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Internet of Things and Long-Range-Based Smart Lampposts for Illuminating Smart Cities

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Abstract: Intelligent and resilient infrastructure is necessary for smart cities for contributing flexible and smart amenities to the citizens. Concerning the United Nations (UN) estimation, the global population residing in urban cities will reach 68% by 2050. Additionally, the Sustainable Energy Action Plans (SEAP) report suggests implementing energy efficiency technologies in smart cities to meet the rising urban population requirement. Internet of Things (IoT) technology empowers to achieve the goal of energy efficiency by integrating sensors, wireless technology, and renewable energy sources in the lighting system. At present, the IoT-based lighting system in urban cities is implemented with streetlamps and lampposts. In this study, we are focusing on lampposts, as it has the flexibility of establishing and implementing a multitude of applications on a single system. Due to technological advancement, the lamppost is embedded with multiple sensors, communication protocols, and energy distribution infrastructure for delivering smart and affordable amenities to the citizens residing in the smart cities. This motivates us to implement a smart lamppost that provides a multitude of applications such as smart light, digital signs, environmental monitoring conditions, electric vehicle (EV) charging port, wireless fidelity (Wi-Fi) hotspot, etc., on a single lamppost. This study proposed the IoT-assisted fog and edge-based smart lamppost for the smart cities to realize the smart infrastructure. Further, this smart lamppost is integrated with low power and long-range communication, i.e., Long Range (LoRa), enabling the smart lamppost to communicate the sensory data to a long-range. Additionally, LoRa is integrated with a Wi-Fi module for establishing the interconnection between the smart lamppost and IoT server. Generally, the proposed architecture is broad perspective; however, we have developed and implemented the hardware models of three components including lighting system, environmental parameters and image sensing in real time. Lighting system and environmental parameter monitoring are integrated on same hardware model for sensing and logging the real-time values of temperature, humidity, CO and light intensity on the IoT server. The developed image sensing prototype based on ESP 32 controller is also evaluated in real-time scenarios, and the performance of the prototype is efficient. The proposed system delivers reliable performance in terms of sensing and communicating environmental parameters and images to the IoT server. Moreover, in future, we will complete the development of other components of the smart lamppost for enhancing the smarter infrastructure in smart cities.

Keywords: smart lamppost; IoT; ESP 32; LoRa; IoT server

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1. Introduction

According to the UN estimation, 68% of the global population will be living in urban cities by 2050 [1], and the rise of the population in the urban cities comes with distinct challenges including economic, social, and environmental sustainability [2]. Poor urban infrastructure, health issues, educational challenges, increasing crime rates, aging infrastructure, energy shortages, traffic congestions, high power loss in transmission, and deficiency of real-time sharing are the basic concerns that exist in urban cities [3]. The limitations on crucial infrastructure and lack of resources lead to challenges in providing the basic amenities to the citizens of the urban city [4]. The cities are facing budget constraints, and this led to the reduction of budgets besides cost reduction measures. Consequently, smarter and resilient infrastructure is essential for supervising the challenges in urban and transforming the urban environment [5]. Here, the integration of smart city technologies can assist to accomplish the goal of smarter and resilient infrastructure [6,7]. However, a huge amount of energy is necessary for maintaining and providing smart infrastructure and amenities to the individuals residing in urban cities. Additionally, the scarcity and continuous rising in fossil fuel prices are demanding effective power management and strategy for enhancing energy efficiency [8].

In order of managing energy efficiency and reducing energy consumption, many local government bodies have replaced high-pressure sodium (HPS) lamps with light-emitting diode (LED) technologies [9]. The LED technology in street lighting enhances the lighting efficiency, consumes low energy, and reduces the impact on the maintenance as its lifetime is ten times more than HPS [10]. Yet, this strategy is unable to meet the energy conservation goals where the streetlights are consuming the 43.9 billion kWh of electricity every year [11]. Streetlights are the foremost contributors of energy consumption in cities as they consume approximately 30% of total energy consumption in any country [11].

Concerning lighting system in urban cities, smart light and lampposts act as a key sources for offering secure and convenient visibility during nighttime on the roads and streets. According to the SEAP report, innovative energy solutions are required for overcoming the global issues in energy [12]. Furthermore, it suggested minimizing CO2 emissions and enhances energy efficiency by employing renewable energy sources [13]. At present LED are embedded on the street lighting for accomplishing the goal of energy efficiency. Besides, upgrading lighting systems with LED leads to saving of 50–70% of energy and maintenance costs [14]. LED can deliver better lighting, reduce CO2 emissions, and minimum energy consumption. However, the amount of electricity consumption of street and highway lights is high because of continuous lighting during nighttime [15]. To minimize the wastage of energy and electricity consumption, the lighting system needs to be interconnected with network infrastructure that provides intelligence to the lighting system [16]. This concept enables street and highway lights for regulating the intensity of light depending upon the traffic conditions and outdoor light intensity [17].

Generally, in smart cities, the significance of smart infrastructure plays a crucial role. When it comes to a lighting system in smart cities, the roads' lights significantly illuminate the light to guide passengers and vehicles. Even though we are advancing sensor and wireless communication technology, we still prefer the manual switch controller. With the manual switch controller, the light glows from sunset to sunrise with high intensity and even in some cases the light also glows in daylight. This leads to high energy consumption irrespective of non-requirement. To overcome this, many studies have proposed distinct solutions for realizing automatic lighting. This automatic lighting system switch the light on and off with respect to light intensity of outdoor environment and movement of the objects. Additionally, the defection in lighting system is also reported to the respective electric authority through wireless communication. As the population is rising in urban cities, the significance of enhancing the infrastructure with minimum complexity and maximum benefits. To date, the individual systems are being implementing in smart cities for light controlling, environmental (temperature, humidity) parameters monitoring, camera for counting of vehicles on the road and also for security surveillance. Therefore, when the lighting system is integrating with multiple applications, it assists city administrative to monitoring things such as temperature, humidity, security, traffic flow, etc., with a single system. The single system is presented as a smart lamppost. For example, if the smart lamppost is integrating with security camera and if the security camera is integrating with communication and intelligence capability, then it senses the situation and sends visuals to the emergency unit and switches on the light for aiding.

The motivation of the study comes from the above studies, where the hybrid-based framework can be implemented in lampposts for delivering a multitude of applications to the citizens in the urban cities. The multitude of applications including air quality monitoring, automate lighting intensity system, Wi-Fi hotspots, electric vehicle charging ports, etc., and the streetlamps enable the establishment of a novel lighting system termed as a smart lamppost. The future of streetlamps that provides flexible services to the citizens of the urban environment is possible with smart lampposts [18]. The advancement in sensor and communication technology is providing an opportunity to design and implement a smart lamppost that can automatically adjust light intensity, provides a Wi-Fi hotspot, and displays weather data, traffic signage, video surveillance, EV charging, and solar-based energy sources [19]. Additionally, the integration of digitalized technology such as IoT in smart lampposts empowers us to obtain the sensor information regarding environment data, traffic data, number of vehicles, and passengers crossing across the lamppost on the server [20].

The contributions of this study are as follows:

a. IoT server assisted fog and edge-based architecture is proposed for smart lampposts.
b. Smart lampposts are integrated with low power and long-range communication, i.e., Long-Range, enabling the smart lamppost to communicate the sensory data to a long-range.
c. LoRa is integrated with a Wi-Fi module for establishing the interconnection between the smart lamppost and IoT server.
d. The proposed architecture is broad perspective; we have designed and implemented three components, namely, lighting system, environment parameter monitoring and image sensing in real time environment.
e. A hybrid system is implemented for monitoring the lighting system, environment parameter monitoring and, moreover, the sensing values of these components are plotted in the graph.
f. Master and slave controller-based mechanism is implemented for the intercommunicating the components of smart lampposts.
g. A proteus simulation is performed for the smart lighting system.
h. The working of developed image sensing prototype based on ESP 32 is also discussed in the study with real-time implementation results.

The structure of the article is organized as follows: Section 2 covers the related works and overview of IoT and nearby technologies. The proposed architecture of the smart lamppost is covered in Section 3. Section 4 covers the hardware and software description. Section 5 covers simulation. Results are covered in Section 6 and the article concludes in Section 7.

