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REPORT PROPOSAL

EPE 4036 PROJECT

Project Title: IoT Enabled Smart Street Lighting System

TRIMESTER 2, SESSION 2022/2023

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The project report is prepared for
Faculty of Engineering
Multimedia University
in partial fulfilment for
Bachelor of Engineering (Hons) Electronics
majoring in Computer

FACULTY OF ENGINEERING
MULTIMEDIA UNIVERSITY
April 2023

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ABSTRACT

The Internet of Things (IoT) has opened new possibilities for enhancing urban infrastructure, and one of the most promising applications is the IoT-enabled smart street lighting system (SSLS). This system utilizes a network of sensors, communication technologies, and data analytics to automate the management of streetlights, optimize energy consumption, and improve the overall quality of lighting. By leveraging real-time data on factors such as traffic patterns, weather conditions, and ambient light levels, the system can adjust the brightness and timing of streetlights to minimize energy waste and ensure the safety of pedestrians and drivers. This paper reviews the key components of IoT-enabled smart street lighting systems, including sensor networks, data analytics platforms, and explores their potential benefits and challenges. In addition, we examine case studies from various cities around the world that have implemented these systems and evaluate their effectiveness in reducing energy consumption and enhancing the liveability of urban areas. The results of a pilot implementation of the system in a selected urban area demonstrate its potential to reduce energy consumption by up to 40%, decrease maintenance costs, and enhance the quality of lighting services. Overall, the proposed IoT-enabled smart street lighting system represents a promising approach towards sustainable and intelligent urban lighting infrastructure.

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Chapter 1 INTRODUCTION

1.1 Background Overview

Smart cities have become a buzzword in the 21st century, with governments and policymakers around the world exploring innovative ways to improve the quality of life of their citizens. One of the most critical elements of a smart city is its street lighting system, which not only provides safety and security to its citizens but also helps reduce energy consumption and maintenance costs. With the advent of the Internet of Things (IoT), the traditional street lighting systems have been replaced by intelligent and connected lighting systems, known as IoT-enabled Smart Street Lighting Systems.

IoT-enabled Smart Street Lighting Systems are equipped with sensors, wireless communication, and data analytics capabilities, which help them to monitor and control the lighting system in real-time. These systems use a variety of sensors, such as motion sensors, ambient light sensors, and occupancy sensors, to detect the presence of pedestrians and vehicles on the street. Based on the data collected by these sensors, the lighting system can adjust the brightness and intensity of the lights to optimize energy consumption and provide better visibility.

One of the main challenges faced by traditional street lighting systems is the waste of energy caused by over-illumination. This problem is especially prevalent in areas with low traffic density, where the lights remain on even when there are no pedestrians or vehicles on the street. IoT-enabled Smart Street Lighting Systems can address this problem by using occupancy sensors to detect the presence of pedestrians and vehicles and adjusting the brightness of the lights accordingly. This not only helps to save energy but also reduces light pollution and the negative impact on the environment.

Another significant advantage of IoT-enabled Smart Street Lighting Systems is the ability to collect and analyse data on energy consumption and performance. These systems use wireless communication to transmit data to a central control system, which can then be used to monitor and manage the lighting system in real-time. This allows the system to identify and rectify faults quickly, reduce maintenance costs, and improve the overall performance of the lighting system.

Moreover, IoT-enabled Smart Street Lighting Systems can be integrated with other smart city systems, such as traffic management systems and surveillance systems, to provide a comprehensive view of the city's operations. For instance, the lighting system can be used to monitor traffic flow and adjust the timing of traffic signals, accordingly, reducing congestion and improving the overall traffic management system.

In addition to the benefits mentioned above, IoT-enabled Smart Street Lighting Systems can also contribute to the safety and security of citizens. With the help of motion sensors and surveillance cameras, the lighting system can detect any suspicious activity on the street and alert the authorities immediately. This not only helps to prevent crimes but also creates a sense of safety and security among the citizens.

In conclusion, IoT-enabled Smart Street Lighting Systems represent a significant leap forward in the evolution of smart cities. These systems have the potential to transform the way we live and work in our cities by improving energy efficiency, reducing maintenance costs, and enhancing safety and security. As the world becomes increasingly urbanized, the importance of smart city technologies, including IoT-enabled Smart Street Lighting Systems, will only continue to grow.

1.2 Problem Statements

Traditional street lighting systems are not efficient and often result in high energy consumption, maintenance costs, and environmental impact. To address these challenges, an IoT-enabled smart street lighting system can be implemented to reduce energy consumption, improve maintenance, and enhance safety. However, the current smart street lighting systems are costly and complex, making it challenging for municipalities to adopt them.

The problem is that existing smart street lighting systems are too expensive and difficult to implement. This limits the ability of municipalities to leverage the potential benefits of the IoT-enabled smart street lighting system. The lack of cost-effective and scalable solutions is a significant barrier to the adoption of the smart street lighting system. Additionally, existing systems often rely on AI-based algorithms to detect and control the lighting, which increases the complexity of the system and raises concerns about privacy and security.

Therefore, there is a need for a cost-effective, scalable, and easy-to-implement IoT-enabled smart street lighting system that does not rely on AI-based algorithms for detection and control. This system should be able to optimize energy consumption, reduce maintenance costs, and enhance safety while preserving the privacy and security of citizens. By addressing these challenges, the proposed smart street lighting system will contribute to building sustainable and liveable cities.

1.3 Project Scope and Objectives

1.3.1 Project Scope

The main objective of this final year project (FYP) is to create a Smart Street Lighting System with IoT technology, which would enable controlling the brightness of the streetlights. The IoT-enabled Smart Street Lighting System project aims to implement an intelligent and energy-efficient lighting system for urban streets, public spaces, and highways. This system will integrate IoT technology, smart sensors, and energy-saving LED lights to provide adaptive and responsive lighting, improving safety, reducing energy consumption, and lowering maintenance costs. The project will cover the design, development, and testing.

The primary objective is to establish an Internet of Things (IoT) system that monitors various factors such as vehicles, pedestrians, and rainfall. This is achieved using sensors like Light Dependent Resistor (LDR) and LED components, which will be discussed later. The entire system can be managed through a central system using a web interface, and a central database is established to retrieve data from the system.

The secondary objective is to include a feature in the system that identifies cracks and potholes on the roads and contributes to safety. This project aims to use solar panels to power the entire system, aligning with Sustainable Development Goals (SDGs) goal number 7, which is to provide access to affordable, reliable, sustainable, and modern energy for everyone. Solar energy is a renewable source that will never be depleted and has no negative environmental impact. This project also provides users with easy access to real-time data monitoring via a web page. Furthermore, the model factors in variables such as the number of vehicles and environmental conditions like rain and night to regulate the brightness of streetlights.

In summary, the project's executive objectives include enabling IoT sensors to transmit and store data using a firebase cloud database through the internet network, implementing a real-time road monitoring web page, and using solar panels as the power source for the entire IoT-enabled Smart Street Lighting System.

Project Activities:

The following activities are involved in the development of the IoT-enabled Smart Street Lighting System:

Project Planning: The first phase of the project involves planning and designing the system's requirements. This includes identifying the objectives, the scope, the stakeholders, and the resources needed to implement the project.

System Design: The second phase involves designing the IoT-enabled Smart Street Lighting System. This includes selecting the appropriate sensors and devices that can be used to monitor and control the streetlights. The system design will also include selecting the communication protocols and network topology.

System Development: The third phase involves developing the IoT-enabled Smart Street Lighting System. This includes developing the software and hardware components of the system. This also involves testing and validating the system's performance to ensure that it meets the project objectives.

Installation and Testing: The fourth phase involves installing the IoT-enabled Smart Street Lighting System and testing its performance. This includes installing the sensors, devices, and the communication infrastructure needed to run the system. It also involves testing the system's performance under various operating conditions.

System Integration: The fifth phase involves integrating the IoT-enabled Smart Street Lighting System with other systems. This includes integrating the system with the city's traffic management system, emergency services, and other public service systems.

What is not included in the Project Scope:

The following activities are not included in the project scope:

Upgrading the existing electrical infrastructure: The project does not involve upgrading the city's electrical infrastructure to accommodate the IoT-enabled Smart Street Lighting System.

Maintenance of the System: The project does not include the maintenance of the system once it is installed. However, the project team will provide documentation on how to maintain the system.

Project Limitations:

The following limitations are associated with the IoT-enabled Smart Street Lighting System:

Cost: The cost of implementing the system can be high, depending on the size of the area covered by the system.

Technical Limitations: The system's performance can be affected by environmental factors such as weather conditions, signal interference, and network congestion.

Security Risks: The IoT-enabled Smart Street Lighting System may be vulnerable to cyber-attacks, and security measures must be put in place to protect the system from such attacks.

Conclusion:

In summary, the IoT-enabled Smart Street Lighting System project involves the development of a smart lighting solution that utilizes IoT technology to monitor and control streetlights. The project scope includes project planning, system design, system development, installation and testing, and system integration. The project's limitations include cost, technical limitations, and security risks.

1.3.2 Project objectives

The main project objectives for an IoT-enabled Smart Street Lighting System are:

1. To reduce energy consumption and carbon footprint by utilizing renewable energy sources and optimizing energy use through intelligent control systems.
2. To enhance public safety by improving visibility and reducing the occurrence of accidents, crime, and vandalism.
3. To improve maintenance and reduce downtime through real-time monitoring and detection of faulty bulbs or damaged fixtures.
4. To collect data on pedestrian and vehicle traffic patterns, weather, air quality, and noise levels to optimize urban planning and improve overall quality of life in the city.
5. To ensure accessibility to all individuals, including those with visual impairments, by utilizing intelligent lighting control technologies and devices.
6. To track energy usage and predict maintenance needs to optimize resource allocation and reduce overall operating costs for the city.
7. To create a lighting system that is aesthetically pleasing and enhances the urban landscape.
8. To foster community engagement and participation in the decision-making process regarding the design and operation of the lighting system.
9. To increase economic growth by creating a safe, secure, and attractive environment for residents and visitors, and by developing a smart lighting system that can attract tourism and improve business activity.
10. To contribute to the wider goals of smart city initiatives by developing a prototype IoT-enabled Smart Street Lighting System that can be scaled up and integrated with other smart city projects and technologies.

Chapter 2 Literature Review

2.1 Introduction

The rapid urbanization of the world's population and the increasing demand for efficient, environmentally friendly, and cost-effective solutions for public services make IoT-enabled smart street lighting systems an important area of interest. These systems have the potential to greatly reduce energy consumption, lower maintenance costs, and provide real-time data for better decision-making. Moreover, smart street lighting can play a vital role in enhancing public safety, reducing light pollution, and contributing to the development of sustainable smart cities.

This literature review will cover several key aspects of IoT-enabled smart street lighting systems. The areas of focus will include:

A review of the most recent research publications on the topic, within the past decade, to identify the current state of knowledge, technological advancements, and existing gaps that need to be addressed.

An analysis of the current academic and industrial applications for smart street lighting systems, with a focus on the specific problems these applications are trying to solve and the effectiveness of the solutions being implemented.

A discussion of the various products and software that have been developed for IoT-enabled smart street lighting systems, their capabilities, and their relevance to the FYP project. This will include an examination of the industrial context of the project and its potential contributions to the field.

A comprehensive exploration of the key challenges and problems that the FYP project aims to address, such as energy efficiency, cost reduction, public safety, light pollution, and integration with other smart city initiatives.

In conclusion, this literature review will provide a comprehensive understanding of the importance, scope, and current state of research and development in the field of IoT-enabled smart street lighting systems. By examining the most recent research, industrial applications, and existing products, this review will establish a solid foundation for the FYP project and help identify the specific problems that the project aims to address and solve.

This chapter presents a literature review of IoT-enabled smart street lighting systems, focusing on various aspects related to these systems. Section 2.2 delves into IoT Technologies for Smart Cities and discusses the critical role that sensors, cloud computing, and data analytics play in Smart Cities. The section explains how these technologies can be used to improve street lighting systems in the present and future.

Section 2.3 covers Smart Street Lighting Systems, describing the systems that focus on energy efficiency, safety, and security. The section discusses the potential benefits of these systems, such as improved lighting quality, reduced energy consumption, and lower maintenance costs, that can be achieved presently.

In Section 2.4, the IoT-Enabled Street Lighting System Architecture is presented, explaining the typical hardware and software components involved in an IoT-enabled Smart Street Lighting System. These systems are currently being implemented in many cities around the world.

In Section 2.5, examples of cities that have adopted Smart Street Lighting Systems are presented. The section discusses their experiences and the advantages and challenges of these systems. It also provides insights into how these systems can enhance the sustainability and liability of urban areas.

Finally, in Section 2.6, problem statements are presented, and solutions to address these problems are proposed, highlighting the need for further research in this area to enhance the present state of IoT-enabled smart street lighting systems. Overall, this chapter presents a comprehensive overview of the current state of research on IoT-enabled smart street lighting systems, with an emphasis on energy efficiency, safety, and security that are relevant presently.

2.2 IoT Technologies for Smart Cities

The Internet of Things (IoT) describes the network of physical objects— “things”— that are embedded with sensors, software, and other technologies for the purpose of connecting and exchanging data with other devices and systems over the internet. These devices range from ordinary household objects to sophisticated industrial tools. With more than 7 billion connected IoT devices today, experts are expecting this number to grow to 10 billion by 2020 and 22 billion by 2025 [1]. Technology is the application of scientific knowledge to the practical aims of human life or, as it is sometimes phrased, to the change and manipulation of the human environment [2]. A smart city is a framework, predominantly composed of Information and Communication Technologies (ICT), to develop, deploy, and promote sustainable development practices to address growing urbanization challenges [3].

The History of Smart Cities: The concept of the smart city can be traced back to the 1960s and 1970s, when the Community Analysis Bureau started using computer databases, cluster analysis and infrared aerial photography to collect data, issue reports and direct resources to the areas that need them most for fighting off potential disasters and reducing poverty. Since then, three different generations of smart cities have emerged.

