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ITS67404 Internet of Things (IoT)

ASSIGNMENT 1

Propose an IoT-based system with an entrepreneurial mindset for a real-world problem.

HAND OUT DATE: **28th April 2025**

HAND IN DATE: **6th June 2025 (Week 7)**

WEIGHTAGE: 30%

Instructions to students:

- The assignment should be attempted individually.
- Complete this cover sheet and attach it to your assignment – this should be your first page.

Student declaration:	
I declare that: ▪ ***I understand what is meant by plagiarism*** ▪ ***The implication of plagiarism have been explained to us by our lecturer*** ***This project is all our work and I have acknowledged any use of the published or unpublished works of other people.***	
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1.0 Introduction

1.1 Background of IoT and Smart Infrastructure

Internet of Things (IoT), is known as a collection of physical devices with sensors, software, and networking that can gather and share data without requiring human contact. With an emphasis on safe and efficient use of resources, it has become the foundation of smart infrastructure technologies, especially in Smart Cities. Lately, Smart Cities employ IoT technologies for more advanced functions such as traffic control, energy management, garbage disposal, and most importantly, street lighting.

Street lighting acts as a key element of urban infrastructure and consumes a great deal of energy as well. However, conventional systems use set time intervals for switching lights on and off and do not adapt to real time environmental parameters or traffic patterns, which leads to significant wastage. Based on a 2022 case study on Sheffield's streetlight infrastructure, "streetlights can account for up to 30% of a city's energy usage, or roughly 43.9 billion kWh annually worldwide." While the use of LED lights has enhanced lighting efficiency, cities like Sheffield still struggle with what they call the 'static behavior' of their systems. Street lights turn on and off based solely on time and do not take into consideration a variety of factors like rain, fog, and low visibility. (Dizon and Pranggono, 2021)

1.2 Problem Recognition

Although there is growing excitement in global cities about the use of IoT-driven lighting systems, unfortunately, many locations still do not use them efficiently due to the continued usage of outdated and poor lighting models. For example, in Sheffield, 99.5% of streetlights now operate on the energy-saving LED technology, yet they are still controlled manually based on the time of the day. (Dizon and Pranggono, 2021) This strongly illustrates one of the issues present in urban areas that are not fully prepared for the changing needs of modern street lighting.

Moreover, a similar issue has been clearly experienced by me on a local level. I am a student from Melaka currently studying in Subang Jaya. While travelling back and forth between Melaka and Subang Jaya via the North-South Expressway (E2), I have encountered countless situations where the street lighting of the highway is totally off or functioning poorly, especially during heavy rain or foggy nights. Due to the existing system which only switches street lights on and off between 7 PM and 7 AM, it frequently does not adapt to actual visibility conditions, making night time transport particularly risky during storms or off-peak hours. As a result, the sections of the roads become dark or poorly-lit, which can significantly increase the risk of accidents and driver fatigue.

1.3 Purpose of the Assignment

This assignment's goal is to research, investigate and propose an Internet of Things-based solution to the problems with the current street lighting systems. The aim will be to construct a **Smart Street Light System** that enhances safety, lowers energy use, and promotes sustainable development by utilizing automation and real-time data collection.

2.0 Current State of Street Light Systems

Street lighting is a key feature of urban infrastructure which not only ensures the safety of a road but also the visibility, energy efficiency, and urban development. However, the majority of the systems are still operating on outdated technology, which is not optimized for energy use, therefore contributing significantly to environmental and economic issues.

2.1 Energy Consumption in Current Street Lighting

Street lighting is a large-scale energy consumer, constituting about 15–19% of worldwide electricity consumption and roughly around 5 to 6% of greenhouse gas emissions. Traditional lighting systems are scheduled to operate during fixed times and run at full brightness irrespective of road traffic or ambient light. Hence, there is a massive waste of energy, mainly during late hours of low traffic or when ambient light is sufficient. Such electricity wastage weighs very heavily on the finances of the city, with some cities spending up to 40% of their municipal electricity budget on outdoor lighting. As urban populations swell and global energy demand is expected to almost double by 2050, this will surely go against any environmentally-based and economically-oriented effort to curb the menace. As you can see from **Figure 1** below, with the continuous growth of time and population, energy demand consequently increases, especially in Asia Pacific. (Bachanek et al., 2021)

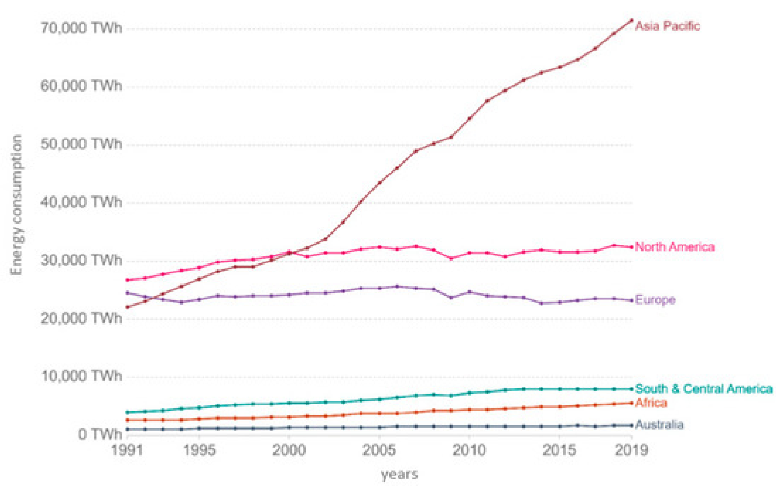


Figure 1: Global trends in energy demand by continent.