2. Related Works and Overview of IoT

In this section, we will discuss the existing studies on smart cities and lighting systems. Further, we will explain the overview of IoT with nearby technologies that assist in realizing the smart lamppost in the smart city scenario.

2.1. Related Works

A smart city is a novel concept that is explored globally for establishing and enhancing the affordability and suitability of the lives of the inhabitants [21]. The concept is to utilize the emerging and advanced technologies for transforming each element in the city into an autonomous element. The autonomous elements will provide an opportunity to reduce the impact of environmental hazards by implementing eco-friendly and cost-effective technologies. The significance of information and communication technology (ICT) empowers the concept of smart cities for delivering services and amenities to the masses [22]. The leveraging of ICT also enables us to achieve the target of energy efficiency that is relevant throughout the world. As discussed earlier, energy management is possible by managing the streetlights efficiently, as streetlamps are consuming a major proportion of the energy consumption globally. The streetlamp and lamppost are the sources of light in the streets and roads during night. However, in many places, such as Florida (United states), the streetlamps continues to glow even in daylight and due to this, the amount of energy consumption increases and sometimes it leads to defects in the lamps and extreme conditions it is challenging for the respective authorities to switch off the streetlamps for avoiding the necessary damage to the streetlamps [23]. An innovative and smart light energy management system is an optimal solution for reducing the energy consumption and monitoring of the streetlamps [24]. "Energy on demand" is the concept under which the energy is provided when it is required [25]. The technology facilitates the implementation of intelligent street lighting that works on the sensing of individual vehicles and the dimming of the streetlamps accordingly. The energy savings rise more than 50% even in low-traffic areas.

However, this kind of intelligent lighting system is not widely implemented practically because this kind of system is not cost-efficient [26]. The key aspect of the smart street lighting system is: (i) to light the streetlamps with the well-developed and integrated lighting system; (ii) to provide eco-friendly lighting which is also easy to maintain; (iii) to lessen power consumption and wastage of energy [27]. Basically, the energy savings of the lighting system are evaluated on the basis of standard formulated by European standards [28]. At present, EN 13201-1-5 explains the calculation of energy performance for road lighting installations. Moreover, these indicators are helpful for analyzing the energy performance of distinct road light solutions. Green Public Procurement organization is suggesting dimming the light by 50% for reducing the pollution and CO2 emissions [29].

With fast pace depletion of non-renewable resources and a negative impact on the environment, the need for smart streetlights is greater than ever. The model proposed here can be made more eco-friendly by adding a solar panel. Solar energy is eco-friendly because it does not generate CO2 and other gases during the generation of electricity. Moreover, solar energy is obtained from natural sources [30]. Furthermore, data from all the sensor nodes can be saved onto a central monitoring system for further use. Streetlights are an integral part of road safety and security on streets but we often find them lit up throughout the night and, due to lack of attention, they stay lit up during the day as well [31]. The target of the project is to come up with an intelligent system, which can reduce this waste of energy by making decisions for light control, either to switch lights on, off, or dim the light depending on the strength of ambient light [32]. The system allows the person who is monitoring the system to control in relation to the current intensity of light as well as predict monthly power consumption. The load sensing functionality of each unit allows us to detect whether the light is at fault [33]. The system detects the movement of the pedestrian and illuminates his path till the next streetlight and shuts off when a pedestrian walks out of the lamp range [34]. The most recent evolution in solid-state lighting based on leading technology accelerated the phase-out of inefficient lighting systems [35]. Adding IoT connectivity to streetlights adds the benefits of sustainable development [36]. Smart lighting helps save energy, reduces the cost of power, reduce maintenance, and saves tax payer's money; along with automation and network control, the system becomes even more efficient. A cloud-based system is proposed by integrating ZigBee and NodeMCU for monitoring the environmental parameter from any remote location [37]. An IoT-based pollution monitoring system is implemented with the assistance global system for mobile communication (GSM) module and distinct gas sensors are utilized for sensing the gases [38]. Real-time air quality monitoring is designed and developed for detecting pollutant levels by employing distinct gas sensors [39]. From the above literature, it is realized they are need of implementing fog- and edge-assisted IoT server architecture for a smart lamppost to support the smart infrastructure that is required in smart cities. From the above review, it is concluded that the distinct wireless communication and sensor technologies are implemented in the lighting system for enhancing energy efficiency. However, with respect to smart cities, the resource management and establishment of hybrid framework-based system are lacking as it delivers the multitude applications with single system. Multitude applications are possible with smart lamppost as it provides the smart infrastructure and amenities to the citizens. Before addressing the proposed architecture, we will discuss the overview of IoT and enabling technologies that supports the implementation of multitude applications with smart lamppost.

2.2. Overview of IoT

According to GSM association (GSMA) intelligence forecasting, the number of IoT connections will reach 25 billion globally by 2025 [40]. The growth of IoT devices from 2015 to 2025 is presented in Figure 1.

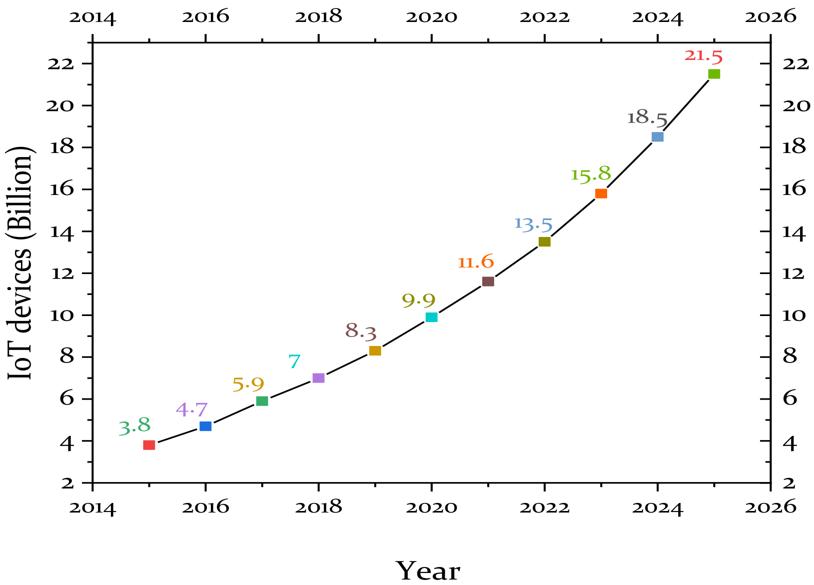

Figure 1. Growth of IoT devices (2015–2025) [40].

IoT is an interconnection of physical things with a virtual environment through internet protocol (IP) connectivity. In IoT, the physical things are embedded with sensors and actuators for sensing and controlling. A communication protocol is integrating with the sensors and actuators for updating and transmitting the sensory data to the server. Integration of sensor/actuators, connectivity, data processing, and user interface (UI) forms an IoT network. IoT comprises the four components that define the functionality and it is shown in Figure 2.

A sensor is a device that senses and responds to the input from the physical environment. The output signal of the sensor is converted into a digital signal. Connectivity is necessary for the transmission of sensory data and they are different wireless protocols for establishing connectivity. The distinct kinds of wireless communication technologies are existing in the Internet of Things. GSM/global packet for radio service (GPRS), Zigbee, BLE (Bluetooth Low Energy), IPv6 over low -power wireless personal area networks (6LoWPAN), radio frequency identification (RFID), LoRa, Sigfox, narrow band-IoT (NB-IoT), long term evolution (LTE), IEEE 802.11g Wi-Fi, near field communication (NFC), and Z-wave are the communication technologies. Zigbee, Z-wave, BLE, 6LoWPAN, and IEEE 802.11 g are the short-range wireless communication technologies, and GSM/GPRS, LTE, LoRa, Sigfox, and NB-IoT are the communication technologies for the long-range distance. Generally, the transmission range of these communication technologies such as IEEE 802.11 Wi-Fi, IEEE 802.15.4 Zigbee, and IEEE 802.15.1 BLE is short-range; however, except IEEE 802.11 Wi-Fi, the remaining two wireless communication technologies consume low power for the data transmission. LoRa, NB-IoT, and Sigfox are emerging low power and long-range communication technologies that meet the goal of the IoT. Among the three low-power wide-area network (LPWAN) technologies, LoRa is the optimal communication system with secure bi-directional communication and free licensed band capabilities. RFID and NFC are identification technologies that work on radio waves. Both technologies communicate up to a range of 4 cm–10 cm. The data processing is one more component of the IoT, where the sensory data is converted to machine-readable form. Classification, sorting, and calculations are performed on the data for getting meaningful information. Different tools are existing for data processing in the IoT. The technical specifications of the communication technologies are briefly mentioned in Table 1.