Smart City 1.0 was led by technology providers. This generation focused on implementing technology in cities despite the municipality's inability to fully understand the possible implications of the technology or the effects it may have on daily life.

In contrast, Smart City 2.0 was led by the cities. In this second generation, forward-thinking leaders within the municipality helped determine the future of the city and how smart technologies and other innovations could be deployed to create this future.

In the third generation, Smart City 3.0, neither the technology providers nor the city leaders take control; instead, a citizen co-creation model is embraced. This most recent adaptation seems to be inspired by issues of equity and a desire to create a smart community with social inclusion.

Vienna, Austria is one of the first cities to adopt this new, third generation model. Within Vienna, a partnership has been established with a local energy company called Wien Energy. As part of this partnership, Vienna included citizens as investors in local solar plants. Vienna has also highlighted citizen engagement in resolving issues such as gender equality and affordable housing.

Vancouver, Canada has also adopted the Smart City 3.0 model by involving 30,000 of its citizens in the co-creation of the Vancouver Greenest City 2020 Action Plan [4]. Smart city technology is increasingly being used to improve public safety, from monitoring areas of high crime to improving emergency preparedness with sensors. For example, smart sensors can be critical components of an early warning system before droughts, floods, landslides, or hurricanes [4]. Examples of smart cities: New York City, Singapore, Tokyo, Dubai.

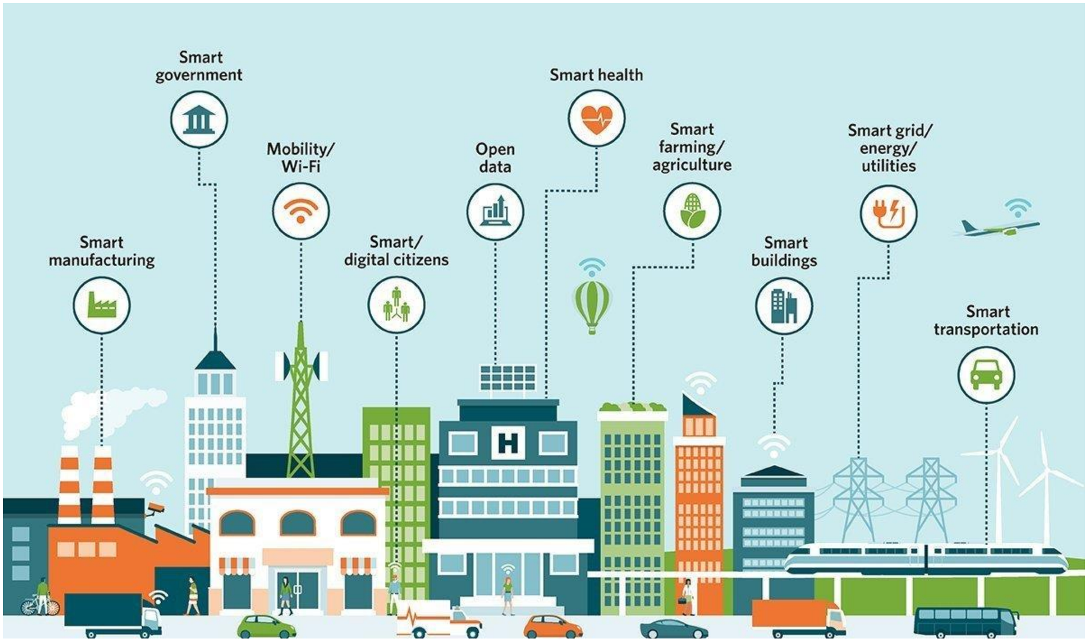


Figure 2. 1: smart city components [4]

In the book [5], The concept of smart cities has gained immense popularity worldwide in recent years due to its potential to transform urban areas into more livable, sustainable, and efficient places. Smart cities use advanced technologies, such as AI, IoT, and big data analytics, to enhance the quality of life of their citizens in various ways, including improving the economy, environment, social and cultural aspects, and governance.

One of the most significant impacts of smart cities is on the economy. Smart transportation systems, for example, can reduce congestion, improve public transportation efficiency, and decrease commuting times, leading to a more productive workforce. In addition, smart infrastructure, such as energy-efficient buildings and smart grids, can help to reduce energy consumption and costs, creating new job opportunities in the clean energy sector.

Smart cities also have a positive impact on the environment. Smart transportation systems can promote the use of electric vehicles, which have a lower carbon footprint than traditional gasoline-powered cars. Similarly, smart waste management systems can optimize waste collection, reduce landfill waste, and promote recycling. Moreover, smart buildings can reduce energy consumption and emissions, making them an excellent way to reduce greenhouse gas emissions and mitigate climate change.

Smart cities also enhance the social and cultural aspects of life. Smart mobility solutions can enhance accessibility for people with disabilities and reduce the digital divide by providing high-speed internet access to underserved communities. Additionally, smart city initiatives can promote cultural heritage and tourism by using technology to enhance the visitor experience.

Lastly, smart cities have a significant impact on governance. Smart city platforms facilitate citizen engagement and participation in decision-making processes. Smart city data analytics can also help to identify areas for improvement in public services and track progress towards achieving policy goals, increasing transparency and accountability in governance. In conclusion, smart cities are transforming urban areas into more livable, sustainable, and efficient places through advanced technology. They have a positive impact on the economy, environment, social and cultural aspects, and governance. Smart cities are an excellent way to address urban challenges and provide solutions for creating more inclusive, resilient, and equitable societies.

In paper [6], emphasizes the crucial role that sensors, cloud computing, and data analytics play in the development and implementation of smart city initiatives. Sensors are a critical component of smart city infrastructure, providing real-time data on a range of environmental, social, and economic factors. For example, sensors can monitor air quality, traffic flow, and pedestrian footfall. This data can be used to optimize city services, improve public safety, and reduce energy consumption. Cloud computing enables the storage and processing of large amounts of data generated by sensors and other devices. Cloud-based platforms can provide secure and scalable infrastructure to handle the massive amounts of data generated by smart city initiatives. They can also enable real-time analysis of data, allowing city officials to make informed decisions quickly and efficiently. Data analytics allows city officials to extract insights from the vast amounts of data generated by smart city initiatives. By using advanced data analytics techniques, city officials can identify patterns, trends, and

correlations in the data. This information can be used to optimize city services, improve resource allocation, and identify areas for improvement. Together, sensors, cloud computing, and data analytics form a powerful ecosystem that can enable smart city initiatives to achieve their full potential. By leveraging these technologies, cities can improve the efficiency, sustainability, and livability of urban environments, while also driving local economic development. For example, smart transportation systems that use sensors to monitor traffic flow can optimize the timing of traffic lights to reduce congestion, while also providing real-time information to drivers on the best routes to take. This can improve commute times, reduce emissions, and enhance the overall transportation experience for residents and visitors. Smart energy systems that use sensors to monitor energy consumption in buildings can identify areas where energy efficiency can be improved. This data can be used to optimize heating, cooling, and lighting systems, reducing energy consumption, and lowering costs for building owners and tenants. Smart waste management systems that use sensors to monitor waste levels in bins and dumpsters can optimize waste collection routes, reducing the amount of time and resources needed for waste collection. This can also reduce the amount of waste that ends up in landfills, improving environmental sustainability. In addition to improving city services, smart city initiatives can also drive local economic development. By leveraging technology to create a more connected and efficient city, smart city initiatives can attract new businesses, create jobs, and improve the quality of life for residents. Overall, the critical role of sensors, cloud computing, and data analytics in smart cities cannot be overstated. By harnessing the power of these technologies, cities can create more livable, sustainable, and economically vibrant urban environments.

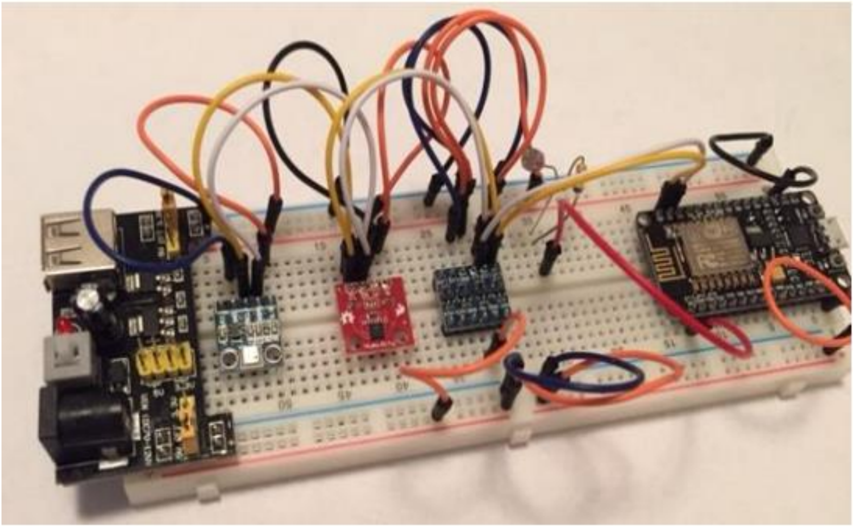


Figure 2. 2: Arduino (IoT) Weather Station [6]

In paper [7], explores the potential of Internet of Things (IoT) technologies to transform urban environments into smarter and more efficient cities. The authors argue that smart cities can be created through the integration of various IoT technologies, which can provide real-time data and feedback to city planners and residents.

The authors begin by defining what they mean by a smart city, which they describe as a city that uses information and communication technologies (ICTs) to enhance the quality and performance of urban services, reduce costs, and improve sustainability. They argue that IoT technologies are particularly well-suited to creating smart cities because they can collect and analyze vast amounts of data in real time, which can be used to optimize city services and improve the quality of life for residents.

The paper provides several examples of how IoT technologies can be applied to different aspects of city life. For instance, the authors describe how sensors can be used to monitor traffic patterns and adjust traffic lights in real time to reduce congestion. They also discuss how smart waste management systems can use sensors to monitor trash levels and optimize waste collection routes to reduce costs and improve efficiency.

The authors acknowledge that there are several challenges to implementing IoT technologies in smart cities, including the need for secure and reliable communication networks, the high cost of implementing IoT infrastructure, and the need for effective data management and analysis. However, they argue that these challenges can be overcome through collaboration between city planners, industry partners, and academic researchers.

Overall, the paper provides a comprehensive overview of the potential of IoT technologies to create smarter and more efficient cities. It highlights the many benefits of these technologies, including improved sustainability, cost savings, and enhanced quality of life for residents. The authors also provide some useful insights into the challenges that need to be overcome to implement IoT technologies in smart cities, which could be valuable for researchers and practitioners working in this area.

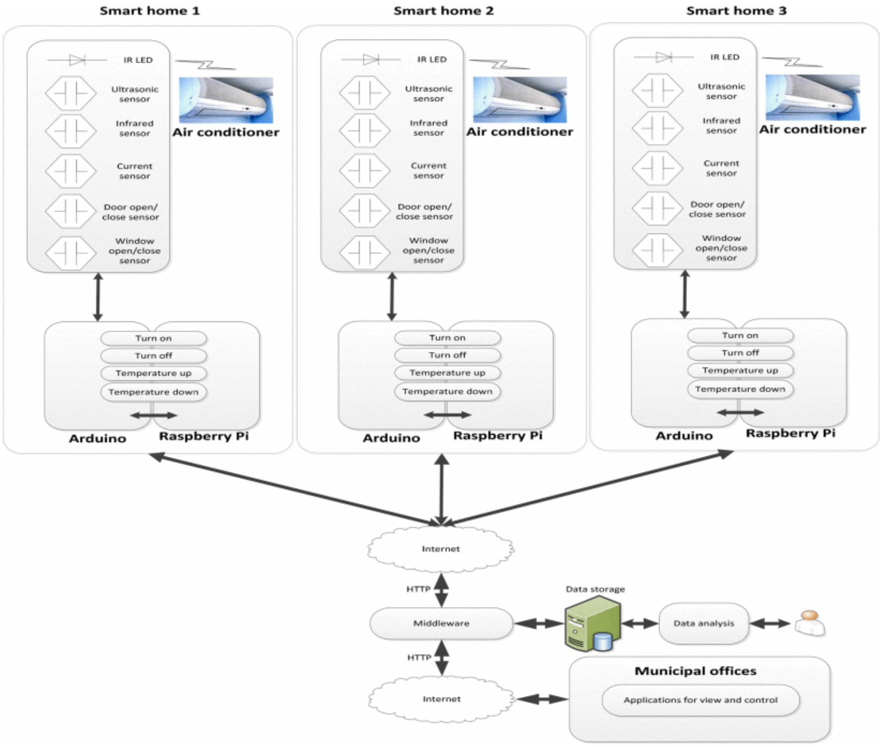


Figure 2. 3: The Architecture of the System that Controls Air Conditioning in the Room [7]

How these technologies can be used to improve street lighting systems in the present and future?

Sensors, cloud computing, and data analytics can be leveraged to improve street lighting systems in the present and future by creating smart street lighting systems that are more efficient, cost-effective, and responsive to the needs of residents. Here are some ways in which these technologies can be used:

Sensors: Smart Street lighting systems can use sensors to detect changes in ambient light levels and adjust the brightness of streetlights accordingly. By using occupancy sensors, smart street lighting systems can also detect the presence of pedestrians or vehicles and adjust lighting levels to enhance safety and reduce energy consumption.

Cloud computing: Smart Street lighting systems can leverage cloud computing to collect and analyze data from sensors in real time. This data can be used to monitor the performance of street lighting systems, detect malfunctions or outages, and optimize energy consumption. For example, cloud-based analytics can identify areas where streetlights can be dimmed or turned off during periods of low usage to reduce energy consumption and save costs.

Data analytics: By analyzing data from sensors and other sources, city officials can gain insights into how people use and interact with the city's infrastructure. For example, data on pedestrian and vehicle traffic can be used to optimize the placement of streetlights and improve public safety. Analytics can also identify areas where streetlights are underused or overused, helping to optimize their placement and improve energy efficiency.