2.2 Time-Based Operation and Lack of Adaptability

Street lighting is very crucial when it comes to public safety, urban mobility, and energy management. Nevertheless, most of the current street light systems, especially in developing countries, use time-based operations that are considered conventional or outdated. These street lights turn on at fixed hours, for example, from 7 PM to 7 AM, regardless of weather, traffic, or visibility conditions. This method lacks adaptability and not only often leads to under-illumination during heavy rain, fog, or cloudy days, but also causes wasteful energy consumption when the lighting is actually not required.

2.3 Safety Risks from Poor Illumination

Research studies also show that there are significant risks associated with inefficient or inadequate street lighting. For instance, road accidents are one of the leading causes of fatalities, and nighttime accidents are discovered to be much more prevalent and fatal compared to those at daytime. This is primarily due to poor visibility, reduced contrast sensitivity, and slower reaction time during the night. Proper street illumination or conversion to LEDs (**Figure 2**) has the potential to reduce accidents at night by 40% and is crucial in enabling drivers to detect hazards, road markings, and pedestrians all around them effectively. (Fawaz Alharbi et al., 2023)

Figure 2: A row of streetlights before (left) and after (right) converting to LEDs.

2.4 Design Flaws and Visual Distractions

Apart from safety, poor lighting design leads to other issues. Over-lighting or wrongly placed lights lead to glare, fatigue among drivers, and light pollution, which disturb ecosystems and sleeping patterns of humans. In addition, poor spacing, inappropriate color of the light, and wrongly placed electronic billboards create visual distractions that disable a driver's focus. In the Qassim region of Saudi Arabia, one study revealed that lighting conditions were one of the major elements in road accidents, hence the government began replacing traditional lights with LED systems and conducting public opinion-based evaluations to improve performance and safety. (Fawaz Alharbi et al., 2023)

These problems, backed by both international case study and local government research, clearly highlight the failures of current systems. Their inability to function under actual operating conditions, their inability to spot faults in real-time, their inefficiencies in power consumption, and their inefficient lighting design all pose an enhanced risk of accidents and cost of operations. Hence, there is a pressing need for a modern, smart solution: an **IoT-based Smart Street Lighting System** that dynamically adjusts lighting levels as a function of visibility, weather, traffic flow, and available energy to balance safety and efficiency.

3.0 Proposed IoT-Based Solution

3.1 System Description - Smart IoT-Based Street Lighting System

By transforming street lights into smart, adaptable, and responsive systems, the proposed solution is Smart Street Lighting System powered by the Internet of Things which seeks to overcome the limitations of traditional lighting setups. This smart street light system introduces a dynamic, sensor-based model that relies on real-time data, such as motion detection, ambient light levels, weather conditions, and other environmental factors, replacing the outdated fixed-schedule lighting approach. (Gagliardi et al., 2020)

Each smart streetlight unit has a set of IoT sensors that can detect the following variables:

1. **Ambient light intensity** to determine natural lighting (daylight, dusk or cloudy conditions).
2. **Motion sensors** to detect vehicles or pedestrians.
3. **Weather sensors** to monitor fog, rain, temperature and humidity.
4. **Camera modules (optional)** for basic object visibility detection.
5. **Solar panels** to harvest solar energy and reduce dependency on the main power grid.

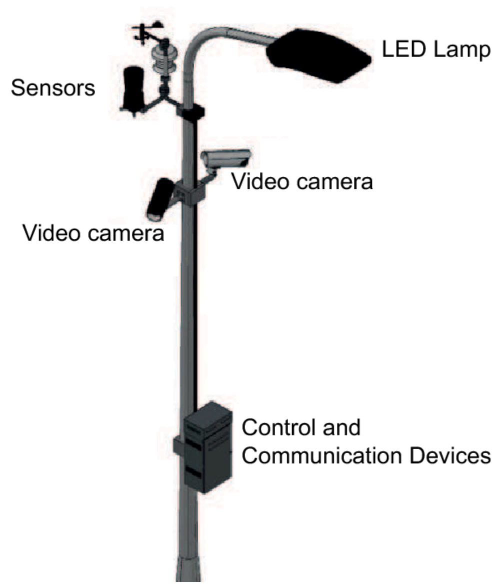


Figure 3: Overview of the proposed Smart Street Light (Sample)

As shown in **Figure 3**, the proposed smart street light includes components such as sensors, a microcontroller, a communication module, an LED lamp, a video controller and more. These components work together and communicate with each other through signals and data instantly, which enable them to adapt to environmental and traffic conditions in real time.

All the data that are collected by sensors, such as motion, ambient light, temperature, fog, and rainfall, are processed first locally by a microcontroller or gateway unit which is installed within each smart street light. This local processing serves as an edge processor to the street light, which can decide immediately, for example, whether to open or dim accordingly based on the real time situation without receiving the cloud command.

After the local processing, the data is wirelessly sent to a centralized IoT platform using technologies like Wi-Fi, LoRaWAN, or NB-IoT, depending on where it is deployed and the range needed. This centralized system, as shown in **Figure 4**, gathers updates from all the street lights, allowing for remote monitoring, performance analysis, fault detection, and network optimization from a central control and management center.

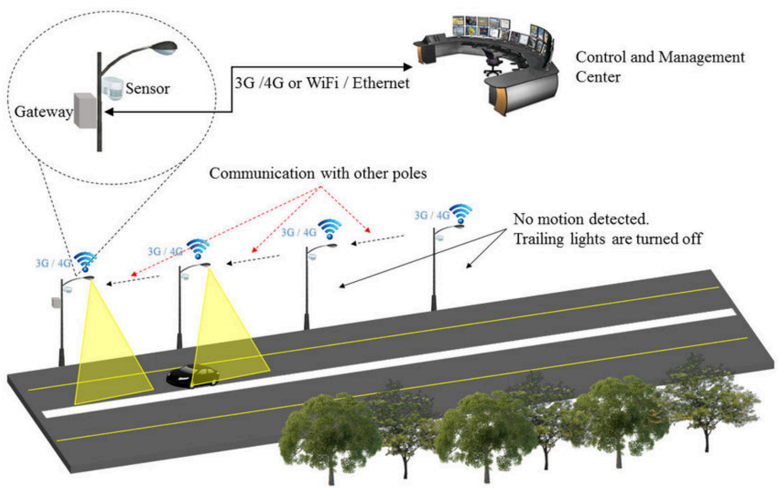


Figure 4: Data Connectivity of Smart Street Light System (Gharaibeh et al., 2017)

Also, each smart street light is built to communicate by sending signals to nearby poles, which enables them to work together closely. For instance, when one light detects movement, it will send a signal to the next few poles in advance, then they will turn on the light ahead and dim the light behind it. This not only reduces the energy consumption but also ensures road safety.