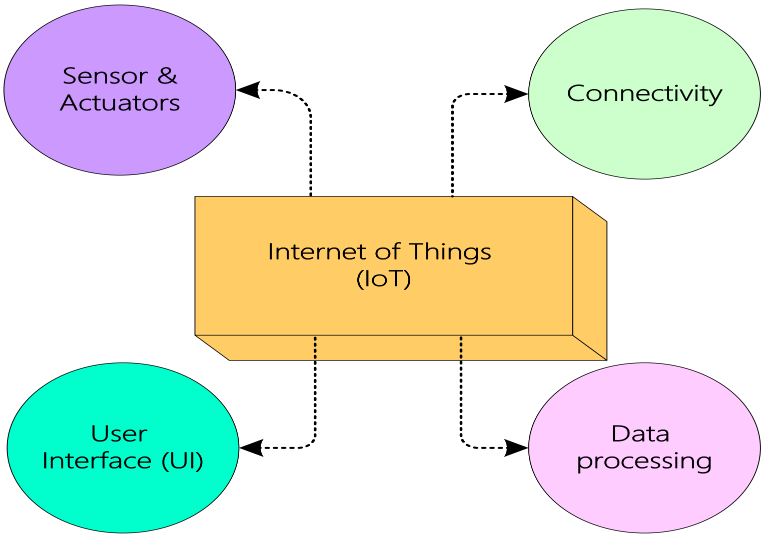

Figure 2. Four components of IoT.

Table 1. Technical Specifications of wireless communication technologies [41].

Parameters	Zigbee	BLE	6LoWPAN	LoRa	Sigfox	NB-IoT	GSM/GPRS	Wi-Fi
Network	**LAN**	**PAN**	**PAN**	**WAN**	**WAN**	**WAN**	**LAN**	**LAN**
IEEE Standard	802.15.4	802.15.1	802.15.4	802.15.4g	802.15.4g	NA	NA	802.11a, b,g,n
Frequency Band	868/915 MHz and 2.4 GHz	2.4 GHz	868/915 MHz and 2.4 GHz	433 MHz, 868 MHz, 915 MHz	868/915 MHz	Licensed LTE bands	850–1900 MHz	2.4/5 GHz
Range	(10–50) m	10 m	(10–50) m	5 km (Urban), 20 km (Rural)	10 Km (Urban), 40 km (Rural)	1 Km (Urban), 10 Km (Rural)	(5–30) km	100 m
Network Topology	Star, P2P, mesh, tree,	Star, bus	Star, mesh	Star of stars	Star		Cellular system	Point-to-hub
Power Consumption	Low	Low	Low	Low	Low	Low	High	High
Company	Zigbee Alliance	Bluetooth Special Interest Group	Internet Engineering Task Force	Semtech alliance	Sigfox company	3GPP	GSM Association.	Wi-Fi Alliance

3. Proposed Smart Lamppost Architecture

The advancements in sensor and wireless communication technology have encouraged us to build a hybrid system that is able to provide the multiple features with less space. Here, the smart lamppost is a hybrid system, where a single lamppost is integrating with multiple features that are required for implementing a smarter infrastructure in smart cities. Smart lampposts are the integration of distinct unique features that are embedded in it for providing smart and efficient features to the citizen of urban cities. In this study, we are proposing and implementing a smart lamppost that provides features such as smart lighting, digital signage, environmental sensing, push to talk system, charging port infrastructure, Wi-Fi mobile and mesh, image sensing pedestrian counting, parking monitoring and public security, and digital street signs. The proposed architecture is illustrated in Figure 3 where it is integrating with fog computing and edge computing for reducing the latency in between the smart lamppost and IoT server. The architecture is the amalgamation of multiple wireless communication protocols for establishing reliable and secure connectivity between a smart lamppost and IoT servers. As mentioned before regarding the applications that exist in the smart lamppost, it can monitor environmental parameters such as air quality and noise. Smart lighting feature in the lamppost enables us to illuminate the light according to the light intensity that is around the lamppost. Digital signage provides details such as weather data, digital images, information, video, and streaming media. Additionally, it is also utilized for outdoor adverting, marketing, and wayfinding. Image sensing is for sensing the visuals of surroundings to estimate possible security concerns, and to count the number of vehicles and passengers passing across the smart lamppost through a camera. Push to talk systems provide an opportunity for asking queries related to the route of a restaurant, petrol station, hospital, etc.

Here, we need to push the button available on the smart lamppost. Charging port infrastructure is a feature that enables citizens to power the electric charging to their vehicles. Solar panel-based power infrastructure is also available in the smart lamppost, so it powers the controller board of the lamppost. The Wi-Fi hotspot feature is present in the smart lamppost, where it delivers free Internet access to the citizens passing across the lamppost. A digital street sign is embedded in the lamppost as a traffic signal. Bio-diversity is included in the smart lamppost for encouraging the building of artificial nests for the sustainability of birds during extreme conditions.

The architecture of the smart lamppost also illustrates the mechanism of integration of the smart lamppost with IoT servers via edge nodes and fog nodes. Here, sensor input to the multiplexer is embedded with a computing unit, where it enables us to transmit data related to lamppost to the IoT server via LoRa based gateway. LoRa communication acts as a transceiver in the LoRa-based gateway and the Wi-Fi module available in the gateway logs the data related to a lamppost on the IoT server.

Edge nodes in the architecture assist the smart lamppost in detecting the security issues nearby the lamppost in a short interval of time. Edge/fog nodes are generally installed near the lamppost because they can perform analytics on the images receiving from the image sensing. As the mobile application is integrating with the IoT server, the smart lamppost is monitored in real-time. Preprocessing, cleaning, and analytics are done at the IoT server.

Figure 4 illustrates the technological architecture that provides the hardware working of distinct features availing in the smart lamppost. In the feature of charging port infrastructure, the electricity is providing in two distinct forms namely alternating current (AC) and direct current (DC). The power generating from the windmill, generator, and grid back up is rectified according to requirable voltage to the lamppost. Further, the battery is loaded and charged with electricity coming from the windmill and photovoltaic (PV) solar array. As the smart lamppost has two different powering sources (AC, DC) and it is controlled with AC load and DC load. Two slave controllers are embedded in the smart lamppost for sensing the environmental parameters, adjusting light, and image capturing. A single master controller is used for delivering the features of the speaker and display screen. Here, the slave controller initiates working after receiving the instructions from the master controller. Slave controller '1' performs sensing the parameters such as air quality and noise pollution. Additionally, this controller works during adjustments in the intensity of light. Slave controller '2' is used for supporting the feature of image capturing, counting the number of passengers and vehicles, and communicating to the IoT server through an inbuilt Wi-Fi modem.

The architecture illustrates the interfacing of sensors and actuators with master and slave controllers and it is shown in Figure 5. The master controller is interfaced with slave controller '1' and slave controller '2' and it is highlighted in yellow. As discussed earlier, the slave controller '1' is embedded for monitoring the environmental parameters. To realize this, the slave controller '1' is embedded with a light-emitting resistor (LDR) sensor, noise sensor, DHT sensor, CO sensor, and NO sensor. Slave controller '1' is based on Atmega 2560 as it interfaces with the relay for adjusting the intensity of LED light. Digital signage is also an interface to the slave controller '1' through the signage driver. Slave controller '2' is embedded with an ESP 32 hybrid module that is inbuilt with BLE, Wi-Fi module, and camera. This controller assists in the feature of image sensing. The master controller delivers the features of the mic for listening to the queries during the push to talk feature and, simultaneously, the speaker delivers the queries invoice format.