In the future, smart street lighting systems could also be integrated with other smart city technologies, such as traffic management systems, public transportation networks, and emergency response systems. For example, smart street lighting systems could be used to guide emergency responders to the location of an incident or to provide real-time traffic data to drivers to help them avoid congestion.

Overall, by leveraging sensors, cloud computing, and data analytics, smart street lighting systems can help reduce energy consumption, lower maintenance costs, and improve public safety, making urban environments more sustainable, livable, and efficient.

2.3 Smart Street Lighting Systems

This section places a spotlight on Smart Street Lighting Systems, exploring the systems that prioritize energy efficiency, safety, and security. Furthermore, the potential advantages of implementing such systems, including better lighting quality, decreased energy consumption, and lower maintenance costs will be discussed in the section. It is worth noting that these benefits are currently attainable.

A smart streetlight is a public lighting fixture that incorporates technology, such as cameras, light-sensing photocells, and other sensors, to introduce real-time monitoring functionalities. Also referred to as adaptive lighting or intelligent street lighting, this type of lighting system is recognized as a significant step in the development of smart cities [8].

Deploying intelligent lighting not only enables cities to provide suitable street lighting for local conditions but also enhances citizen satisfaction regarding safety and security while yielding substantial savings in power consumption and lighting system upkeep for municipalities. Additionally, the outdoor lighting infrastructure can serve as a foundation for a variety of Internet of Everything (IoE) applications, such as weather, pollution, and traffic monitoring. According to ABI Research, around 20% of light-emitting diodes (LEDs) technology integrated with lighting control systems can be classified as smart during the transition from traditional lighting to LEDs by municipalities. However, ABI predicts that by 2026, central management systems will connect to over two-thirds of new LED streetlight installations [8].

Figure 2. 4: capabilities of smart streetlight [8]

Smart streetlight systems offer several advantages, including energy efficiency through adaptable dimming controls that reduce energy consumption and expenses. They also enhance safety by improving visibility and increasing pedestrian satisfaction. The use of monitoring software reduces repair and maintenance costs, and the reduced carbon emissions and light pollution make them environmentally friendly. The systems also have longer lamp life and shorter response times to outages, ensuring more reliable lighting. They provide insights into actual traffic patterns, enabling better architectural planning, and can generate revenue through leasing poles for digital signage or other services [8].

Smart street lighting provides several advantages, such as significant energy savings, which can be as high as 60% to 80% beyond the savings obtained from LED streetlights conversion, as shown by Smart City Dortmund (Germany). Other benefits include complete control over lighting infrastructure, proactive maintenance, enhanced public safety, reduced light pollution, protection of local flora and fauna, and contribution to the fight against climate change. Additionally, smart street lighting can act as a foundation for Smart City initiatives, thanks to its interconnectivity with different IoT systems. As a result, cities worldwide are increasingly adopting smart street lighting, and investing in smart controllers guarantees preparedness for LED streetlights. Overall, smart street lighting is a practical, sustainable, and cost-effective solution for communities aiming to improve their public lighting infrastructure [9].

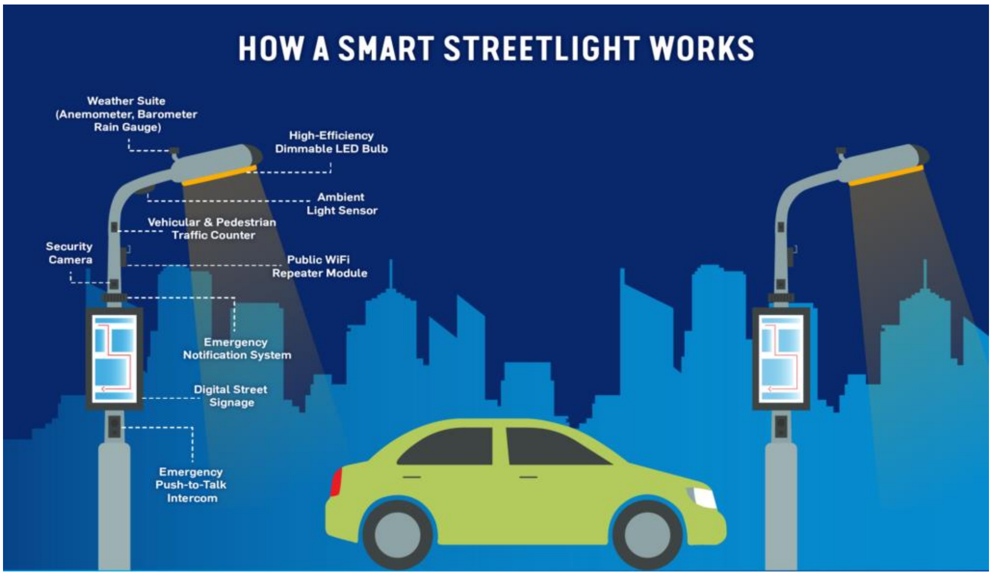


Figure 2. 5: How a smart streetlight works [10]

The increasing population density in urban areas has led to the development of smart city concepts, which aim to enhance the quality of life for citizens while reducing the environmental impact of urbanization. One of the crucial aspects of smart cities is intelligent energy-efficient lighting systems that promote energy conservation, enhance safety and security, and reduce maintenance costs.

The authors in the paper [11], proposed an intelligent energy-efficient streetlight controlling system based on the Internet of Things (IoT) for smart cities. The system was designed to enhance the quality of lighting, reduce energy consumption, and lower maintenance costs. The costs of energy can be reduced immediately to 35% through an intelligent on/off mechanism and targeted progressive dimming and organized way of power consumption, thus making it a sustainable solution for urban areas. Energy efficiency is an essential aspect of smart lighting systems, and the IoT-based approach employed allowed for efficient utilization of energy by monitoring and controlling the lighting system in real-time. This approach enabled the system to automatically adjust the brightness of the lights based on the traffic density, thus reducing energy consumption, and promoting sustainable development. Safety and security are also critical aspects of smart lighting systems, and the proposed system addressed this concern by using motion sensors to detect any unusual activities and alerting the relevant authorities in real-time. This feature enhances the safety of citizens while reducing the likelihood of criminal activities in the area. In addition to energy efficiency, safety, and security, implementing intelligent energy-efficient street lighting systems also provides other potential advantages, including better lighting quality and lower maintenance costs. The study revealed that the proposed system produced better lighting quality than traditional lighting systems, thereby enhancing the visibility of road users and reducing the risk of accidents. Moreover, the use of LED lighting in the proposed system significantly reduced maintenance costs, as LEDs have a longer lifespan than traditional lighting systems. The IoT-based approach also enabled the system to detect faulty lights and provide real-time alerts to maintenance personnel, thus reducing downtime and improving the efficiency of maintenance.

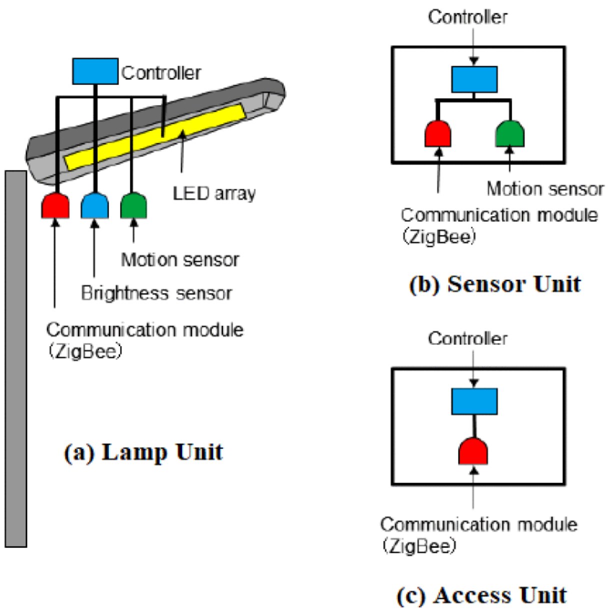


Figure 2. 6: The Components of a Smart Street Light System [11]

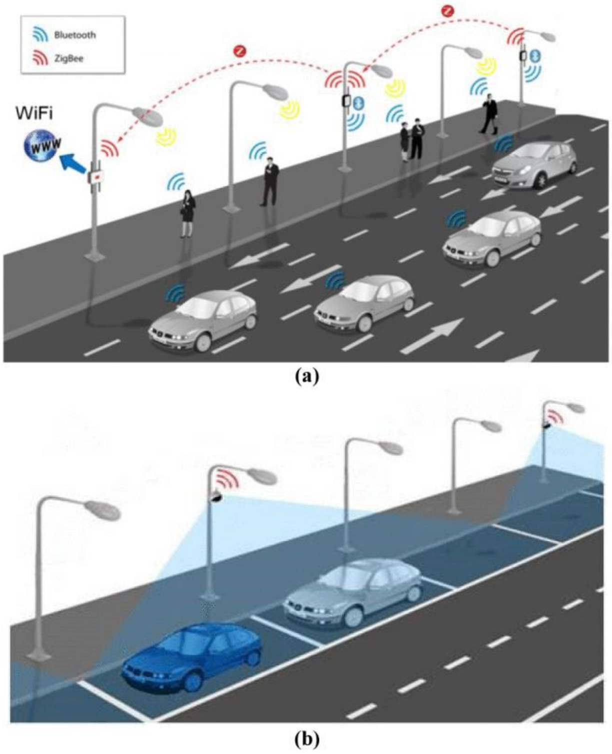


Figure 2. 7: Coverage of light in case of (a) Pedestrians walking or vehicles crossing the lights (b) Vehicles crossing the night [11]

Energy efficiency has become an increasingly important topic in recent years, and smart street lighting systems have emerged as a promising solution to reduce energy consumption and costs.

The author in the paper [12], presents an innovative approach to smart street lighting that utilizes IoT technology to improve energy efficiency and reduce costs. The paper describes the design and implementation of a smart street lighting system in Nagpur, India, which uses sensors to detect the presence of vehicles and pedestrians on the streets and adjusts the brightness of the streetlights accordingly. This approach ensures that lighting is provided only where and when it is needed, reducing energy consumption, and lowering costs. One of the key advantages of this system is its ability to provide better lighting quality. By using sensors to detect the presence of people and vehicles, the system can adjust the brightness of the streetlights in real-time, providing a more comfortable and safer environment for pedestrians and motorists. This is especially important in urban areas, where the quality of street lighting can have a significant impact on public safety. Another significant advantage of this system is its potential to decrease energy consumption. By only providing lighting where and when it is needed, the system reduces the amount of energy required to operate the streetlights, resulting in lower energy bills and a reduced carbon footprint. This is particularly important in cities, where energy costs can be a significant expense for local governments. The paper also highlights the potential cost savings that can be achieved through the implementation of a smart street lighting system, The Table 2.1 depicts the energy consumption analysis of the old lighting system with respect to smart street lighting system (SSL). By reducing energy consumption and lowering maintenance costs, cities can save money and invest in other important infrastructure projects. Furthermore, the use of IoT technology can provide valuable data on lighting usage and maintenance needs, allowing for more efficient and effective management of street lighting systems.

this paper shows huge energy savings of approximately 55% over older/ conventional lighting system without compromising on the quality of life of citizens. This smart lighting creates a safe environment and requires very less operational maintenance too.

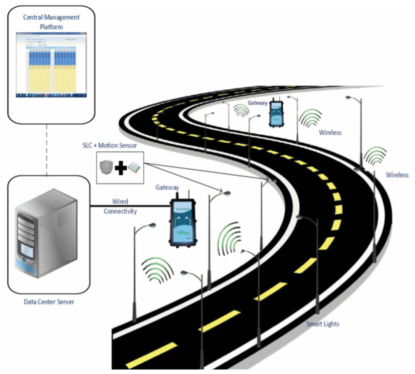


Figure 2. 8: Schematic diagram of SSL in Nagpur smart city [12]

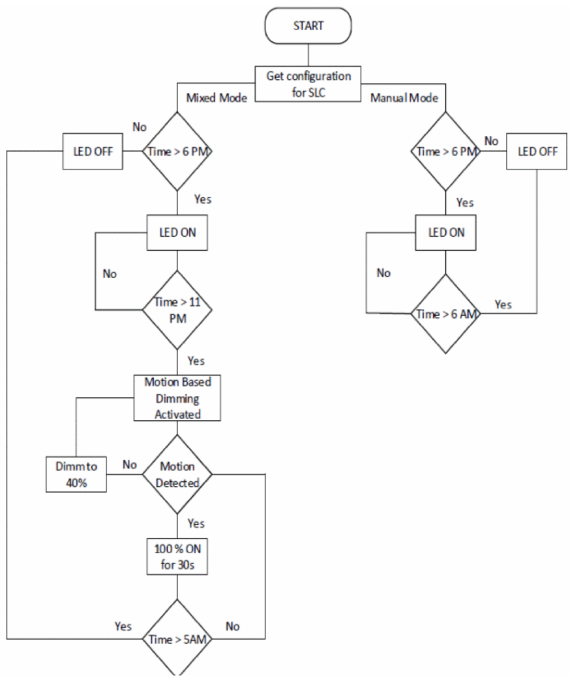


Figure 2. 9: Flow diagram for smart streetlights in Nagpur [12]

	February	*March*
Smart Lights (kWh)	10029	10409
Old Lights (kWh)	22218	24598.5
Savings (kWh)	12189	14189.5
Savings (%)	54.9	57.7

Table 2. 1: Energy Consumption Using Conventional Lighting vs Energy Consumption Using SSL [12]

In the paper in terms of security [13], Motion detection alarm and security systems are widely used in various settings to enhance security and prevent unauthorized access. The design and implementation of such systems have been the subject of numerous studies in the literature.