Last but not least, the system is powered by solar panels and includes battery storage. This is to ensure that even during blackouts or any energy shortage, the smart street light will be able to continue to function and secure user's safety. On the other hand, this IoT-based approach not only enhances public safety but also improves operational efficiency, supports energy conservation, and aligns with smart city development initiatives. (Gagliardi et al., 2020)

3.2 Key Technologies and Components

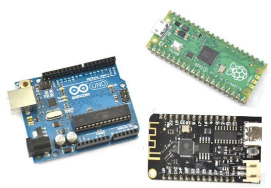
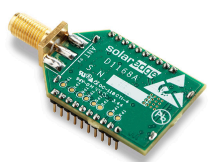
Component / Technology	Example	Function
IoT Sensors	 **Microwave and Radar Sensor**	The IoT sensor of smart street light is employed to recognize motion, ambient light, temperature, humidity, mist, and rain through microwave and radar technologies. The data of the environment received in real-time from the device helps in the precise regulation of the light levels that are necessary for safe and energy-efficient living.
AI-Powered Smart Cameras		The AI-based camera is able to distinguish not only vehicles or pedestrians but also the real-time check of the visibility level. In case of poor visibility because of rain or fog, the camera immediately reacts by giving the LED lights the command to increase the light intensity, thus making sure that the road is still brightly and safely lit.
Microcontroller Unit (MCU)	 **PIC16F877A, Arduino, or ESP32**	The Microcontroller Unit (such as PIC16F877A, Arduino, or ESP32) serves as the processing core for each smart pole. It collects data from sensors and cameras, processes it locally, and transmits relevant information to the central system for further action.
Wireless Communication Module	 **ZigBee - SE1000-ZB06-MOD**	The wireless communication module (e.g., ZigBee SE1000-ZB06-MOD) enables seamless data transfer between streetlights and the cloud platform. It supports technologies such as LoRaWAN, Wi-Fi, or NB-IoT, ensuring reliable and low-power connectivity across the network.
LED Light Module		Provides energy-efficient lighting with adjustable brightness levels.
Solar Panel + Battery Backup		Powers the light independently and stores energy for backup use.
Cloud Server / IoT Platform		Stores data, monitors performance, and issues maintenance alerts in real time.

Table 1 : Table of Key Technologies and Components

3.3 Features and Capabilities

The proposed smart street light system offers several innovative features:

1. **Adaptive Brightness Control -** Automatically adjusts brightness based on detected visibility and motion to ensure optimal lighting while saving energy.

2. **Environmental Awareness -** Detects rain, fog, and temperature to activate lights earlier or increase intensity when necessary.

3. **Energy Efficiency -** Incorporates solar panels and dimming functionality to significantly reduce power consumption and reliance on the grid.

4. **Real-Time Fault Detection -** Immediately alerts maintenance teams when a light malfunctions or stops operating, reducing downtime.

5. **Remote Monitoring and Control -** A centralized dashboard provides live data, system control, usage reports, and performance analytics for decision-makers.

6. **Emergency Response Mode -** In emergency scenarios (e.g., accidents or extreme fog), the system can switch to maximum brightness to improve visibility.

7. **Low-Cost Maintenance -** Predictive maintenance powered by sensor data minimizes manual inspections and repair delays.

8. **Public Feedback Integration** - Future expansions could allow citizens to report faulty lights through a mobile app, integrating community engagement.

9. **Scalability -** The system is modular and can be deployed across urban roads, highways, tunnels, and pedestrian walkways.

10. **Support for SDGs -** The solution supports multiple Sustainable Development Goals, including SDG 3 (Good Health & Well-Being), SDG 7 (Affordable & Clean Energy), SDG 9 (Industry, Innovation & Infrastructure), and SDG 11 (Sustainable Cities & Communities).

4.0 Value Creation and Innovation

4.1 Unique Value Proposition

The proposed IoT-based Smart Street Light System offers unique value propositions such as energy efficiency and weather adaptability. With the use of IoT, this system turns an old static infrastructure into a modern, responsive and eco-friendly approach. Whereas traditional lighting follows the same schedule at all times, this new system responds to on-the-spot changes in motion, sightlines and weather. Only makes use of energy when required to, allowing for great energy savings and better roadway safety.