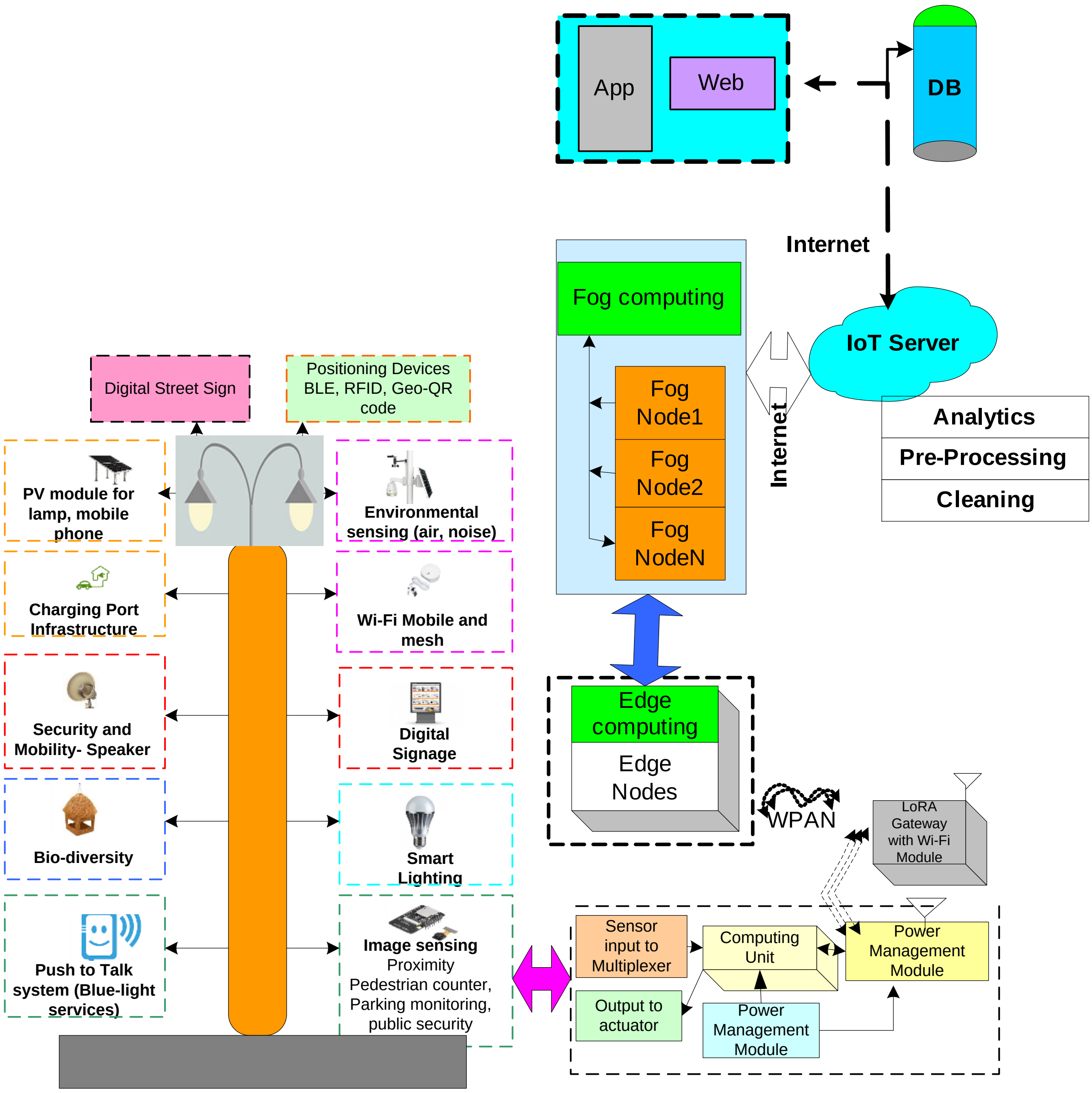

Figure 3. Architecture of Streetlamp.

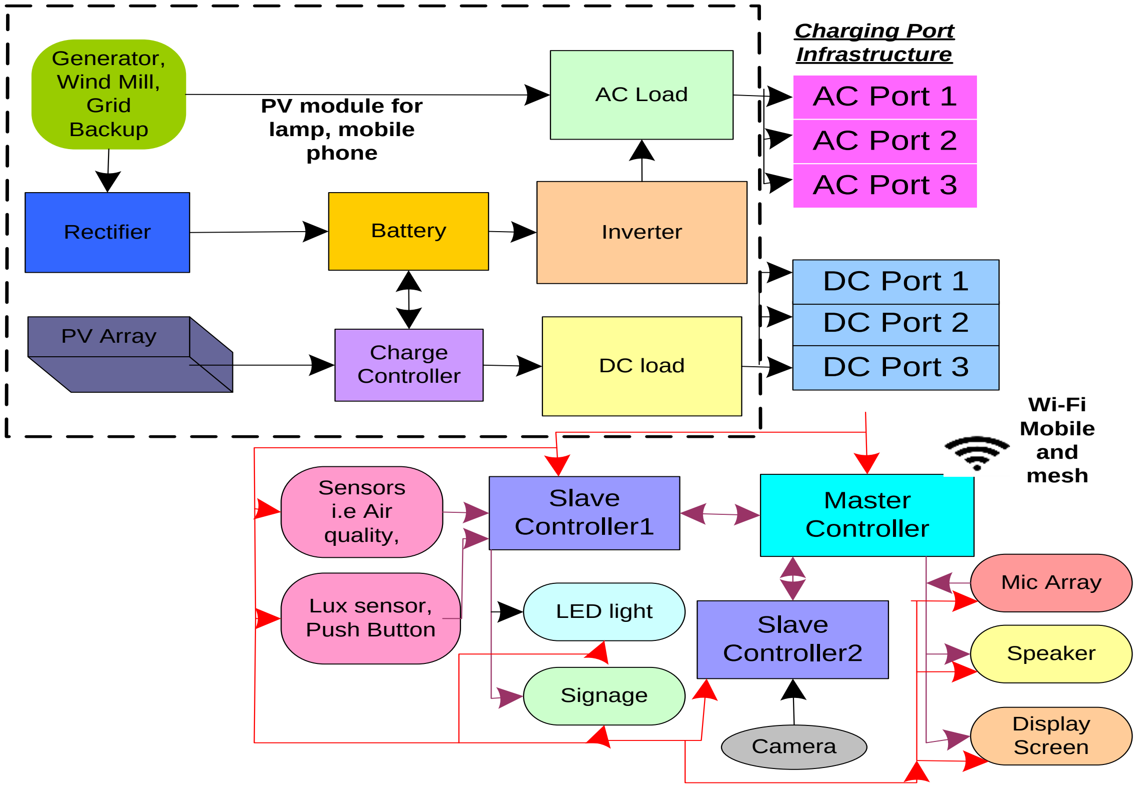

Figure 4. Technological Architecture.

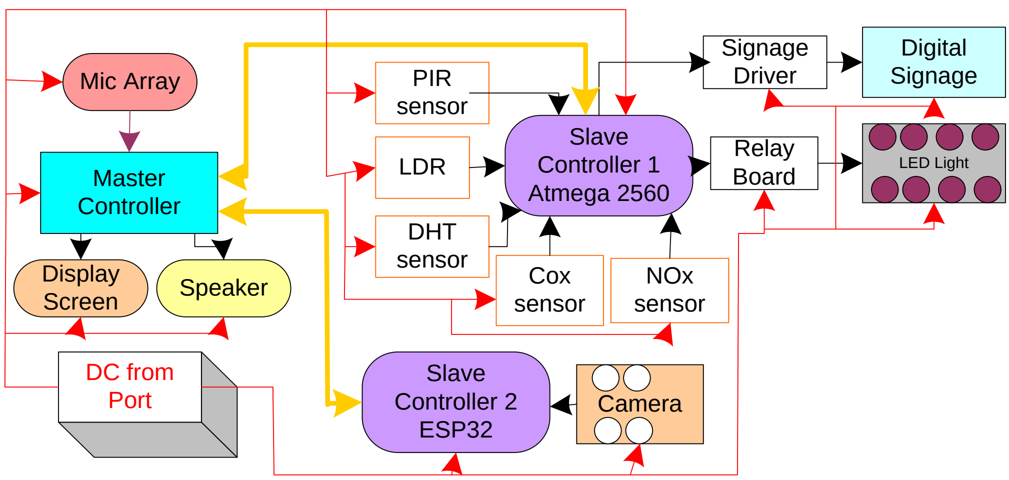

Figure 5. Sensor and actuator with Master and slave Unit.

