An energy-efficient smart street lighting system [9] utilizes sensors and a controller to activate lights whenever people or vehicles are detected in the dark. This system solves the issues associated with traditional street lighting. The Smart Street Light System comprises three units: Lamp, Sensor, and Access Point. The Lamp unit includes a sensor that detects motion and brightness of the LED device, a controller, and a communication device. The Sensor unit consists of a motion sensor, a controller, and a communication device. The Access Point is employed when the distance between the sensor and the lamp units is too great for direct communication. The Zigbee technology is utilized for communication as it is wireless, low-cost, and has lower power consumption rates. The Zigbee serves as a communication device with power-saving features and is designed for short distances. This system turns on lights before pedestrians arrive and reduces their brightness as they pass by. The LDR detects light, and the module is linked with a Thingspeak cloud to monitor street lights and the on/dim/off of the LED lights. The Zigbee module sends a signal to the controller, and the light switches on only if it's nighttime. This saves energy consumption of lights in a city, and this proposed model will help energy saving for a smart city.

A case study introduced by Ruchika Prasad [20] described that the smart cities are a recent concept in India that aim to optimize energy consumption for a better environment and quality of life. As urbanization is increasing, so is the city's energy demand. Smart street lighting is a solution to reduce energy consumption in large Indian cities, where public lighting alone consumes two percent of the total energy used and ten to fifteen percent of the municipal budget. Installing smart lighting technology on the streets of Nagpur, India, has resulted in energy savings and improved the quality of life of its citizens. The Smart Street Lighting system has three layers: the sensor layer, communication layer, and management layer. These layers work together to provide an energy-efficient smart lighting system. The Nagpur Smart City's smart street lighting system is a successful case study that aimed to replace older street lights with smart lighting technology. The project included the replacement of existing streetlights/floodlights with LED streetlights/floodlights. Additionally, the installation of sensors and smart controllers added more efficiency to the system. Smart LED Control Nodes, sensors, gateways, and the central management platform are the four components used in the Nagpur Smart City lighting system. The sensors detect motion and send operational data to the controllers, which are managed from the central management platform. The gateways connect to the city network and are an aggregation point for the