For example, the smart street light system dims the street lights instead of turning them off when there isn't much traffic after dark. When the motion sensors detect any incoming vehicles, it will activate and the nearby lights will increase their brightness to ensure drivers can see safely and the road visibility is clear. After the vehicle passes by, the lights are restored to a safe-energy state gradually. To validate this concept, simulations were made using a design of vehicle LEDs that dim based on speed and movement (displayed in **Figure 5**). (Omar et al., 2022)

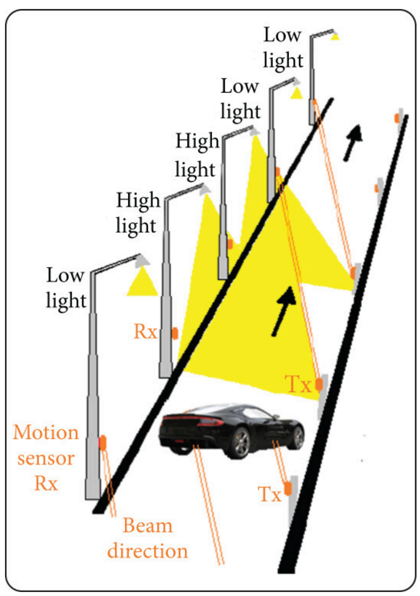


Figure 5: Layout of the luminaires

Alongside motion sensing, the system features an AI-powered smart camera and a board for controlling lighting based on how the visibility, traffic flow and environmental condition is. Besides, specific video processing algorithms were designed to help identify moving objects, such as vehicles and pedestrians and report to the main system as a "motion detected" event. (refer to **Figure 6**). (Gagliardi et al., 2020).

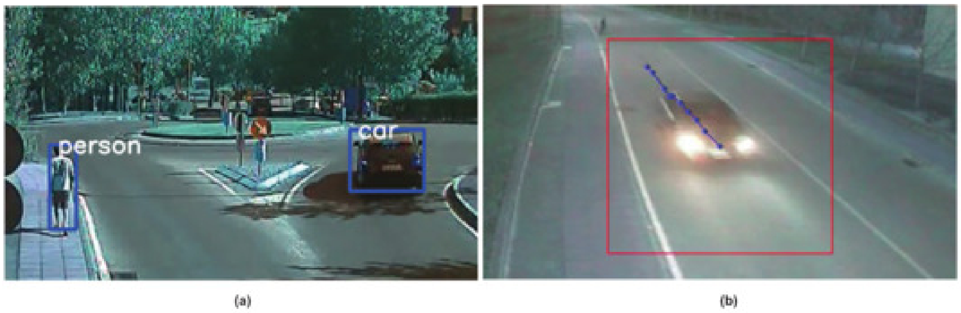


Figure 6: An example of the output of the video processing algorithm

Instead of sending infrared radiation, the system relies on wireless ZigBee to communicate with nearby lighting poles which adjust their brightness. (Gagliardi et al., 2020)

Aside from motion detection, the lighting control board also gathers data from ambient light and weather sensors to automatically react to oncoming fog, heavy rain, or early darkness. It is designed to brighten the area if the visibility is reduced. It can also identify defects or irregularities in the pole network, sending a signal to a central dashboard which then triggers the emergency mode to keep operations ongoing. (Gagliardi et al., 2020)

In **Figure 7**, we see how the smart camera guides the lighting control board and how these devices organize themselves to coordinate lighting at several poles.

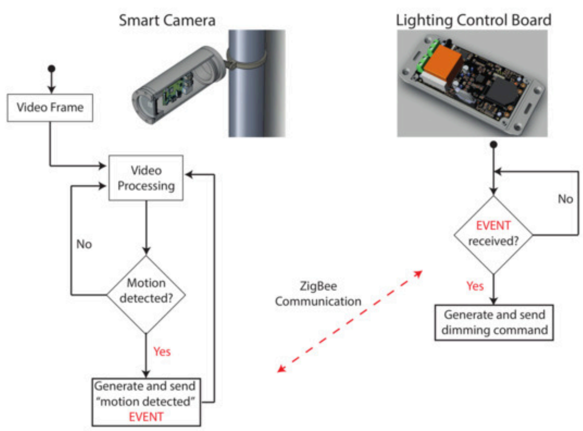


Figure 7: Interaction between Smart Camera and Lighting Control Board

In a nutshell, our Smart Street Light System is designed to be both modular and scalable, which means it can easily adapt to future upgrades like AI-driven analytics and smart city features. Unlike traditional systems, it tackles complex societal issues with adaptive lighting, real-time sensing, and the use of renewable energy. This ensures that it stays relevant and cutting-edge in a fast-changing tech landscape.

4.2 Entrepreneurial Mindset

This project uses an entrepreneurial mindset by identifying a common, high-impact real-world problem — road accidents under poor visibility and inefficient, antiquated street lighting. Then, designating an innovative, scalable, and sustainable solution of high market potential. The proposed IoT-based Smart Street Light System addresses not only public safety but also rising energy spending and environmental impacts, which are the most critical issues for modern cities and municipalities.

Socially, the system ensures road safety by enhancing real-time visibility during poor weather or nighttime. By adapting light levels based on actual traffic and visibility, the system avoids accidents, reduces driver stress, and improves the road environment safety for all individuals like pedestrians, cyclists, and motorcyclists. This focus on human well-being makes the system highly appealing to government bodies and urban planners prioritizing citizen safety and smart infrastructure. (Kabir et al., 2023)

Economically, the system has been set up to avoid high costs, minimize upkeep and be modular in structure. Since motion-activated lights increase brightness only when someone is within the area and can dim low when there's no one present, electricity and utility bills are noticeably lower. Using solar panels with battery backups helps businesses keep their energy costs down by using less power from the grid. Advanced systems also make it possible to spot faults early and supervise them from a distance which requires few personnel and saves on expensive, long-term maintenance. For these reasons such buildings offer value and can be affordably deployed in cities, as well as in rural regions. (Dr.Kaushalya Thopate, 2025)

From a sustainability point of view, the system is a contribution to sustainable agendas by limiting carbon emissions and saving additional energy consumption. The application of solar power operation, LED efficiency, and brightness adjustment maximizes light reduction and increases climate-friendly infrastructure development. As urban centers attempt to meet global environmental standards, such as reducing greenhouse gas emissions by 80–90% by 2050, this system offers a feasible and efficient step toward more sustainable urban planning. (Bachanek et al., 2021)

4.3 What Makes It a "Purple Cow"

Smart Street Lighting System is technically a "Purple Cow" because it brings some characteristics that are not present in both traditional or even smart lighting systems that are already on the market. One of the aspects in which it is the best is environmental adaptability, with the system showing a change of emergency response mode, energy self-sufficiency, performance monitoring of the system and a design of a scalable model. All of these are not merely cutting-edge in technology but also carry sociological value. All these factors make the system standout from traditional industry standards.