4. Hardware and Software Description

The section provides information related to hardware development and software development. The smart lamppost is proposed as broad perspective concept, where we have implemented three features proposed in the smart lamppost. Environmental parameter monitoring, lighting systems and image sensing systems are designed and implemented. Generally, for lightning systems, we have integrated the LDR sensor and PIR sensor to the slave controller 1. LDR sensor is utilized for sensing the change in light intensity of outdoor environment. The AC 256 level dimmer integrating to the slave controller 1 enables dims the light according to light intensity value provided by LDR sensor. AC 256 level AC dimmer is utilized in the applications where the AC power is between 110 and 220 V AC, and it is interfaced to the pin of PWM signal in a microcontroller. The LDR sensor is an analog sensor, and it senses the intensity of the light as voltage.

For the environmental parameter monitoring, the two gas sensors are integrated to the slave controller 1 to sense the CO and NO level in the air. MQ 7 gas sensor is CO sensor that is embedded for sensing the CO level in the air around the lamppost. The CO level is generally represented in particles per million (ppm) and its range is between 10 and 10,000 ppm. Image sensing is a system that is specifically for security purposes on the roads, for sensing unexpected events that occur near the smart lamppost. A hardware description of the three components is presented along with the schematic view of the proposed system. A software description provides the level of IoT that supports the proposed architecture.

4.1. Hardware Description:

To check the performance of the proposed system, we have designed hardware so that it can sense the environmental parameters and is also able to accurately sense people through a camera. Figure 6 illustrates the connection between the distinct components of the smart lamppost system. Arduino UNO is the master controller that is addressed in the previous section. Slave controller '2' is the raspberry pi controller that is interfaced with pi camera for image sensing. The sensors including DHT11, LDR, and gas sensors are interfaced to the slave controller '2'. A +12 V power supply is powered to the complete circuit for performing the essential action. The technical specifications of the sensors and other components are illustrated in Table 2.

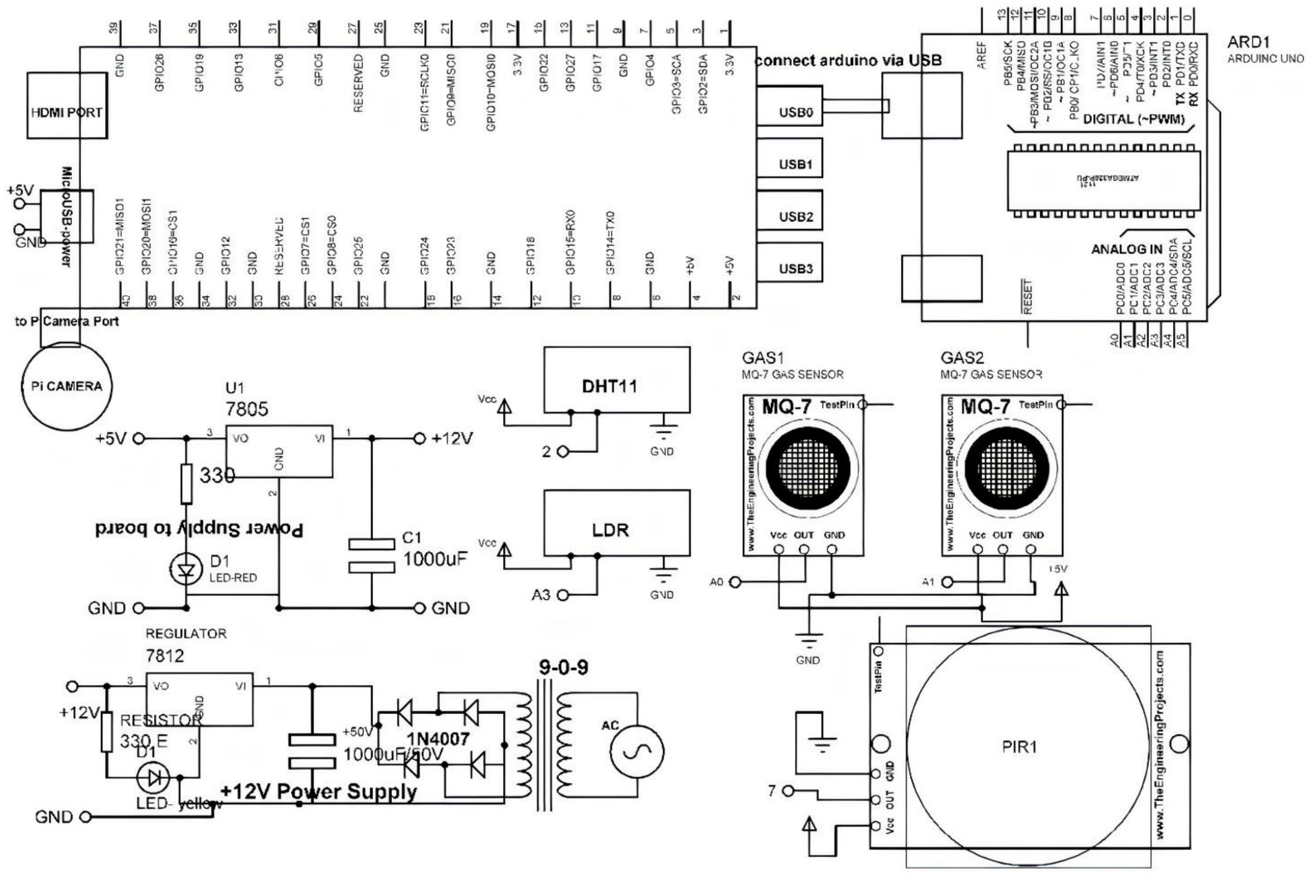

Figure 6. Circuit Diagram of the proposed system.

Table 2. Hardware Specifications.

Sensor Name	Characteristics
LDR sensor	6 V, 10^{12} Ω
DHT sensor	20–90% RH, 0–50 °C
Cox sensor	200~300 °C, 5 V
NOx sensor	120 Ω, 12 V to 32 V
Pi camera	5 Megapixels, 2592 × 1944 pixels

4.2. Software Development

In any system, the hardware node hardly stores the encryption keys and, therefore, it is challenging for the hardware node to handle and manage the encryption simultaneously. However, in parallel with its neighbors, network designers can provide the encryption facility in the node hardware. To overcome this challenge, we have a Request-Response communication model, and it is shown in Figure 7. In this communication model, the client generates the request to the server and the server acknowledges the request. Concerning the request from the client, the server retrieves the data, formulates the response, and sends the response to the client.

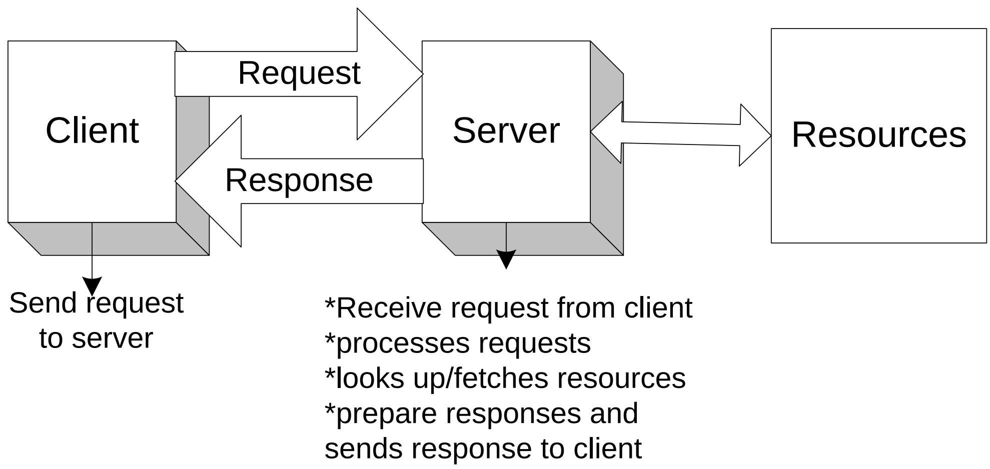

Figure 7. Request Response Communication Model.