In their paper, Iyapo et al. presented a motion detection alarm and security system using a PIR sensor and an Arduino microcontroller. The system is designed to detect motion and trigger an alarm to alert the user of any intrusions. The authors evaluated the performance of the system and discussed its potential applications in enhancing security. Other studies have also investigated the use of PIR sensors for motion detection. For example, Garg et al. (2015) developed a PIR-based motion detection system for indoor surveillance. The system was able to detect motion within a range of up to 5 meters and had a low false alarm rate.

Another study by Ahmed and Islam (2017) proposed a motion detection system using a combination of PIR and ultrasonic sensors. The system was designed to detect motion and trigger an alarm in the presence of intruders. The authors evaluated the performance of the system and demonstrated its effectiveness in detecting human presence.

In addition to PIR sensors, other types of sensors have also been used for motion detection. For example, Soni et al. (2014) developed a motion detection system using a combination of infrared and ultrasonic sensors. The system was designed to detect motion and trigger an alarm in the presence of intruders.

Overall, the literature suggests that motion detection alarm and security systems are effective in enhancing security and preventing unauthorized access. The use of PIR sensors has been widely investigated and shown to be effective in detecting motion. The paper by Iyapo et al. contributes to this body of knowledge by presenting a practical and cost-effective approach to implementing a motion detection alarm and security system using readily available hardware components.

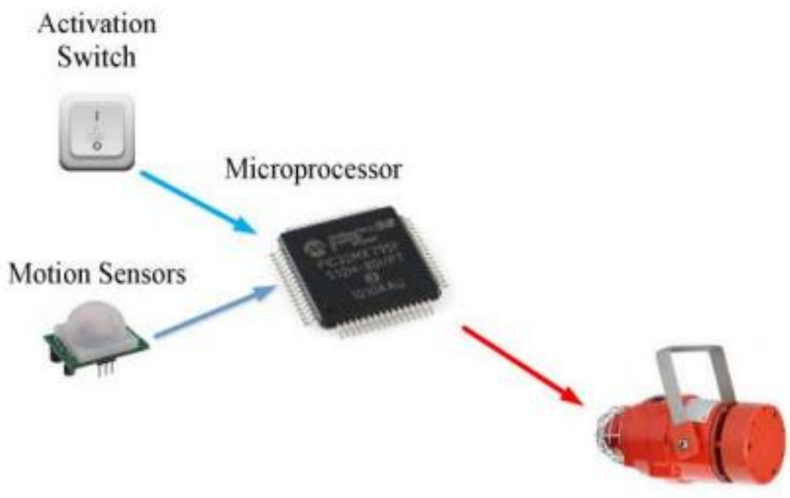


Figure 2. 10: A block diagram of the burglar alarm system [13]

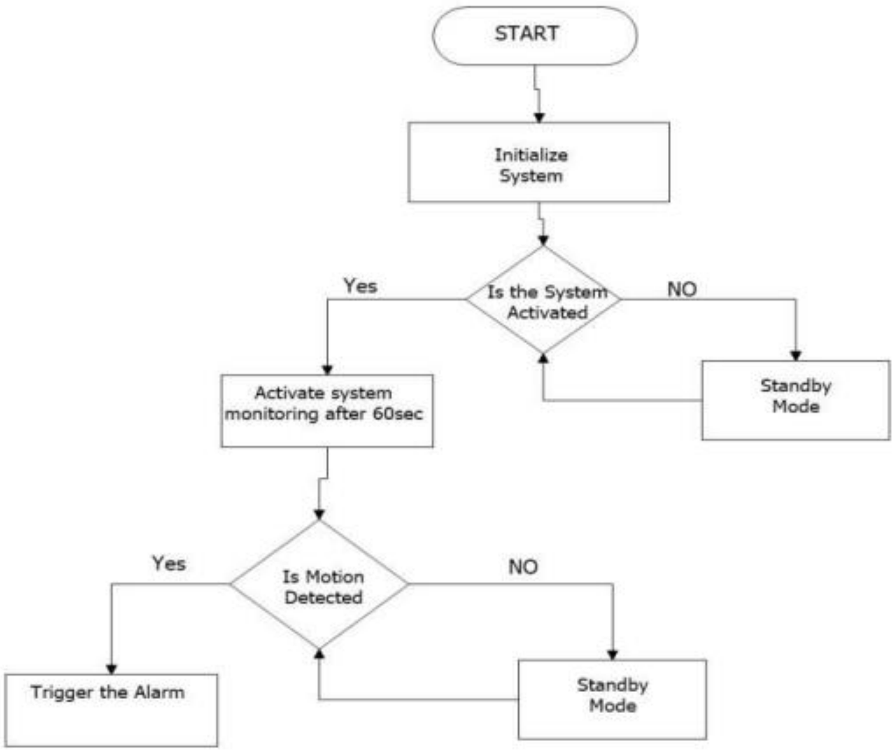


Figure 2. 11: Flowchart for the program in the embedded processor [13]

2.4 IoT-Enabled Street Lighting System Architecture

The Smart Street Light System is a cutting-edge street lighting control system that utilizes Artificial Intelligence (AI) technology to provide automated services. This article will delve into the Smart Street Light System's architecture, operation, applications, benefits, and drawbacks in detail.

The provision of street lighting is a communal service that accounts for a significant proportion of energy resources. Studies reveal that 18% - 38% of power resources are expended in meeting this requirement. Due to the increase in power demand and a substantial gap between supply and demand, problems like power outages and suboptimal usage of high-intensity streetlights in low-traffic areas result in considerable wastage. To optimize energy consumption while ensuring public safety, Smart Street Light systems must be implemented [14].

As previously mentioned, Smart Street Lights rely on the Internet of Things (IoT) to gather diverse electronic data from various physical devices through sensors, and then relay this information to the devices. As a result, significant reductions in street lighting costs can be achieved, and the resulting savings can be allocated towards advancing the nation's development.

The Internet of Things (IoT) is a cutting-edge automation system that leverages Artificial Intelligence (AI) technology to provide automated services. IoT finds application in numerous domains, including but not limited to Smart Cards, Smart Roads, Smart Homes, Smart Kitchens, Smart Parking, and Smart Lighting. The use of IoT technology can address various issues inherent in the existing manual street lighting system, such as connectivity problems, timing issues, and maintenance concerns. By relying on automation, this technology streamlines several manual efforts.

Figure 2.12 provides a visual depiction of Smart Street Lighting, where the brightness of the light intensifies as an object approaches the light pole and diminishes as the object moves away from the pole [14].

Figure 2. 12: Smart Street Light (a) Bright Light (b) Dim Light [14]

In reference [14], outlines the critical components that constitute the basic architecture of the Smart Street Light System, which include LDR input, IR sensor, LED, and UART. LDR is a photo-resistor that works on the principle of photoconductivity. IR sensors detect motion and heat using infrared radiation. LEDs emit light based on surrounding light, and a relay switches the light on/off. UART is a microchip that controls the computer's interface to the attached street light system.

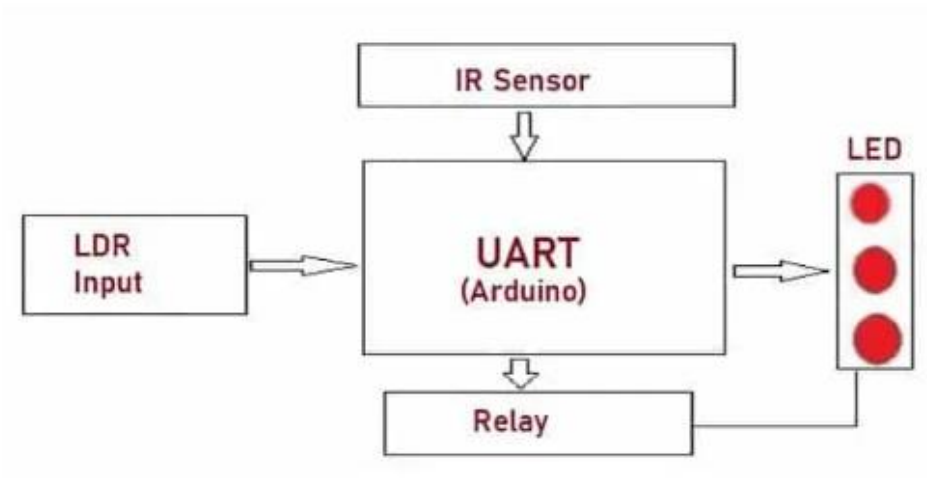


Figure 2. 13: Architecture of Smart Street Light System [14]

The function of the Smart Street Light System was succinctly explained by the researcher. This system substitutes conventional HID lamps with energy-efficient LED lights that emit light directionally and are automatically turned on and off using infrared IR and light sensors. The system also gathers environmental data via a DHT11 temperature-humidity sensor and wirelessly sends it to a base station. The microcontroller adjusts LED intensity in response to the sensor readings, and the system can be controlled manually or automatically. This efficient system is instrumental in reducing energy consumption and regulating power usage.

Figure 2. 14: Working Principle of Smart Street Lighting [14]

Based on [14], The Smart Street Light system has various applications such as equipping it with radar sensors to detect nearby objects and serving as a hub for smart applications, including charging stations for electric vehicles and digital signage. The advantages of the system include automatic switching on and off streetlights, cost-effectiveness, wireless communication, and power-saving, reducing CO2 emissions and light pollution. However, there are also some disadvantages such as high implementation costs, complex troubleshooting in case of defects or repairs, and vulnerability to environmental conditions.

In paper [15], The authors begin by providing an overview of the importance of smart street lighting systems in reducing energy consumption and minimizing the environmental impact of lighting systems. The introduction highlights the potential benefits of smart street lighting systems, such as improved safety, lower costs, and reduced carbon emissions. The authors also introduce the scope and objectives of the paper. The paper presents a conceptual model for a smart street lighting system that incorporates the proposed design and implementation guidelines. The authors discuss the different components of the proposed system, including the sensors, communication system, and control system. They also provide a detailed explanation of the data analytics and monitoring systems that can be used to improve the performance of the system. The author discussed the Recommended Hardware for Smart Street Lighting System: The NodeMCU ESP32 as shown in Fig. 2.15 is chosen as the microcontroller of the Smart Street Lighting System. Light Dependent Resistor *(LDR)* as shown in Fig. 2.16 is light sensitive and is mainly used to detect day or night. Infrared Sensor Module (IR) as shown in Fig. 2.17 is used widely for obstacle/object detection systems. 5mm Super Bright White LED: The researchers have selected a white LED as the light bulb option for the proposed system as shown in Fig. 2.18. Resistors*:* The researchers have chosen 220 ohm and lk ohm resistors for the LED and LDR as shown in Fig. 2.19.the paper provides a detailed analysis of the potential benefits of smart street lighting systems. The authors discuss how smart street lighting systems can reduce energy consumption, lower costs, and minimize the environmental impact of lighting systems. The authors also highlight the potential benefits of smart street lighting systems in improving safety and reducing crime.

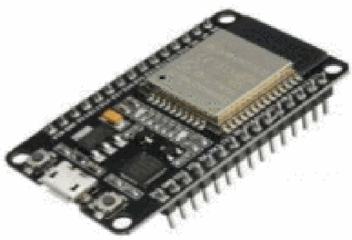


Figure 2. 15: NodeMCU ESP32 [15]

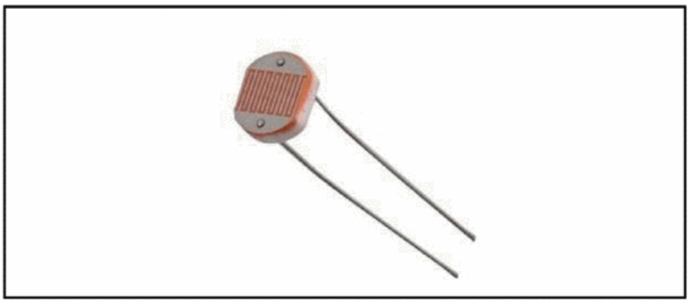


Figure 2. 16: Light Dependent Resistor (LDR) [15]

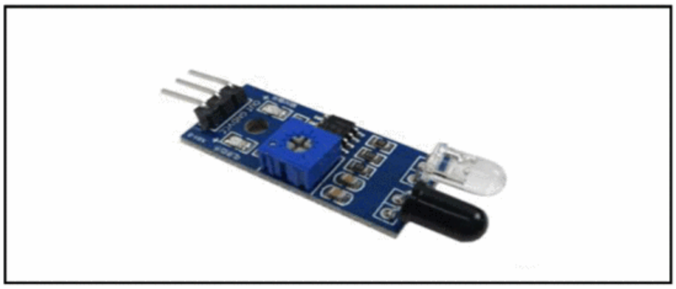


Figure 2. 17: Infrared Sensor Module (IR) [15]

Figure 2. 18: White LED [15]

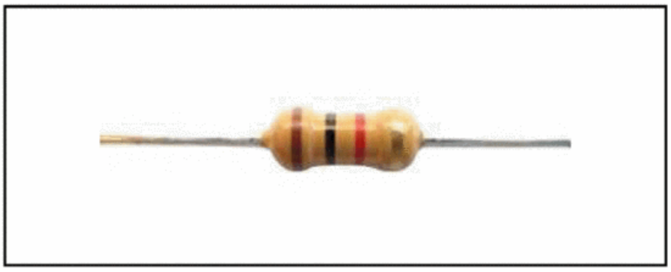


Figure 2. 19: lk ohm resistors [15]