4.3.1 Comparison

To demonstrate why this system is a “Purple Cow”, a comparison with traditional street lighting is carried out and is found in **Table 2**. It points out important distinctions in performance, flexibility and efficiency when there is bad weather or low light.

Condition / Event	Conventional Street Light System	Proposed Smart IoT-Based Street Light System
Time of Day	Operates only during fixed hours (e.g., 7 PM to 7 AM)	Operates based on real-time visibility, not just time
Weather Condition	No adaptation to fog, rain, or cloud cover	Sensors detect rain/fog and increase brightness immediately
Visibility Level	Cannot respond to reduced visibility	Dynamically adjusts brightness for clearer vision
Vehicle Detection	No motion sensing	Lights turn on or brighten as vehicles approach
Energy Usage	High energy usage regardless of traffic or need	Optimized usage—dims when not needed, saving energy
Fault Response	Manual fault detection and delayed repairs	Real-time fault alerts sent to maintenance system
Power Outage	Lights go out entirely	Battery backup with solar keeps the system running
Driver Safety	Increased risk due to delayed or dim lighting	Improved confidence and reduced accident risk with responsive lighting

Table 2: Comparison between Conventional and Smart Street Light System

5.0 Alignment with Sustainable Development Goals (SDGs)

The proposed IoT-based Smart Street Light System directly supports multiple **United Nations Sustainable Development Goals (SDGs)** by addressing challenges related to safety, energy efficiency, innovation, and urban sustainability. For instance,

1) **SDG 3: Good Health and Well-Being** - By improving visibility on roads during poor weather, nighttime travel, and emergency conditions, the system helps reduce road accidents, injuries, and fatalities. It creates safer environments for both drivers and pedestrians, contributing to overall public well-being. (Fawaz Alharbi et al., 2023)

2) **SDG 7: Affordable and Clean Energy** - The system promotes energy efficiency through motion-based dimming and brightness control based on environmental conditions. Additionally, the use of solar panels and LED technology reduces reliance on fossil fuels, lowers electricity costs, and supports the transition to clean energy. (Choubey, Rakesh and Bhujade, 2019)

3) **SDG 9: Industry, Innovation, and Infrastructure** - This solution modernizes outdated infrastructure by incorporating IoT, AI, and wireless communication technologies. Its modular and scalable design supports innovation and sets a new standard for smart infrastructure in both urban and rural settings. (admin_itracking, 2025)

4) **SDG 11: Sustainable Cities and Communities** - By optimizing energy use, reducing carbon emissions, and improving road safety, the system contributes to the development of smarter, more resilient, and environmentally friendly cities. It also enables real-time monitoring and maintenance, which enhances urban management efficiency. (SDG Knowledge Hub, 2018)

6.0 Target Industry and Stakeholders

The Smart Street Light System is primarily designed for the Smart Infrastructure and Smart Cities industries. Many of the industries concentrate on using the Internet of Things (IoT) and other smart technologies to enhance safety, improve efficiency and support the environmental sustainability of the cities. Besides, this system targets government departments that are responsible for the development of public roads, highways and city maintenance. There is a constant effort in these sectors to improve street lighting control, reduce energy consumption, and ensure the safety of both drivers and pedestrians. Moreover, Smart Street Light System is also suitable for private companies that manage large areas such as industrial parks, housing developments or transport centers. Since the system is designed to save energy, it provides a cost effective solution and makes it stand out from other conventional alternatives. (Business Insight, 2025)

7.0 Scope of the Proposed System

The intelligent street lighting system is a smart infrastructure solution that has been designed to operate within designated city and highway areas, for example main roads, tunnels, or selected expressways. It utilizes a combination of IoT technologies such as sensors, smart cameras, solar-powered LED lights, and a centralized cloud platform to adjust lighting according to the real-time situation. The main objective of this system is to automate the street light control in order to enhance road safety, reduce energy waste, and to develop a sustainable infrastructure.

7.1 Data Collection and Processing Scope

The system collects data from motion sensors, environmental sensors (like rain, fog, and light sensors), and smart cameras. These devices gather information such as:

1. Vehicle or pedestrian movement
2. Visibility level (daylight, fog, rain, etc.)
3. Ambient brightness
4. System health and lighting faults

The collected data is processed by microcontrollers on each lighting pole and is then transmitted to a central IoT-based platform using wireless communication technologies such as ZigBee or LoRaWAN (refer to **Figure 8)** .

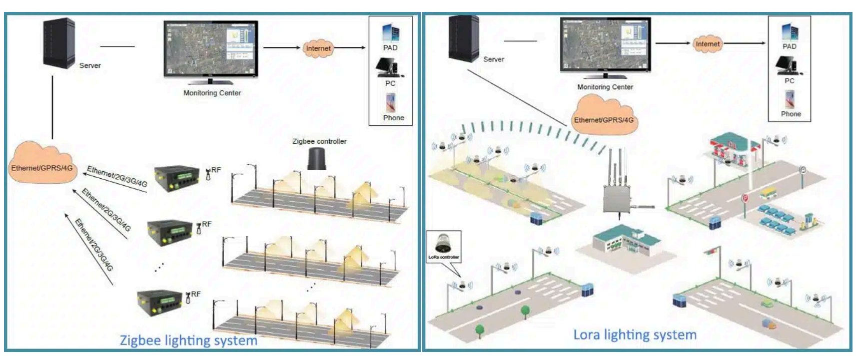


Figure 8: Zigbee and LoRa Smart Street Lighting System

Technologies like Zigbee and LoRa are used heavily in the infrastructure of smart cities due to their low power usage, low cost, and high sensor network supportability. Sensors and intelligent controllers are placed on each lamp post in order to communicate with each other. They are monitored and managed by the central monitoring system through Zigbee or LoRa networks. Zigbee is optimally suited for short-range, low-latency communication of proximal devices, while LoRa is utilized for long-range, low-power transmission, especially in wider or rural deployments. They support the remote control of lighting features such as turning lights on or off, modifying brightness levels, and fault detection or environmental sensing. (Gong, 2023)