IoT comprises six different levels of the architecture in the aspects of hardware complexity, several nodes, observer nodes, and cloud servers. Our architecture is framed based on level 6 IoT and it is shown in Figure 8. The level 6 architecture consists of independent end nodes, observer nodes, devices, controller service, local server, and cloud server. The independent end nodes sense the data of the physical elements, and communicates with the cloud server. Generally, this architecture is applicable where a large amount of data is generated from the final nodes. As the number of data points is huge, analytic tools are required for validating the data. The analytic tools will be applied to the data, which are present in the cloud server. A cloud-based application is available in this architecture for monitoring the end nodes in a graphical user interface.

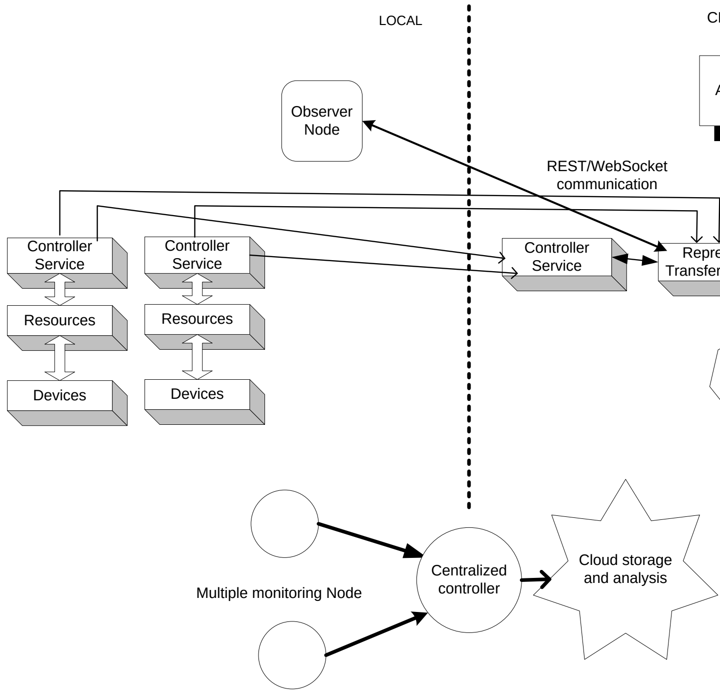

Figure 8. IoT Level 6.

5. Simulation of Smart Lighting System

Smart lighting systems are for controlling the light intensity with respect to the movement and intensity of outer light. However, in some cases, the system fails to the light the streetlight and, in other cases, a voltage surge occurs. Here, the dimmer control using LDR, voltage and current sensors can be implemented for monitoring voltage and current supply to the light. We have performed a simulation on proteus for identifying the change in the voltage and current and it is shown in the Figure 9. In the simulation, we have designed a circuit with the AC voltage and AC current sensor for sensing the malfunction in the light.

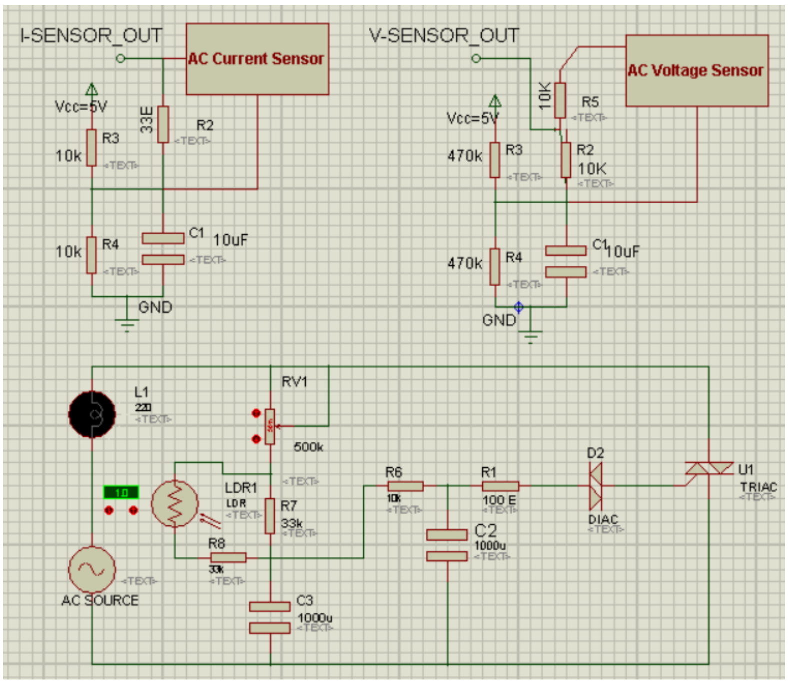

Figure 9. Simulation model of the lighting system with voltage and current sensors.

6. Results and Discussion

In this study, we have proposed a smart lamppost that delivers a multitude of applications that are addressed in the above sections. However, we have developed and implemented a few components of the smart lamppost, namely, smart lighting, environmental sensing, and image sensing. Smart lighting in the lamppost assists in maintaining the light in relation to the light intensity in an outdoor environment. Generally, the smart lighting system is for controlling the intensity of the streetlight with respect to the outer environment light intensity and movement of the objects crossing the smart lamp. The intensity of streetlight is measured with the assistance of LDR sensors, and movement of the objects is sensed through the PIR motion sensor. LDR sensors are very effective, particularly in streetlight and dark sensor circuits. The working principle of LDR sensors is that when the light falls on the LDR sensor, the resistance value of the LDR decreases, thus reducing the intensity of the streetlight accordingly. The following Equation (1) explains the relationship of resistor–inductor (RL) and lux:

$$\mathrm{RL} = \frac{500}{\mathrm{Lux}} \quad \mathrm{K\ ohm} \tag{1}$$

Therefore, the light intensity value sensed by the LDR sensor are represented in terms of analog value, i.e., voltage (V). The output of the LDR sensor that is receiving the voltage can be converted into lux with following Equations (2) and (3):

$$\mathrm{V_o} = \frac{5 \times \mathrm{RL}}{(\mathrm{RL} + 10)} \tag{2}$$

where $\mathrm{V_o}$ indicates the output voltage

$$\mathrm{Lux} = \left(\frac{\frac{2500}{\mathrm{V_o}} - 500}{10} \right) \tag{3}$$

where $\mathrm{V_o}$ indicates the output voltage

In this study, the movement of the person or vehicle is detected through PIR sensor. At the same time, streetlights switch on at a particular dimming level as per the time scenario. Here, the LDR sensor is placed at a location on the lamppost which is not affected by the car light. The LDR sensor adjusts the intensity of the streetlight in relation to environmental sunlight and, moreover, the streetlight glowing according to the environmental intensity reduces energy consumption. The energy saving is also achieved in our system, because of 256 level AC dimmer. Briefly, the AC dimmer diverts the flow of electricity through the streetlight. As the electricity flow is diverted, the amount of electricity supplied to the streetlight also reduces and this reduces the light intensity of the streetlight. The working principle of the dimmer can be explained with firing angle equation (Equation (4)).

$$\mathrm{V_o} = \frac{\mathrm{Vs}\sqrt{1/\pi(\pi - \alpha + (\sin 2\alpha)}}{2} \tag{4}$$

where $\mathrm{V_o}$ indicates the RMS value of output voltage, Vs indicates the applied voltage, α indicates the firing angle.