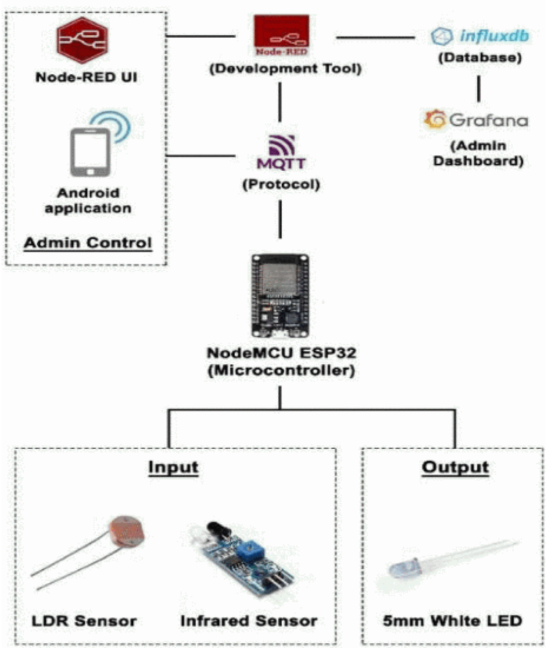


Figure 2. 20: System architecture diagram [15]

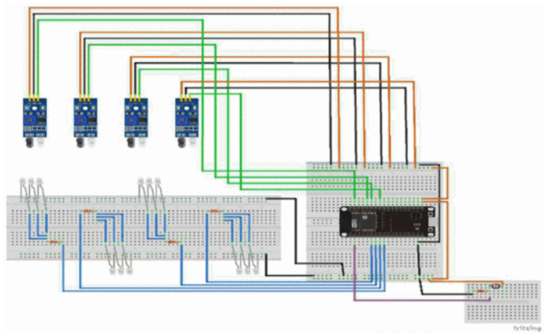


Figure 2. 21: Circuit diagram of the prototype [15]

Figure 2. 22: Prototyping model of the proposed system [15]

In paper [16], The use of smart street lighting systems has gained attention in recent years due to their potential to improve energy efficiency and enhance safety for pedestrians and drivers. The integration of Internet of Things (IoT) technology in these systems has enabled real-time monitoring and control of lighting infrastructure. One such technology that has gained popularity in this context is the Narrowband Internet of Things (NB-IoT), which is designed for low-power, wide-area networks and has the potential to support large-scale deployments of smart city applications. In their paper, Chen et al. (2018) proposed a smart street lighting system based on NB-IoT technology. The system comprises various sensors for monitoring ambient light, pedestrian and vehicular traffic, and weather conditions. The collected data is transmitted to a central server through the NB-IoT network, where it is processed and used to dynamically adjust the street lighting intensity. The authors also proposed a network architecture and protocol for the system. The architecture includes three layers: the perception layer, the network layer, and the application layer. The perception layer comprises the sensors that collect data on ambient light, traffic flow, and weather conditions. The network layer includes the NB-IoT network, which is used to transmit the data to the central server. The application layer comprises the software that processes the data and controls the street lighting infrastructure. The authors also proposed a protocol for the system, which includes several key components, such as the sensor data collection and transmission, the server data processing and control, and the street lighting infrastructure control. The protocol is designed to support real-time monitoring and control of the lighting infrastructure, enabling efficient energy consumption, and enhancing safety for pedestrians and drivers. The system adopts China Telecom's NB-IoT network. The single light acquisition and control terminal takes the STM32L431 as the main control MCU shown in Fig. 2.28 and uses Huawei's open ecosystem management platform-OceanConnect- based on loT, cloud computing and big data technologies shown in Fig.2.29. In conclusion, the system architecture proposed by Chen et al. (2018) demonstrates the potential of NB-IoT technology in smart street lighting systems. The integration of various sensors and the use of network architecture and protocol enables efficient data collection and processing, as well as real-time monitoring and control of the lighting infrastructure. This system has the potential to significantly improve the efficiency and safety of urban infrastructure and is a promising area for future research and development.

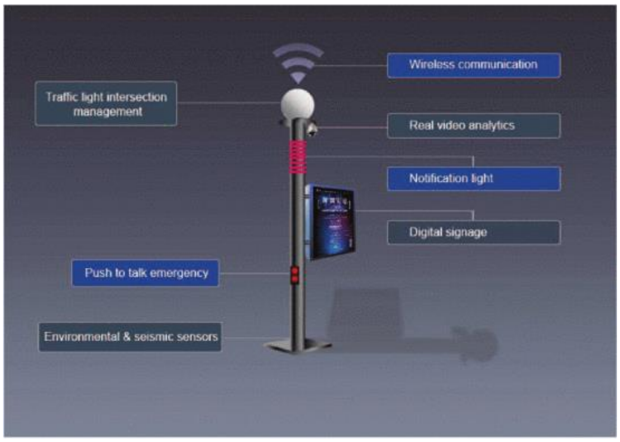


Figure 2. 23: The modern smart streetlight [16]

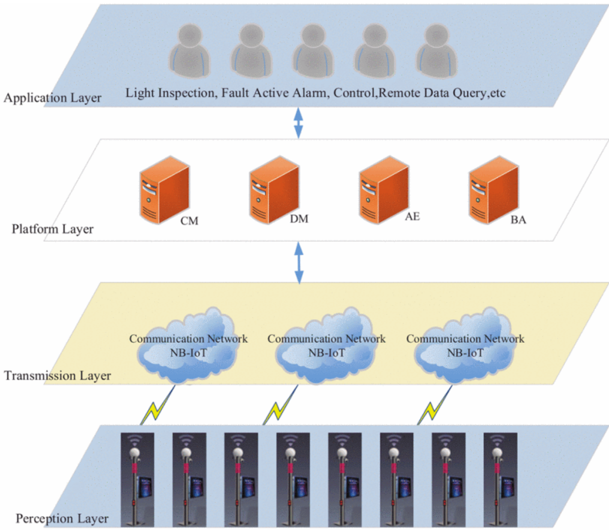


Figure 2. 24: The architecture of the smart street lighting system [16]

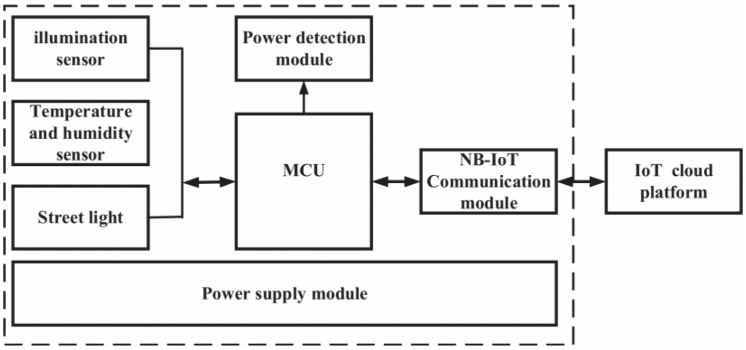


Figure 2. 25: The architecture of terminal [16]

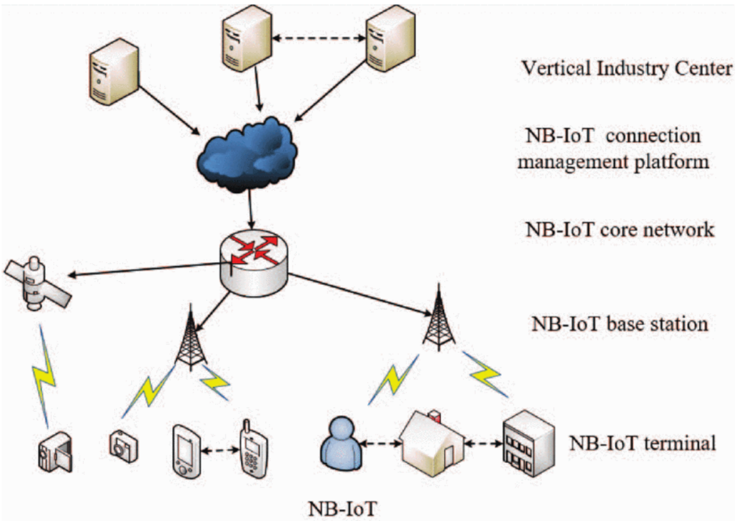


Figure 2. 26: The network architecture of NB-IoT [16]

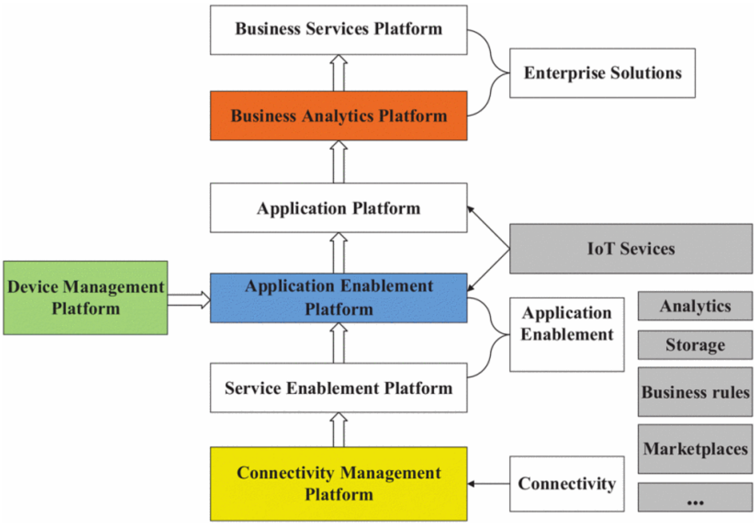


Figure 2. 27: The architecture of IoT platform [16]

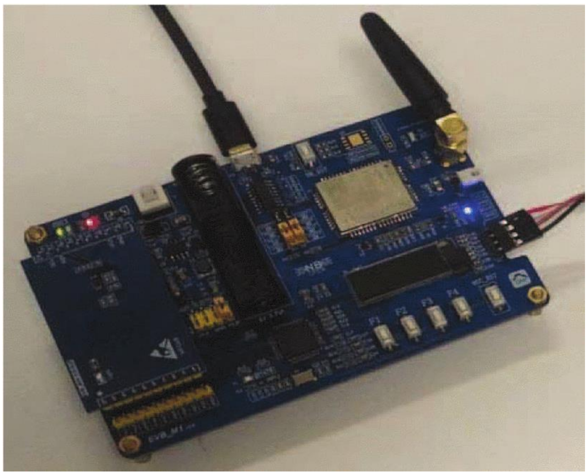
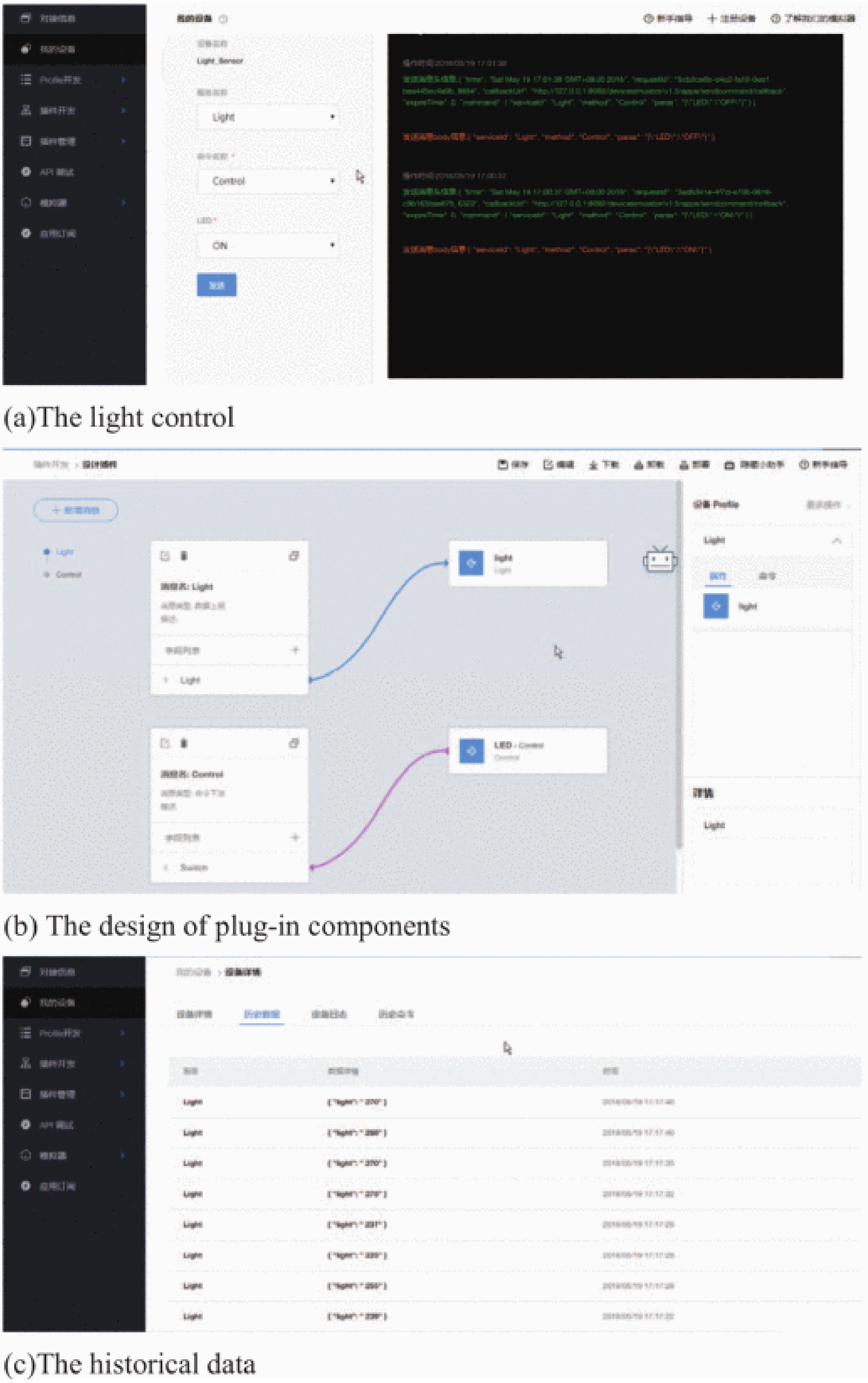


Figure 2. 28: The single light monitoring and control terminal [16]



(a)The light control

(b) The design of plug-in components

(c)The historical data

Figure 2. 29: The OceanConnect platform [16]

In paper [17], The paper proposes a smart street lighting system that utilizes Internet of Things (IoT) technology to optimize energy consumption and reduce costs. The system is designed to automatically turn on and off the streetlights based on the ambient light conditions and provides real-time monitoring. The proposed streetlight control and automation system uses smart LED lights, LDR, relays, a microcontroller, a temperature & humidity sensor, and a cost-effective Wi-Fi module. A single system can control 4-8 lights and monitor the temperature and humidity of the area. The LDR controls the intensity of LED lights based on the amount of light it detects, resulting in low power consumption and efficient illumination. The system can be monitored and controlled through a web interface, and a central database fetches data from individual systems. The system is cost-effective and sustainable, making it a practical solution for modern cities. The paper highlights the advantages of the proposed system over the traditional street lighting systems. The traditional systems often operate based on a fixed schedule and may waste energy by keeping the lights on during the day or when there is no traffic. The proposed system, on the other hand, adapts to ambient light conditions to provide optimal illumination while minimizing energy consumption.