7.2 People Who Control and Access the System

The system is monitored and controlled by **authorized city** or **government staff**, such as:

1. Urban infrastructure managers
2. Road or highway maintenance teams
3. Energy department personnel

They use a **web dashboard or mobile app** to access and view real-time data, receive alerts about malfunctions, and remotely adjust system settings. Access is limited and protected to prevent unauthorized use. **Figure 9** below shows the traffic monitoring web page. (Gagliardi et al., 2020)

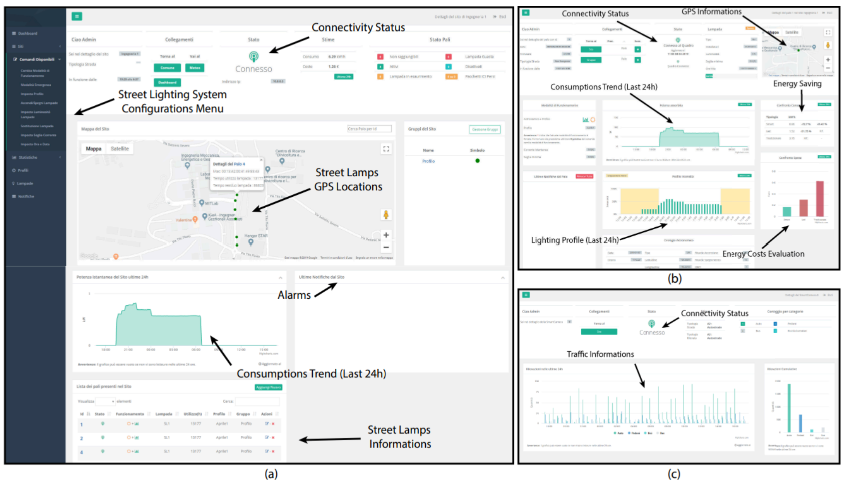


Figure 9: Web Dashboard

7.3 What the System Covers and Not Covers

Table 3 illustrates the functional scope of the proposed smart street light system, outlining what is included within its capabilities and what lies outside its intended use.

Table 3: Scope of Coverage for the Proposed Smart Street Light System

What the System Covers	What the System Does Not Cover
Real-time adjustment of streetlight brightness based on motion and visibility	Manual control by public users or residents
Energy-saving operations through automatic dimming	Surveillance or facial recognition features (no personal data collection)
Solar power integration and battery backup	Traffic enforcement systems (e.g., speed cameras or license plate recognition)
Automatic fault detection and alert system	Emergency response coordination (such as ambulance dispatching)

8.0 Functional and Non-Functional Requirements

8.1 Functional Requirements

No.	Functional Requirement	Description
1	**Motion-Based Lighting Control**	Adjusts brightness based on the presence of vehicles or pedestrians.
2	**Environmental Sensing and Visibility Detection**	Detects weather and lighting conditions such as fog, rain, and cloud cover.
3	**AI-Powered Smart Camera Integration**	Uses computer vision to detect motion and visibility, enhancing decision-making.
4	**Adaptive Brightness Adjustment**	Automatically changes lighting intensity based on visibility and traffic levels.
5	**Solar Power and Battery Backup**	Powers lights using solar panels and stores energy for use during power outages.
6	**Fault Detection and Alert System**	Identifies malfunctioning lights and alerts maintenance teams in real time.
7	**Centralized IoT Monitoring Dashboard**	Allows remote access, monitoring, and control of all connected streetlights.
8	**Emergency Response Mode**	Automatically switches to full brightness during detected emergency conditions.
9	**ZigBee/LoRa Communication Network**	Facilitates secure and low-power communication between poles and control systems.
10	**Scalability and Modular Deployment**	Can be expanded to cover more areas or integrated with other smart city systems.

Table 4: Functional Requirements Table

1. Motion-Based Lighting Control - This function allows each street light to detect nearby motion through sensors. The system operates based on movement within the sensor's range. For example, when a vehicle or pedestrian is detected incoming, the light will automatically increase its brightness. Once they pass, the lights will dim slightly while still providing sufficient light. (Omar et al., 2022)

2. Environmental Sensing and Visibility Detection - The smart street light system includes weather and ambient light sensors that monitor fog, rain, humidity, and overall visibility. The data will be processed and used to determine the brightness of the street light during daytime storms or poor environmental conditions. (Gagliardi et al., 2020)

3. AI-Powered Smart Camera Integration - The AI-powered smart camera is used to detect the visibility of the road and movement of pedestrians or vehicles. It is different from a traditional camera as it can analyze the video input and make decisions such as increasing brightness based on what it sees. For example, if the camera detects that the visibility of the road is low, it will send a signal to increase the brightness. (Gagliardi et al., 2020)

4. Adaptive Brightness Adjustment - This system enables the street lights to become brighter when there is more traffic and dim down the brightness when the roads are empty. For example, during light traffic or clear skies, lights remain dim. During poor visibility or busy traffic, they automatically increase brightness to ensure road safety. (Keh Kim, 2020)

5. Solar Power and Battery Backup - Every street light is equipped with a rechargeable battery and solar panel that can store electricity. This is to ensure the system continues to function even during power shortages or blackouts. This not only enhances public safety, but also makes the system eco-friendly while reducing operational cost and energy consumption. (Mirza Salman, 2024)