In the dimmer, the alternating current (AC) phase method is utilized by for controlling intensity of streetlight. The RMS value of output voltage is controlled by controlling the firing angle. For example, if the firing angle is 180°, then the RMS output voltage that is supplied to the streetlight is low. If the firing angle is less, e.g., 0°, then the RMS output voltage that is supplied to the streetlight is high. Therefore, 256 level AC dimmer in the proposed system minimizes the energy consumption.

Environmental sensing is for sensing the quality of the air, temperature and humidity. Here, we have integrated the MQ 7 gas sensor for sensing the CO level in the air and the DHT sensor is utilized for sensing the temperature and humidity. The DHT sensor provides the temperature value in terms of °C and humidity value in terms of %. The MQ 7 gas sensor provides CO level in terms of parts per million (ppm). All these sensors are connected to the slave controller 1 as shown in Figure 5. Image sensing is for counting the number of pedestrians, proximity, and parking management.

The realization of smart lighting and environmental sensing smart lampposts is achieved by developing the hardware prototype, which is based on Arduino Uno. Arduino Uno is a microcontroller that is built on the ATmega328P, it comprises 14 digital input/output pins, 6 analog inputs, and an operating voltage of 5 V [42]. For environmental sensing, the DHT11 sensor is interfaced to the digital pin in Arduino Uno, and MQ 7 sensor is interfaced to the ADC pins of the Arduino Uno. To realize smart lighting in smart lampposts, a LDR sensor and passive infrared (PIR) motion sensor are interfaced to the analog pins of Arduino Uno. The image sensing is achieved by integrating the pi camera into the ESP 32 module.

The hardware prototype that is developed for environmental sensing and smart lighting is implemented in a real-time environment and it is presented in Figure 10. MQ 7 gas sensor, DHT 11 sensor, PIR motion sensor, and LDR sensor are present in the hardware prototype for sensing the CO level, temperature, humidity, motion sensing, and light intensity. The hardware prototype communicates the sensory data of distinct sensors to the IoT server via internet connectivity through a Wi-Fi modem.

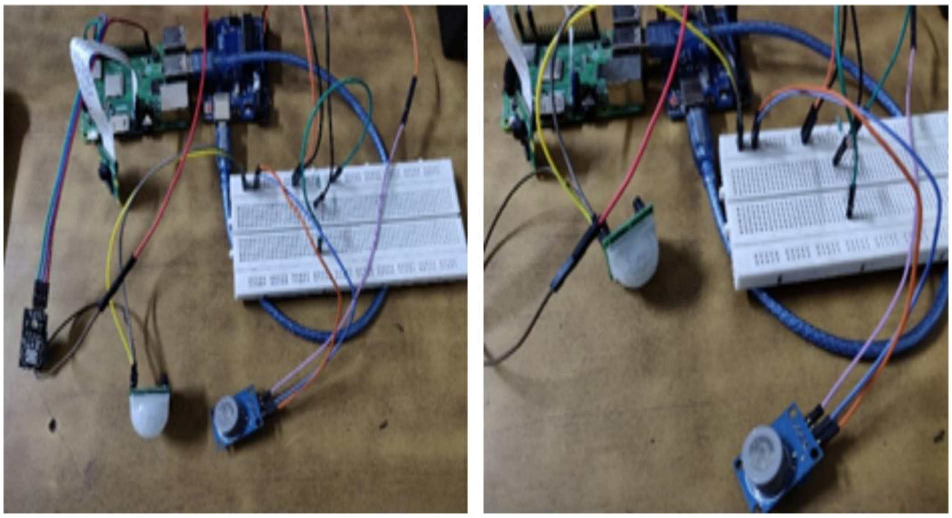

Figure 10. Environmental Parameter Sensing Prototype.

The graph in Figure 11a,b reveals the temperature and humidity values at different intervals. In January 2021, at 11:00 p.m., the temperature is recorded as 11 °C and the humidity is 65%. Between 11:00 p.m. and 11:15 p.m., the temperature increases to 12 °C and the humidity increases to 75%. Between 11:15 p.m. and 11:30 p.m., the temperature remained constant and, after 11:30 p.m., it rose in temperature (14 °C); regarding humidity for the same time interval, it is between 70 and 80%. At 11:45 p.m., the temperature declines to 12 °C, and humidity reaches nearly 70%.

The graph in Figure 11c,d reveals the Cox level and light intensity values at a different time intervals. In this study, we have set the threshold for collecting the sample of the LDR sensor value for a time interval of 5 s. An average is calculated for the total number of LDR sensor values that are recorded for a time interval between 11:00 p.m. and 11:15 p.m. Therefore, the values that are utilized for the plotting the graph are the average taken from the total number of LDR sensor values. In January 2021, at 11:00 p.m., the Cox level in the air is above 120 ppm and light intensity is at 1 V (volts). Between 11:00 p.m. and 11:15 pm, the Cox level suddenly declines to 110 ppm and light intensity also declines below 1 V (volts). Between 11:15 p.m. and 11:30 p.m., the Cox level is between 115 and 120 ppm and, after 11:30 pm, there is declining in the Cox level; regarding light intensity for the same time interval, there is a sudden rise in intensity of light. At 11:45 p.m., the Cox level is in between 110 and 115 ppm and light intensity is in between 1 and 1.3 V (volts).

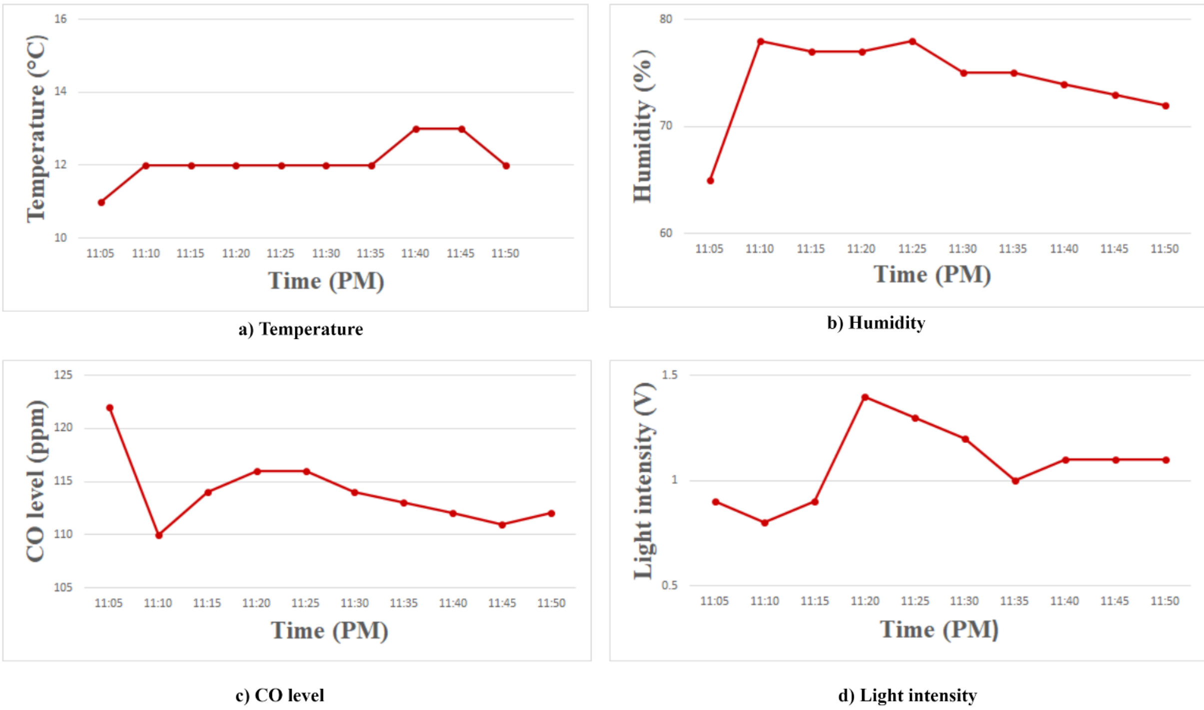

Figure 11. Sensing Data on the Cloud Server.

From the above discussion regarding the two graphs, it can be concluded that the cloud server is useful for continuous, real-time monitoring of temperature, humidity, Cox level, and light intensity.