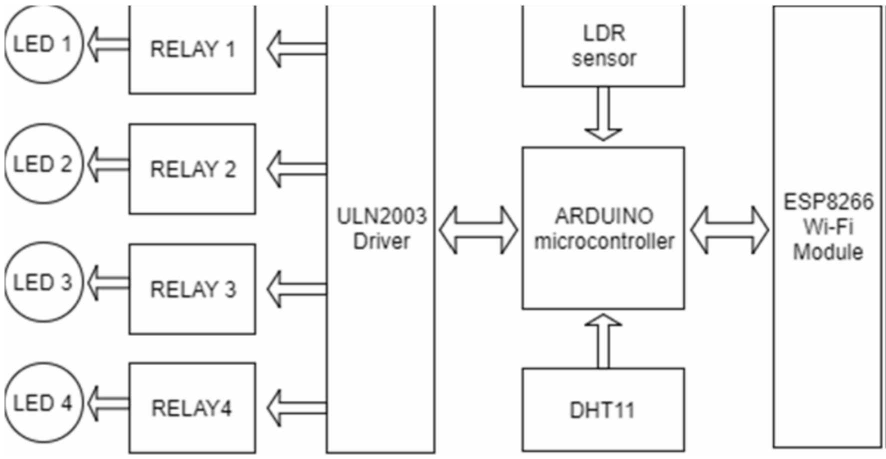


Figure 2. 30: System architecture [17]

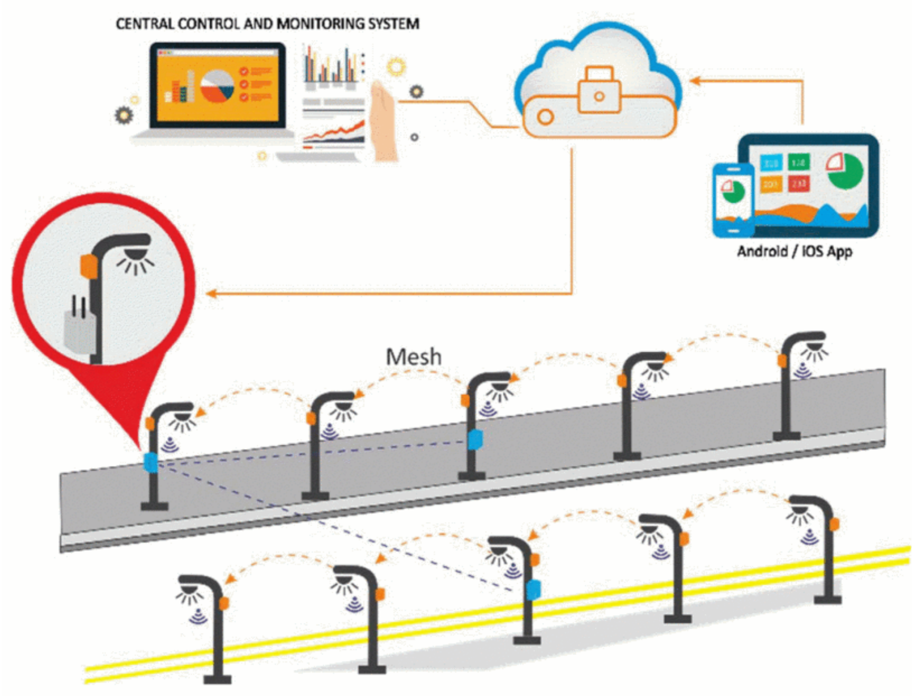


Figure 2. 31: Prototype of system [17]

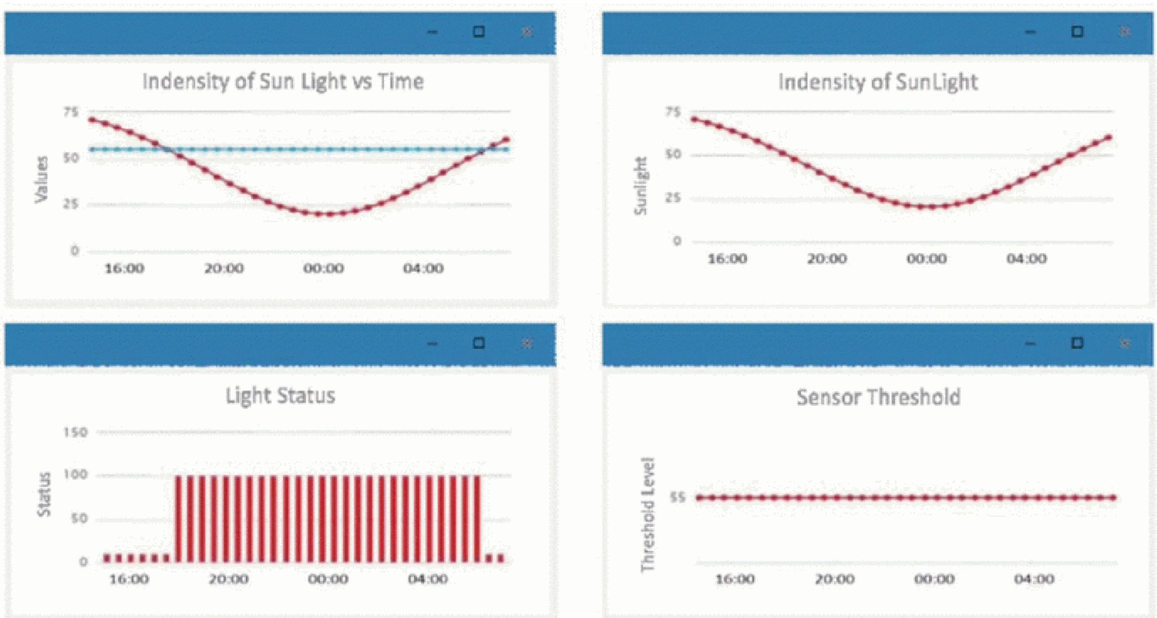


Figure 2. 32: Status dashboard [17]

in paper [18], The paper presents a system that aims to save energy and reduce the negative impacts of the current lighting system in public places. The system uses a microcontroller and sensors to automatically turn on/off streetlights based on the presence of objects or people. The system also allows a person to control the light using Bluetooth on a mobile phone and detects fire or accidents using DHT-11sensor and raises an alarm. The paper describes the design and implementation of the system and shows that it works with accuracy and efficiency. The paper claims that the system can reduce energy consumption by 30% and improve the safety and security of public places. The system consists of a microcontroller, distance sensors (Ultrasonic Sensor), a DHT-11 sensor, and Bluetooth Sensor. The microcontroller is the brain of the system that controls the switching of the streetlights. The distance sensors are attached to the streetlights and detect the presence of objects or people in a nearby area. A DHT-11 sensor that measures temperature and humidity and sends the data to a cloud server. The system works as follows: When the distance sensors sense an object or a person in a nearby area, they send a signal to the microcontroller, which then turns on the corresponding streetlight. When the distance sensors do not sense any object or person in a nearby area for a certain period, they send another signal to the microcontroller, which then turns off the corresponding streetlight. The microcontroller also receives commands from a Bluetooth module that allows a person to switch on/off the streetlight using his mobile phone. The DHT-11 sensor monitors the temperature and humidity of the environment and sends the data to a cloud server. If the temperature or humidity exceeds a certain threshold, indicating a fire or an accident, the sensor sends an alert to the cloud server, which then notifies the authorities or emergency services.

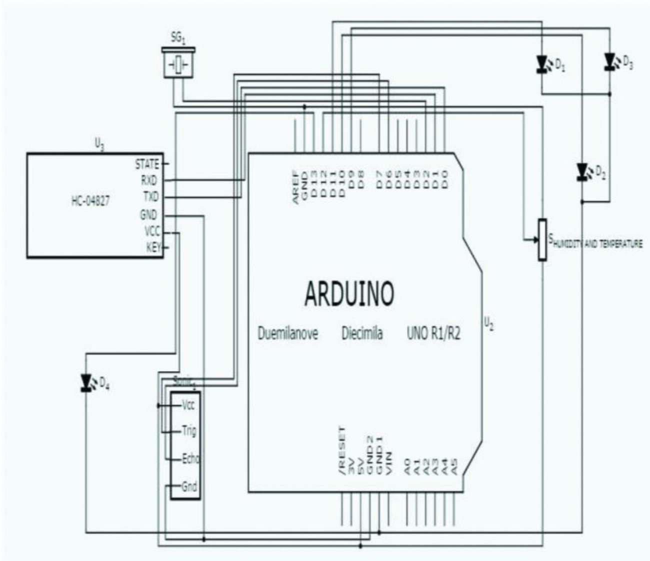


Figure 2. 33: Architecture of The Street Light Control System [18]

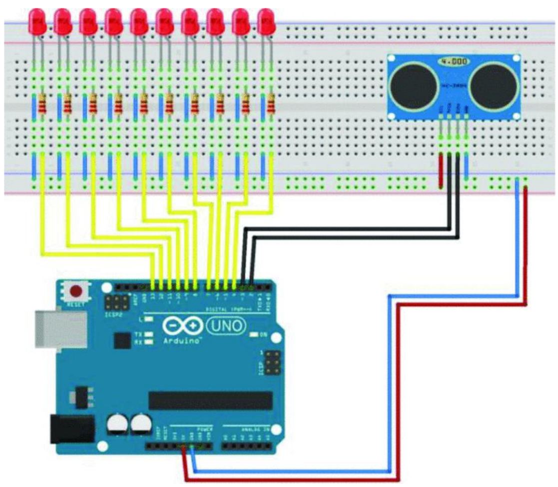


Figure 2. 34: Implementation of Distance Sensor Module (Ultrasonic Sensor) [18]

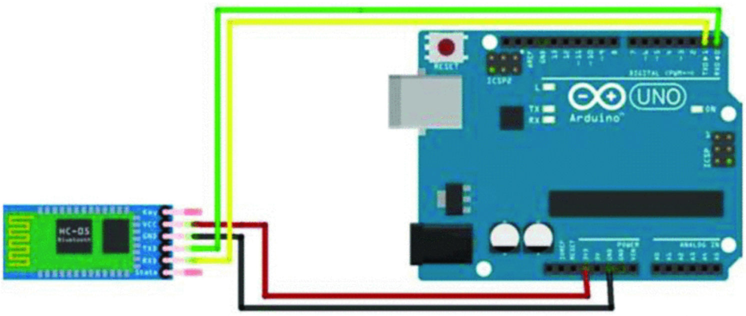


Figure 2. 35: Implementation of Bluetooth Sensor Module [18]

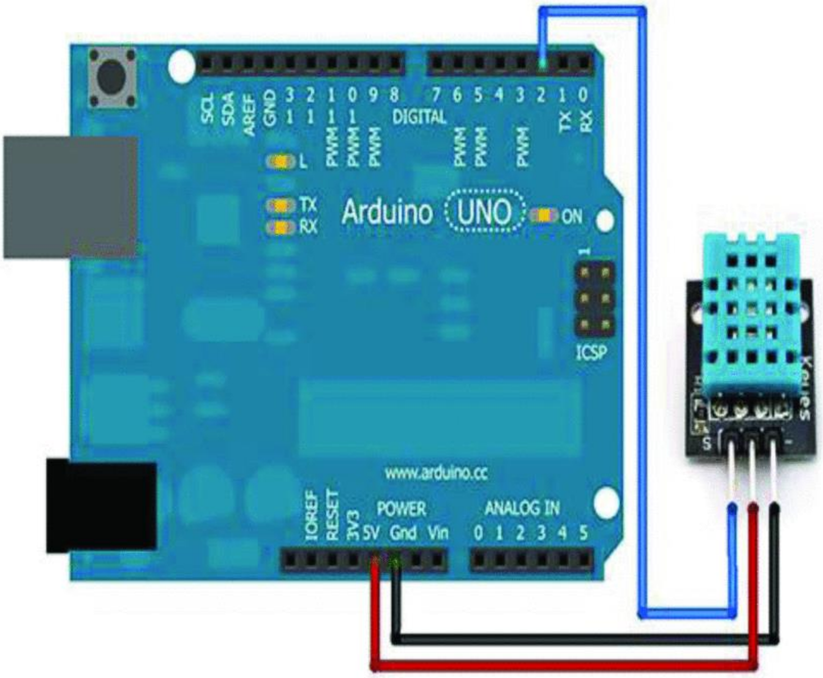


Figure 2. 36: Implementation of DHT-11 Sensor Module [18]

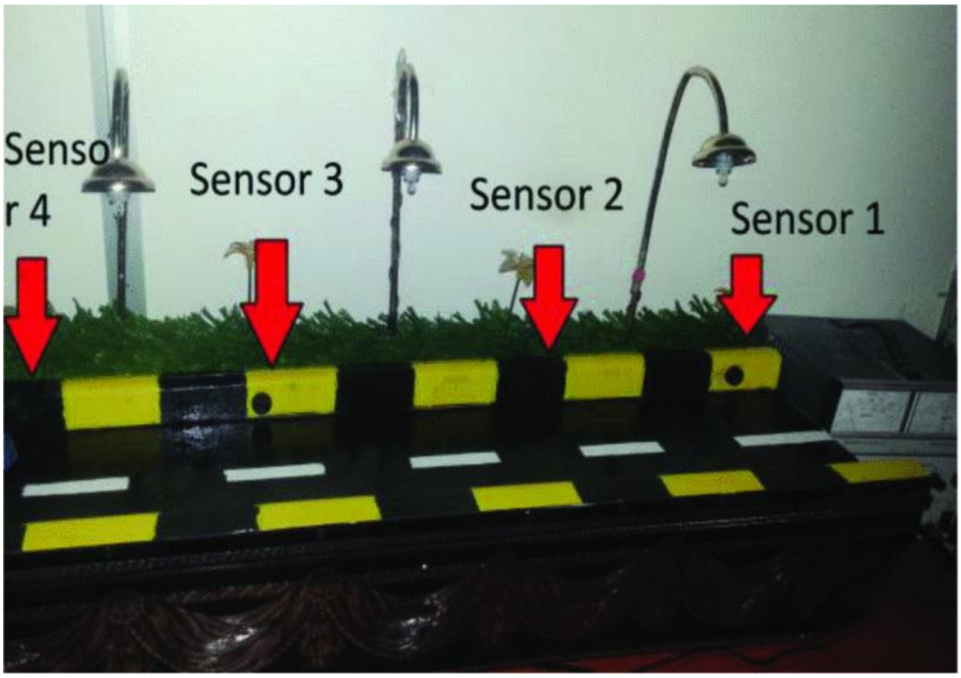


Figure 2. 37: Prototype of system [18]

In paper [19], presents a low-cost environment monitoring system using IoT. The system integrates four subsystems: a smart waste management system, a smart street lighting system, a smart pollution monitoring system, and a density-based traffic controlling system. The paper claims that the system can improve the intelligent and energy-efficient aspects of a city.