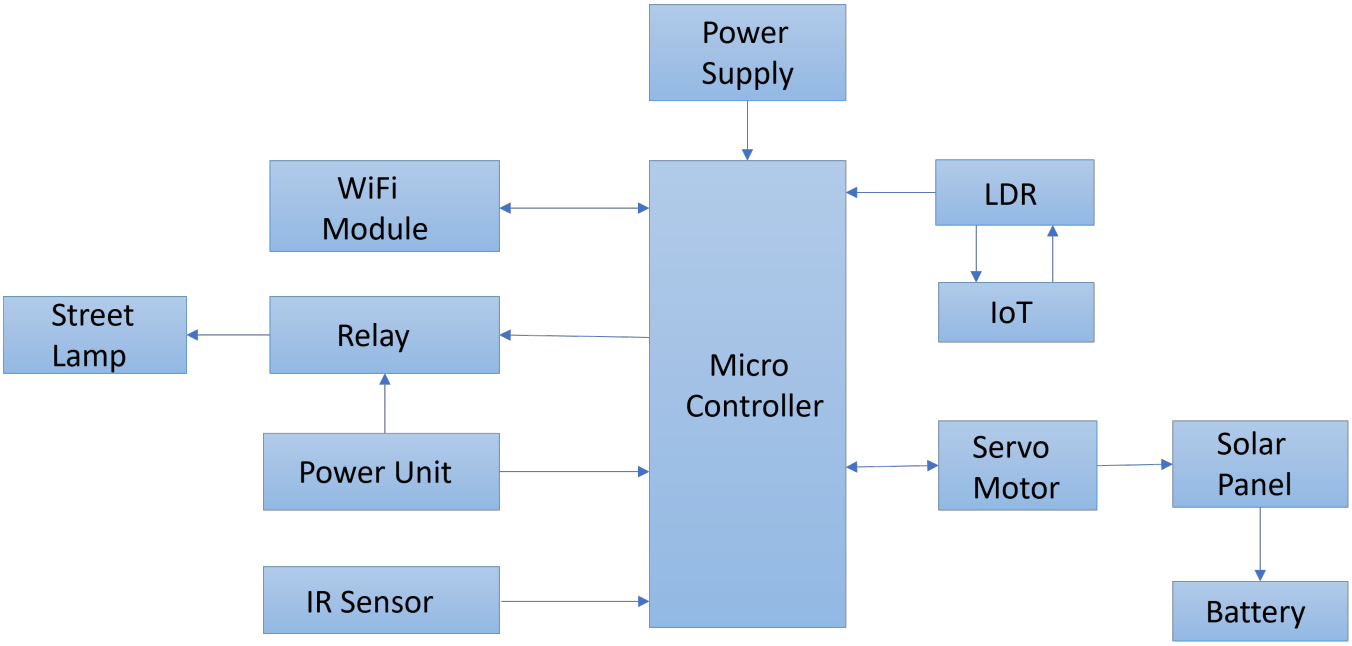

Fig. 5. Block Diagram for Smart Street Lighting

Smart LED control nodes. The central management platform is responsible for device provisioning, policy management, and central operations management for the smart lighting infrastructure. Implementing smart street lighting systems in large Indian cities can be a significant step towards energy conservation and environmental protection.

Also The proposed energy efficient street lighting system [21] is designed to provide intensity variant lighting, flood monitoring, emergency lighting, and maintenance alerting system. The system uses light efficient diodes that are more energy efficient and provide more brightness than conventional lights. The intensity of the light emitting diodes can be controlled as per requirement using light dependent resistors. The flood sensor uses an ultrasonic module to sense the increase in water levels and alerts the authorities through a Wi-Fi module. The smart street pole also has emergency lights and Liquid Crystal Display (LCD) screens to display information of weather or emergencies. The system provides alerts for broken lights needing maintenance, resulting in smarter street lights that provide more than just illumination while saving on energy. The system uses both LDR and micro-controller for lighting using intensity through sensitivity. The entire circuit is connected to Arduino UNO R3 which is a micro-controller board. The system is designed to provide commuters and people present in the area a chance to tread carefully and think about their safety.

Furthermore this paper [12] describes the Smart Street Lighting System that uses motion detectors and illuminance sensors to manage the illuminance level and dimming time of street lights. The system uses pre-calculated illuminance levels of selected road types to compensate with CIE standards by DIALux. The street lights dim when no vehicle is using the street for a certain selected amount of time. The system is controlled by a wireless communication interface based on LoRaWAN networking system that can be easily controlled by connecting to the main server manually or using the LoRaWAN system to control autonomously. The lighting control system design has one of the most accurate lighting illuminances when dimmed while still having high energy-saving capability. The circuit uses a variable resistor controlled by LoRaWAN daughter board, and the NPN transistor is used to switch on the LED lamp at maximum brightness.

Additionaly the concept proposed the development of a 24GHz millimeter wave smart radar by Seungeon Song et al. [11], which is used for intelligent street lighting systems have explained The radar operates in CW mode with a frequency of 24GHz and 200MHz bandwidth. Two radars are used to cover the street in both directions and detect obstacles, including pedestrians, moving at a speed of more than 1km/h. The radar detection controls the street lighting, making the smart lighting system energy-efficient. The LED lighting is controlled via the radar detection output, which is provided by detecting the Doppler shift. Field experiments have shown that the developed radar has a high detection rate of more than ninty nine percent, and it is capable of detecting moving people and cars at a range of up to 30m. The radar is installed at a height of about 4 meters in the street lighting pole, and the FoV(field of view) has a 12-degree azimuthal angle and a 70-degree elevation angle.

IV. Discussion

Automated public lighting systems are set to play a key role in the development of smart cities. [22] These systems will be integrated with other urban systems, such as traffic

management, environmental monitoring, and public safety, to create more efficient and responsive cities. The use of the Internet of Things (IoT) will increase in public lighting, allowing for real-time data collection, analytics, and decision-making. [23] Future lighting systems will allow residents and local authorities to customize lighting preferences and interact with the lighting infrastructure, while advanced sensor technology will enable more sophisticated environmental monitoring and adaptive lighting control. The use of energy harvesting technologies, human-centric lighting, AI algorithms, and decentralized energy management will further enhance energy efficiency, resilience, and sustainability of public lighting systems as benefits of SSL shown in fig 4.

V. Conclusion

Automated public lighting system has a wider scope in the development of sustainable and intelligent smart cities. A literature survey is proposed in this survey paper in brief to discuss various methods to implement smart public lighting systems. Smart Street Light proves to be more beneficial than the current street lights in a variety of aspects. Including energy efficiency, cost savings, improved safety, and reduced environmental impact. Incorporating energy-efficient lighting into new urban development projects is a fundamental part of sustainable city planning. It effectively addresses the two concerns that the world is facing today: energy conservation and the disposal of incandescent bulbs.

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