The image sensing prototype is developed by integrating an ESP 32 cam-based module. The ESP 32 module is the hybrid module that is inbuilt with a camera, Bluetooth, and IEEE 802.11 b/g/n based Wi-Fi module [43]. The working architecture of the image sensing prototype is illustrated in Figure 12.

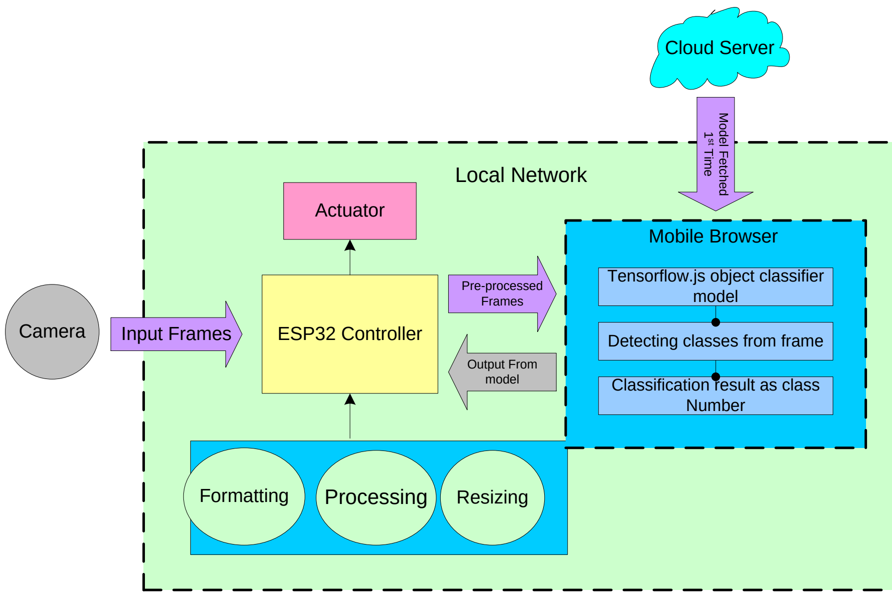

Figure 12. Working architecture of image sensing protype.

The ESP 32 controller takes the input frames from the integrated cam module and then processes them by resizing, formatting, etc. It then sends the pre-processed frames to the connected mobile phone or computer through the local network. The mobile or computer, on the other hand, in the first-time usage, downloads a tensor flow lite object classifier model specifically made for javascript from a cloud server, whose address is already present in the ESP 32's source file, which is shared to the mobile or computer once it is connected with the ESP locally.

After downloading, the model runs on the browser of the host device (i.e., the connected mobile or computer); it then takes the incoming camera feed from the local network process it to classify the content of the frame into various cases, e.g., human, dog, unknown, etc., and then returns the output result as the identified class serial number to the ESP32 controller through the local network. The serial number is then compared and analyzed at the ESP32 end to actuate or produce a reaction.

We have customized this prototype and built a 3D model prototype. In 3D printing, the 3D design file of the prototype is inserted, and it produces a 3D model that can be seen in Figure 13.

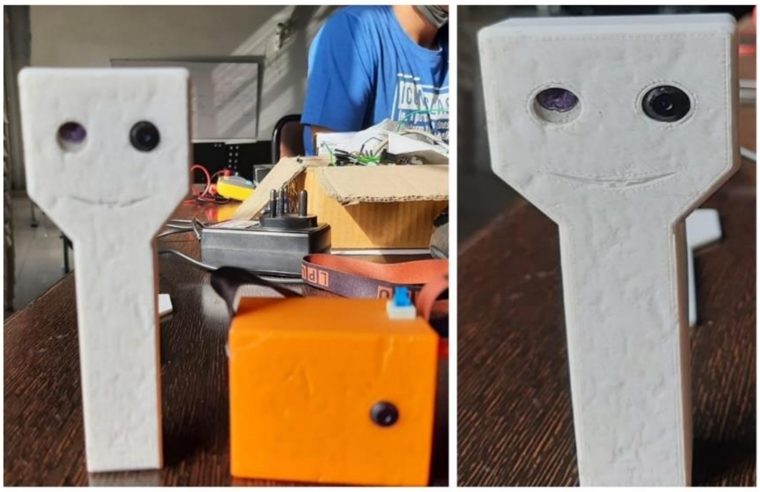

Figure 13. Image Sensing Prototype.

The image sensing prototype is deployed in a real-time environment for analyzing the performance. Figure 14 illustrates that the developed prototype is accurately detecting the person and also labeling the individual name of the person. With the assistance of an inbuilt Wi-Fi module, the prototype logs the visuals to the IoT server via internet connectivity.

Figure 14. Image Sensing Prototype Results.

Table 3 presents the comparison of the previous studies with proposed study. We have categorized the certain parameter's likely objective, lighting system, environmental parameter monitoring, image sensing, communication, architecture, and limitations for comparing with the previous studies. From the table, it is been concluded that the previous studies utilized the lamppost only for controlling the light intensity with respect to the PIR sensor and LDR sensor. However, the proposed system is capable of controlling lighting intensity as well as monitoring environmental parameters such as CO level, temperature and humidity. Additionally, our proposed system is connected to the cloud server through LoRa and a LoRa-based gateway. The sensor values of the CO level, temperature, humidity and light intensity are recorded in the cloud server and also presented in graphical form.

Table 3. Comparing results of previous studies with the proposed study.

Research	Objective	Lighting System	Environmental Parameter Monitoring	Image Sensing	Communication	Architecture	Limitations
[44]	IoT-enabled intelligent lamppost for controlling light with respect to traffic	Yes	No	No	LoRa	Relay network-based light controlling	Limited to controlling light
[45]	Health monitoring of solar lamppost including LED lights	No	No	No	HC12 transceiver	No	Limited to monitoring the health status,
[46]	Automatic lamppost with parallel connected solar".	Yes	No	No	No	No	Only for controlling the light
[47]	Controlling light through light intensity and movement of vehicles.	Yes	No	No	No	Internet of Things (IoT) enabled Relay Network.	Only for controlling highway lighting
[48]	Glowing the lights on street through vehicle movement	Yes	No	No	Zigbee	Not proposed	Only control the streetlights.
Proposed Study	Proposed smart lamppost system based on IoT and LoRa network	Yes	Yes	Yes	LoRa	IoT assisted Fog and edge node based architecture	-

7. Conclusions

The growth of the population and scarcity of fossil fuels have increased the demand for energy efficiency management in smart cities. In smart cities, the major contributor to energy consumption is the lighting system. Generally, the lighting system in smart cities is provided through streetlamps and lampposts. The integration of advanced sensing and communication protocols in a single lamppost will establish a smart infrastructure in smart cities. The single lamppost system can offer a multitude of services to the citizens residing in smart cities, including real-time environment information, Wi-Fi hotspots, EV charging ports, smart lighting, etc. In this study, we have proposed IoT-assisted fog- and edge-based architecture for implementing smart lampposts that provide a multitude of applications. The smart lamppost is capable of providing applications such as smart lighting, digital signage, environmental sensing, push to talk systems, charging port infrastructure, Wi-Fi mobile and mesh, image sensing pedestrian counting, parking monitoring and public security, and digital street signs. To realize the proposed architecture, we have designed and implemented individual applications including environmental sensing, smart sensing, and image sensing. Environmental and light intensity prototypes are based on the Arduino

UNO and image sensing is based on the ESP 32 cam module. We have obtained the sensory value of the environment (temperature, humidity, and CO level) on the IoT server. The sensory values conclude that the lighting system and environmental parameter monitoring component of the smart lamppost are able to provide real time values and plot these in graphical representation. The image sensing is used for sensing the movement of the humans passing across the smart lamppost. As it is based on an ESP 32 module, it is able to send data to the cloud server. Image sensing is also able to record visuals, identify individual persons, and logs the visuals on the IoT server. As we have now developed and implemented the three components of the smart lamppost, in future, we will develop the other components of the smart lamppost and build the complete smart lamppost with a multitude of advanced features and applications.

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