The smart street lighting system is one of the subsystems of the paper. It aims to reduce energy consumption and improve road safety by using sensors and IoT technology. The system can detect the presence of vehicles and pedestrians and adjust the brightness of the streetlights accordingly. The system can also monitor the status of the streetlights. The system can be controlled and managed remotely using a web-based application.

The author describes a smart street lighting system that uses solar energy, sensors, and IoT to save power and improve efficiency. The system consists of a solar panel, a battery, an Arduino, a light-dependent resistor (LDR), an Infra-Red (IR) sensor, a power LED circuit, and a Blynk App. The solar panel converts sunlight into electricity and charges the battery. The battery powers the Arduino, which controls the LDR and the IR sensor. The LDR detects the daylight level, and the IR sensor detects the movement of vehicles or pedestrians. The power LED circuit adjusts the brightness of the streetlights according to the sensor inputs. The Blynk App displays the status of the streets on a web browser and allows remote monitoring and control of the streetlights. The author claims that this system can overcome the limitations of conventional street light systems.

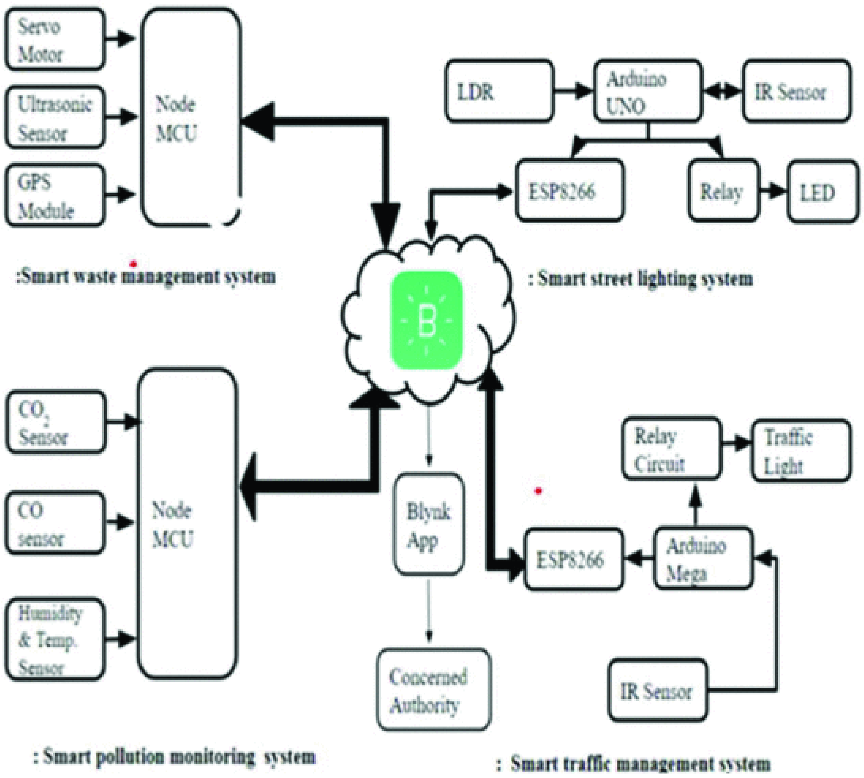


Figure 2. 38: Block Diagram of IoT based smart city prototype [19]

Figure 2. 39: Prototype of the smart street light controller (a) in presence of light (b) under poor lighting conditions [19]

In the research article [20], the paper provides an overview of the Smart Lighting System (SLS) and reviews different IoT-enabled communication protocols that can be used to realize the SLS in the context of a smart city. The paper also analyzes different usage scenarios for IoT-enabled indoor and outdoor SLS and provides an analysis of the power consumption. The paper discusses how Internet-of-Things (IoT) can be used to improve the lighting system of a city, which is one of the core sectors of a smart city. The paper introduces the concept of Smart Lighting System (SLS), which is a lighting system that is integrated with advanced sensors and communication channels to achieve an autonomous and more efficient lighting management system. The paper reviews different IoT-enabled communication protocols that can be used to realize the SLS in the context of a smart city, such as ZigBee, 6LOWPAN, and Jennet-IP. The paper also analyses different usage scenarios for IoT-enabled indoor and outdoor SLS, such as smart home, smart office, smart street, and smart parking lot. The paper provides an analysis of the power consumption of different SLS scenarios and shows that IoT-enabled smart lighting systems can reduce power consumption up to 33.33% in both indoor and outdoor settings. The paper concludes by discussing the future research directions in SLS in the smart city, such as security, privacy, scalability, and interoperability.

Scenarios	No of nodes in rated intensity	No of nodes in 60% intensity	No of nodes in 40% intensity	Power consumed in rated intensity (kWh)	Power consumed in 60% intensity (kWh)	Power consumed in 40% intensity (kWh)	Total power consumed (kWh)
Clear	20	20	20	38.4	23.04	15.36	76.8
Mixed	30	30	-	57.6	34.56	-	92.16
Overcast	40	20	-	76.8	23.04	-	99.84
Conventional Lighting	60	-	-	115.2	-	-	115.2

Table 2. 2: Power consumption calculation for a typical office floor using smart indoor lighting system (sils) [20]

Scenarios	Total no of nodes (n)	Average Operating time (hr)	Time in fully on state during operation (hr)	Total power consumption (kWh)
Conventional Lighting	100	12	12	288
Light Sensor	100	10	10	240
Motion Sensor	100	12	9.6	230.4
Light and Motion Sensor	100	10	8	192

Table 2. 3: Power consumption calculation for a street lighting scenario using smart outdoor lighting system (sols) [20]

In paper [21], The paper presents an IoT-based street lighting system that mitigates the challenges of electrical energy consumption and maintenance costs by automating the system. The proposed system will run entirely on solar power systems and as objects get closer, the lights will become brighter and reduce the brightness as objects travel away. The system also cleans the lights once every week by servo motor. To determine whether the light needs repairing, replacing, or not, an ESP8266 Wi-Fi module is used that transmits a report from the location to a central server. The system also can measure air pollutant gases like Nitrogen Dioxide (NO2), Sulphur Dioxide (SO2), etc., by using the MQ-135 sensors and sending the information to the web server for further analysis of air quality.

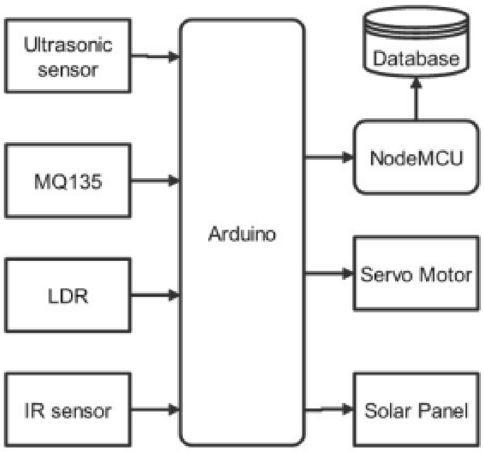


Figure 2. 40: The proposed system's architecture [21]

Figure 2. 41: List of Components (a) Arduino Uno (b) NodeMCU (c) Ultrasonic Sensor (d) Servo Motor (e) LDR (f) MQ-135 Sensor (g) IR Sensor [21]

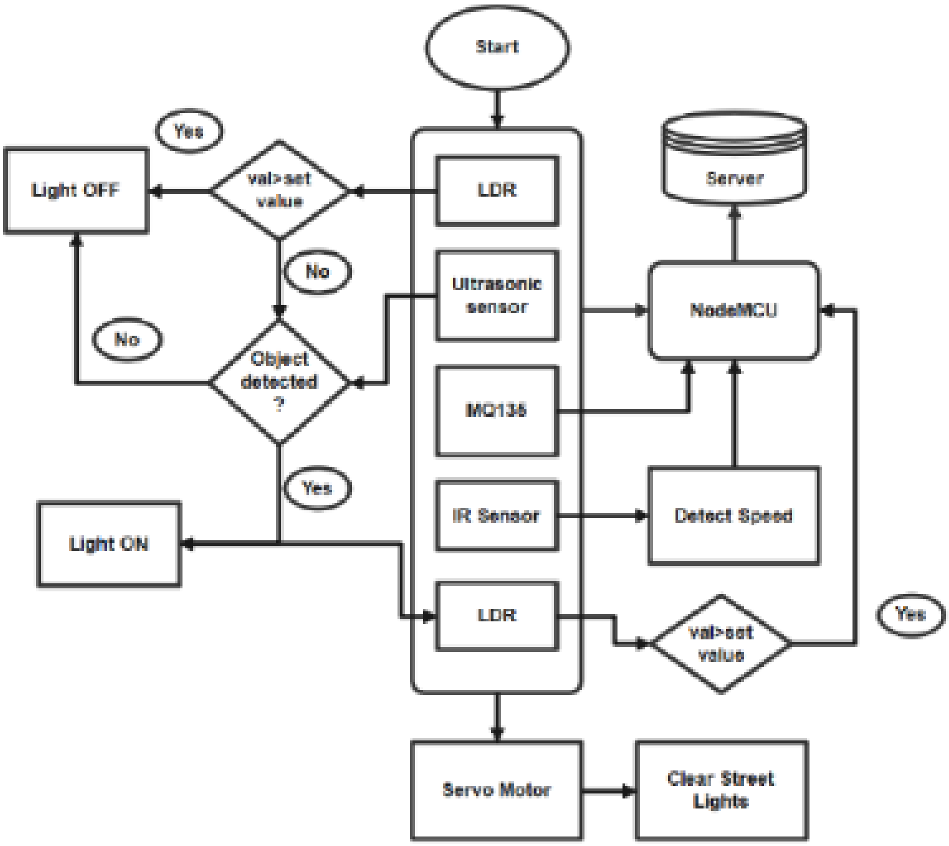


Figure 2. 42: The proposed system's flowchart [21]

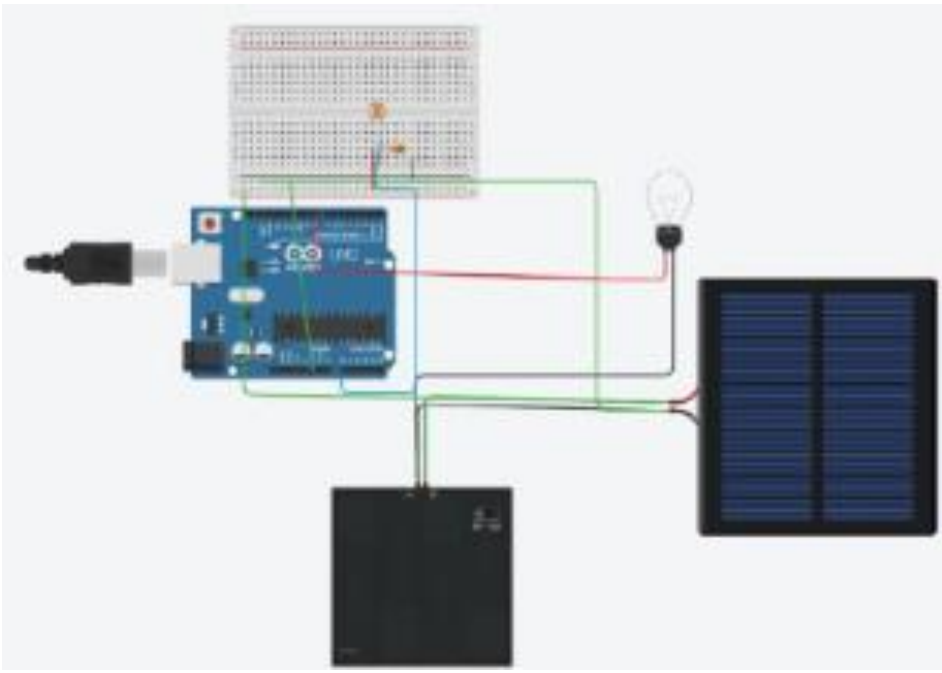


Figure 2. 43: Connecting solar panel with Arduino Uno [21]