6. Fault Detection and Alert System - If a street light does not function properly or fails to respond unexpectedly, the system immediately detects the issue and sends an alert to the maintenance staff through the central platform. This can reduce downtime and improve public safety by ensuring quicker repairs. (V. Hima Vamsi et al., 2024)

7. Centralized IoT Monitoring Dashboard - All street lights details are connected and stored in a cloud-based dashboard which is accessible by the authorized personnel. From the dashboard, users can monitor the system status, view energy usage, receive fault alerts, and make real-time adjustments to lighting schedules or brightness levels. (Gagliardi et al., 2020)

8. Emergency Response Mode - If the smart camera and sensors detect extreme weather or sudden road hazards, the system will automatically increase the brightness to ensure there is sufficient light. This function helps the drivers navigate more safely and enables instant emergency response. (V. Hima Vamsi et al., 2024)

9. ZigBee/LoRa Communication Network - This system provides low-power wireless communication technologies such as ZigBee or LoRa by connecting the poles and transmitting data reliably over short or long distances. ZigBee is used in dense urban areas, while LoRa is ideal for rural or wide-area coverage. (Gong, 2023)

10. Scalability and Modular Deployment - The system is designed to be flexible and scalable. At start, cities can install the system in high-priority areas and expand it gradually. Its modular nature also allows it to be integrated with future smart city features such as traffic management or pollution monitoring. (Herath et al., 2024)

8.2 Non-Functional Requirements

No.	Non-Functional Requirement	Description
1	**Reliability**	System must perform consistently without failure.
2	**Scalability**	Easily expandable to cover more locations or add new features.
3	**Security**	Prevent unauthorized access and protect data communication.
4	**Energy Efficiency**	Minimize power usage while maintaining safety.
5	**Maintainability**	Easy to monitor, diagnose, and fix faults or issues.

Table 5: Non-Functional Requirements Table

1. Reliability - The system must be reliable, especially during extreme conditions such as in the nighttime or adverse weather. In addition, it must reliably sense movement, control lighting, and provide fault reports without error or delay. A reliable system always ensures public safety is secured at all times. (Omar et al., 2022)

2. **Scalability** - The architecture should be flexible enough to support future expansion. Whether adding more smart street lights in new areas or integrating with other smart systems (like traffic signals or pollution monitors), the system should handle the expansion without the need for complete redesign. (Herath et al., 2024)

3. Security - The control interface of the system should only be accessed by licensed users. Data shared among smart streetlights, gateways, and cloud platforms needs to be encrypted and protected from hacking, unauthorized control, or data manipulation. (Jonathan Weinert, 2019)

4. Energy Efficiency - The system should maximize energy savings by using solar panels, battery backups, and smart dimming features. For example, street lights should only consume the least amount of energy necessary while still ensuring road visibility and safety. (Mirza Salman, 2024)

5. Maintainability - The system should allow for remote fault detection and alert generation to notify maintenance teams instantly. Components such as sensors, lights, or communication modules should be easy to replace or upgrade. This can help to reduce repair time and operational costs. (V. Hima Vamsi et al., 2024)

9.0 System Architecture

The proposed IoT-based Smart Street Light System is designed using a five-layer architecture to ensure clear communication, efficient data processing, and real-time system response. The five-layer architecture of the Smart Street Light System guarantees that information is shared efficiently and system reactions happen in real-time and at the same time ensures the system works as it should and can expand for future smart city applications.

1) Application Layer

At this layer, city authorities and technicians can access using a web dashboard or a mobile application interface. On this platform, people with the right permissions can see how the system is operating, be alerted to any failings as soon as they occur and control the lighting arrangements remotely. (Sharma, 2024)

2) Processing Layer (Data & Control Layer)

Data collected from the street lights is transmitted through the gateway to the IoT cloud platform. This layer is where data is kept, data is analyzed and actions are managed. It will brighten the display, issue an alarm or use emergency lighting if the sensors register changes in the environment.(Sharma, 2024)

3) Network Layer (Communication Layer)

This layer handles wireless communication between street lights and the cloud server. ZigBee or LoRa modules are used to transmit data such as motion detection, visibility changes, or fault status to a local gateway. These communication technologies are selected for their low power consumption and reliability in urban and rural settings. (Sharma, 2024)

4) Perception Layer (Sensor Layer)

This layer includes all the physical devices and sensors installed on the street lights. These sensors feature motion detectors, read the environment (fog, humidity, ambient light) and include smart cameras. Data from the sensors is processed directly on the lighting control board and the LED lights' brightness is adjusted as required. (Sharma, 2024)

5) Power Layer (Energy Source Layer)

Each streetlight is fuelled by solar panels and is supported by an automatic battery switching system. As a result, the process operates continually during power cuts and promotes waste reduction and green living. (Sharma, 2024)

Figure 10 below illustrates the five-layer architecture of the proposed smart street light system, which includes the application, processing, network, perception, and power layers, along with the flow of data and control signals between them.

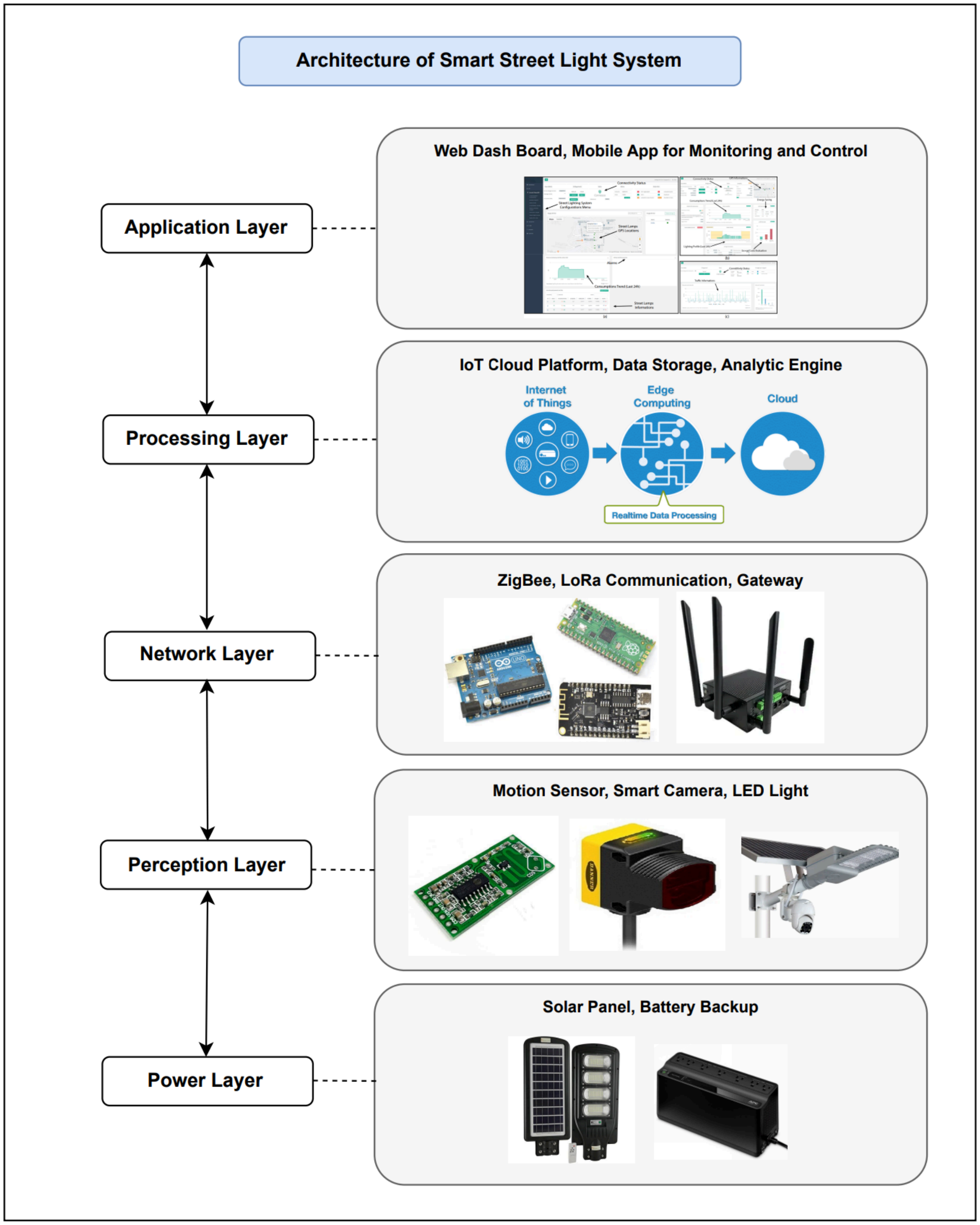


Figure 10: System Architecture of the IoT-Based Smart Street Light System

Meanwhile, **Figure 11** illustrates the infrastructure concept, highlighting the key services, components, and facilities involved in delivering the system's functionality.

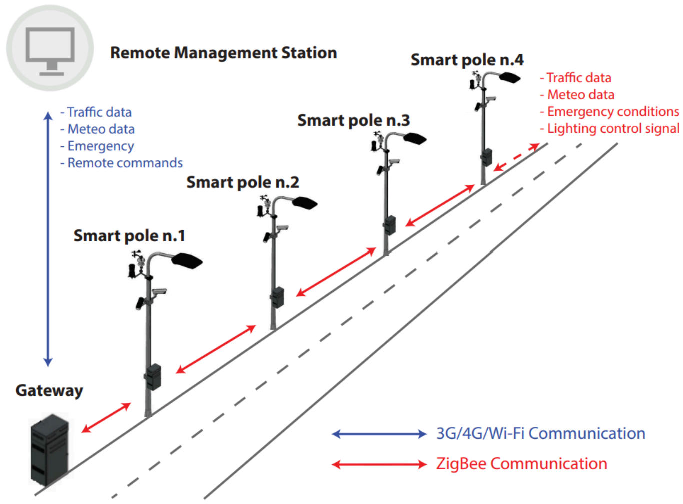


Figure 11: Infrastructure of Smart Street Light System

10.0 Conclusion

In a nutshell, the IoT-based Smart Street Light System presents a cutting-edge solution to the pressing challenges of road safety, energy waste, and inefficiencies caused by traditional street lighting. By integrating motion detection, environmental sensors, AI-driven camera modules, and solar energy with real-time wireless communication, the system is enabled to control the lighting to match actual road and weather conditions. This means lights are only activated when necessary, which not only cuts down on energy use but also enhances visibility during low-light or adverse weather situations.

What makes this solution truly stand out as a "Purple Cow" is its exceptional blend of smart automation, environmental responsiveness, fault detection, and self-sustaining power through solar panels. These features are seldom found together in standard lighting systems, elevating it from merely functional to genuinely extraordinary in the sea of smart infrastructure options.

Moreover, this system aligns with several Sustainable Development Goals (SDGs) like SDG 3 (Good Health and Well-Being), SDG 7 (Affordable and Clean Energy), SDG 9 (Industry, Innovation, and Infrastructure), and SDG 11 (Sustainable Cities and Communities), as it delivers social, environmental, and economic benefits. It not only enhances safety and promotes clean energy usage but also modernizes infrastructure and fosters smarter urban living.

In summary, this system is an innovative, modular, and scalable solution for cities looking to become more intelligent, sustainable, and responsive to the needs of their citizens. It tackles current challenges while being designed to adapt to future smart city advancements.

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