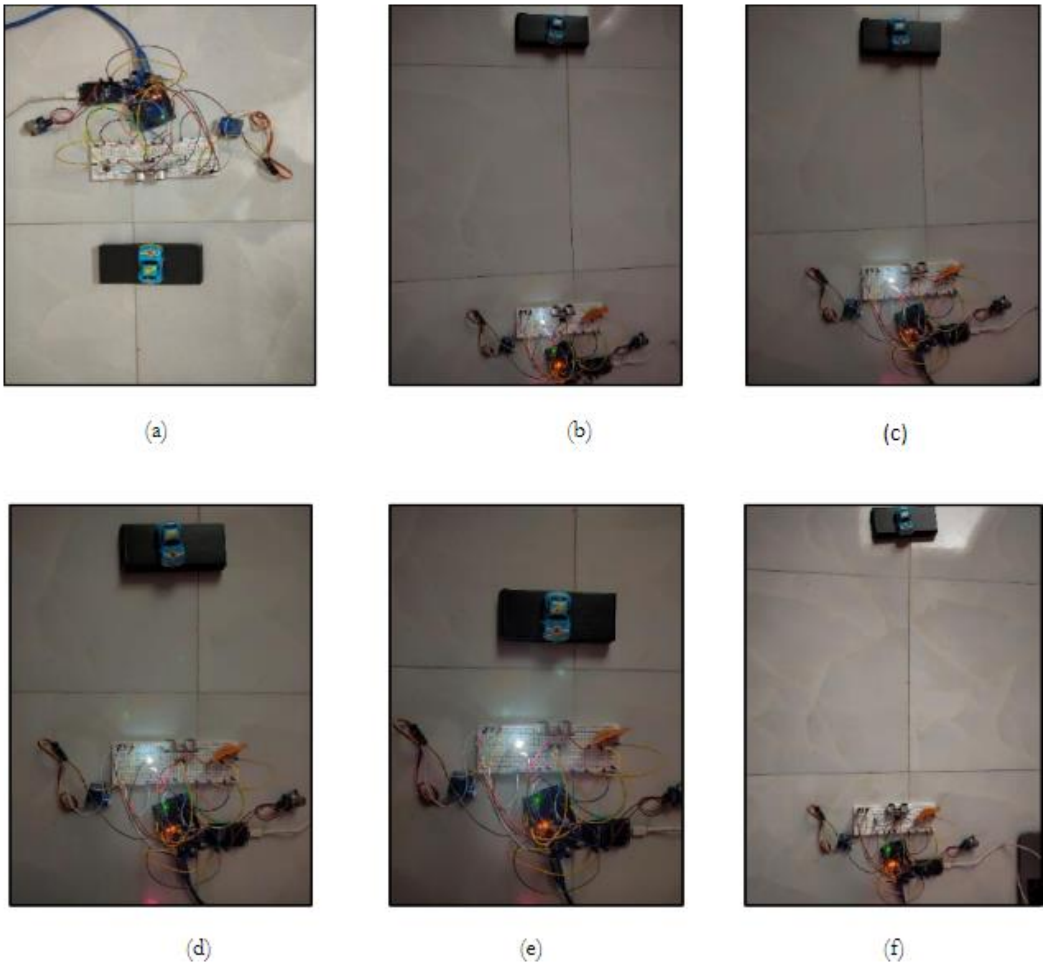


Figure 2. 44: Light's brightness is (a) 0 (turn off) on the day (b) 50 when the object's distance is 50 units away at night (c) 100 when the object's distance is 35 units away at night (d) 180 when the object's distance is 25 units away at night (e) 255 when the object's distance is 15 units away at night (f) when the object's distance is far away at night [21]

2.5 Examples of cities that have adopted Smart Street Lighting Systems

A smart city might seem easy in theory, but how do you get from a smart city plan to the actual implementation of smart solutions? And where does smart street lighting come into play? Street lighting could be considered the backbone of any city and the ideal infrastructure for smart cities everywhere. Why?

Street light poles are omnipresent. They have a high density, and they are connected to the power grid. And even more power is available since cities are upgrading the street lighting grid to LED lamps that are much more energy efficient. There have been experiments where even EV charging plugs have been attached directly to the street lighting poles, without any civil works.

What encourages smart city deployments is the fact that due to the lamp-level control, the smart streetlight networks are continuously under power, even during the day. This means there is many other sensors and IoT devices that can be supplied from the smart street lighting grid, using any available communication, and being coordinated through the street lighting software or other IoT platforms.

By installing additional sensors on the streetlamps, the common issues the cities are facing at the present day could be addressed. The smart poles can accommodate EV charging stations, sensors for smart parking and traffic, environmental sensors, CCTV cameras, or microphones. As the lighting system comes with a safe and secure connection, all of that (and more) can be easily integrated into the power grid [22].

In paper [23], The paper discusses the experiences and the advantages and challenges of the case study of Sheffield's smart streetlight system. The paper reports that Sheffield has about 68,000 streetlights that consume about 22 GWh of electricity per year and cost about £2.4 million in maintenance. The paper proposes four different smart lighting schemes that can reduce the energy consumption and cost of streetlights by using sensors, timers, dimmers, and IoT technology. The paper uses a streetlight simulator called StreetlightSim to compare the performance of each scheme based on different criteria, such as energy savings, carbon emissions, light pollution, and payback period.

The paper presents the advantages and challenges of each scheme as follows:

- Conventional scheme: This is the current scheme used by Sheffield, where streetlights are turned on at dusk and turned off at dawn. This scheme has the advantage of providing constant illumination throughout the night, but it has the disadvantage of wasting energy and money when there is no need for lighting.
- Dynadimmer scheme: This is a scheme where streetlights are dimmed by a certain percentage at different times of the night, depending on the expected traffic and pedestrian activity. This scheme has the advantage of saving energy and money by adjusting the lighting level according to the demand, but it has the disadvantage of requiring additional hardware and software to implement the dimming function.
- Chronosense scheme: This is a scheme where streetlights are turned on and off based on a timer that follows the seasonal changes in sunrise and sunset times. This scheme has the advantage of saving energy and money by avoiding unnecessary lighting during daylight hours, but it has the disadvantage of not being responsive to weather conditions or unexpected events that may affect visibility.
- Part-Night scheme: This is a scheme where streetlights are turned off completely for a certain period of time during the night, usually between midnight and 5 am. This scheme has the advantage of saving

energy and money by eliminating lighting when there is low traffic and pedestrian activity, but it has the disadvantage of compromising public safety and well-being by creating dark zones.

The paper also discusses the experiences of other cities that have implemented smart streetlight systems, such as Doncaster and Edinburgh. The paper highlights the benefits and challenges that these cities have faced, such as reducing energy consumption and carbon emissions, improving public satisfaction and security, enabling new applications and services, facing technical issues and vandalism, complying with regulations and standards, and engaging with stakeholders and communities.

The article [24], is about a new lighting technology that Norway is testing to reduce energy consumption and carbon footprint on remote and less-travelled roads. The technology uses radar sensors fitted on light poles to detect when the road is in use and adjusts the brightness of the LED lights accordingly. When the road is empty, the lights dim to 20 percent brightness, and when a car, bike or pedestrian approaches, the lights brighten to 100 percent. The article claims that this system saves 2,100 kWH per week along a five-mile stretch of a highway near Hole, Norway. The article also mentions that Norway is a leader in sustainable innovation, especially in promoting electric and hybrid vehicles.

In [25], It is an article that ranks the top 10 cities in the world based on their deployment of connected streetlights. Connected streetlights are streetlights that can communicate with each other and with other devices via the internet and can be equipped with various sensors to monitor traffic or provide Wi-Fi access to citizens.

According to the article, the top 10 cities are:

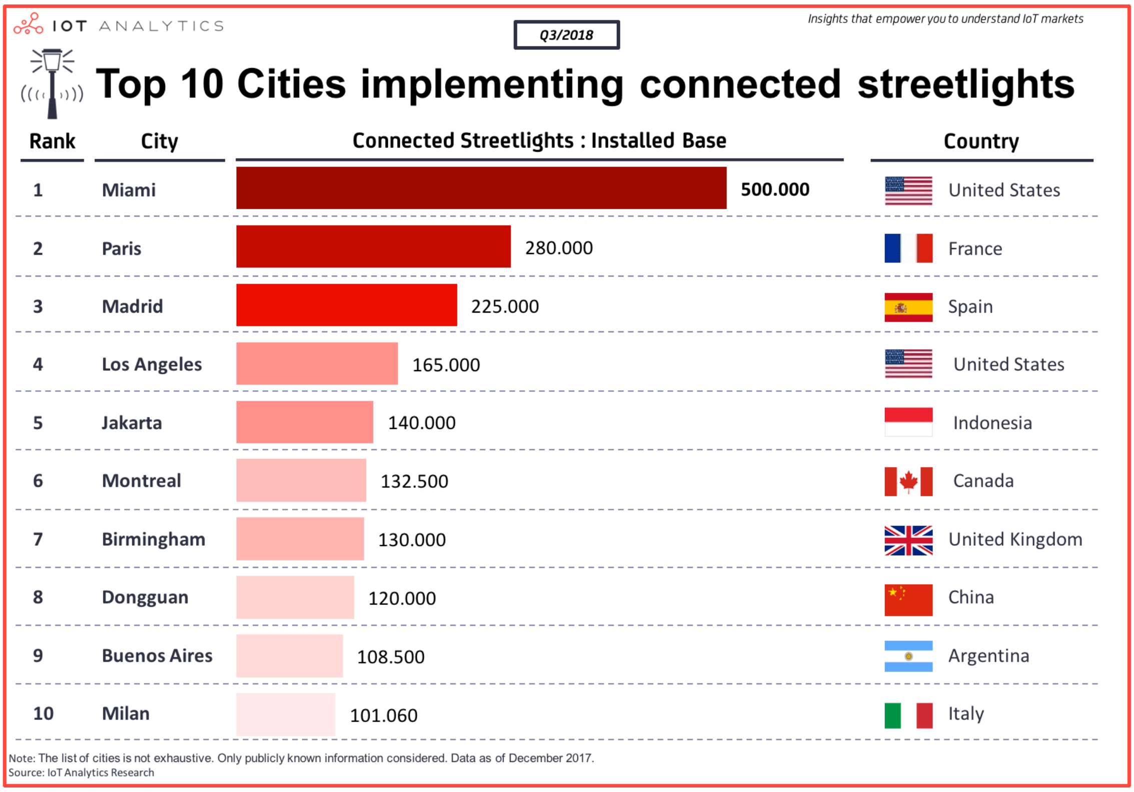


Figure 2. 45: Top 10 Cities Implementing Connected Streetlights [25]

The article also mentions some of the benefits and challenges of implementing connected streetlights, such as energy savings, carbon emission reduction, smart city applications, security issues, and interoperability standards.

2.6 Problem statements and problem-solving

Street lighting is one of the essential public services that provide safety and comfort for citizens during the night hours. However, street lighting also consumes a significant amount of energy and requires regular maintenance. According to Smart Energy International [26], street lighting consumes 19% of global electricity generation and costs approximately 40 billion US dollars per year. Moreover, conventional street lighting systems are often inefficient and wasteful, as they do not consider environmental factors such as light levels, traffic flows, weather conditions, etc. Therefore, there is a need for a smart street lighting system that can optimize energy consumption and reduce operational costs by using information and communication technologies (ICT) such as the Internet of Things (IoT).

The main problems that are faced by the current street lighting systems are:

- High energy consumption: Street lights are often switched on and off at fixed times regardless of the actual lighting needs, resulting in unnecessary energy usage and carbon emissions.
- High maintenance costs: Street lights are prone to failures and damages due to various reasons such as weather, vandalism, accidents, etc. However, detecting and repairing these faults is often a manual and time-consuming process that involves human labour and transportation costs.
- Low user satisfaction: Street lights are often too bright or too dim for pedestrians and drivers, causing glare, discomfort, or insufficient visibility. Moreover, streetlights are sometimes out of service for long periods of time due to undetected faults or delayed repairs, compromising the safety and security of the public.

To address these problems, an IoT-enabled smart street lighting system can be proposed that can:

- Monitor and control the streetlights remotely and dynamically using sensors, actuators, wireless communication modules, and cloud computing platforms.
- Adjust the brightness of the streetlights according to the real-time data on light levels, traffic flows, weather conditions, etc.
- Provide feedback and suggestions to the users and operators on the performance and status of the street lighting system using web or mobile applications.

The benefits of implementing an IoT-enabled smart street lighting system are:

- ✓ Energy saving: By dimming or switching off the streetlights when they are not needed or when it is sufficient natural light, energy consumption, and carbon emissions can be reduced significantly. According to a case study of Sheffield [23], smart street lighting can save up to 50% of energy compared to conventional street lighting.
- ✓ Cost reduction: By detecting and repairing the faults and damages of the streetlights promptly and efficiently, the maintenance costs can be lowered substantially. Moreover, by using LED lamps instead of HPS lamps, the lifetime and durability of the streetlights can be improved, reducing the replacement costs.
- ✓ User satisfaction: By providing optimal lighting conditions for pedestrians and drivers according to their preferences and needs, comfort and visibility can be enhanced. Moreover, by ensuring reliable and continuous service of the street lighting system, the safety, and security of the public can be improved.

CHAPTER 3: Methodology

3.1 Introduction:

In this chapter, the research methodology of the project will be further elaborated into 7 sections. Section 3.2 discusses the building block diagram of IoT Enabled Smart Street Lighting System is listed out. Section 3.3 covers the technology components used to build up the hardware system. Section 3.4 describes the development of hardware and software. Section 3.5 stated the flow chart of the system. Additionally, section 3.6 describes the project activities and the time allocated for each of them. In section 3.7, the description of the project deliverables in accordance with the targeted milestones is mentioned. In section 3.8, the projected timeline for the final year project is shown in the Gantt chart. Finally, section 3.9 stated the project costing analysis and the total estimated budget for the proposed project.

3.2 Building Blocks of IoT-Enabled Smart Street Lighting System

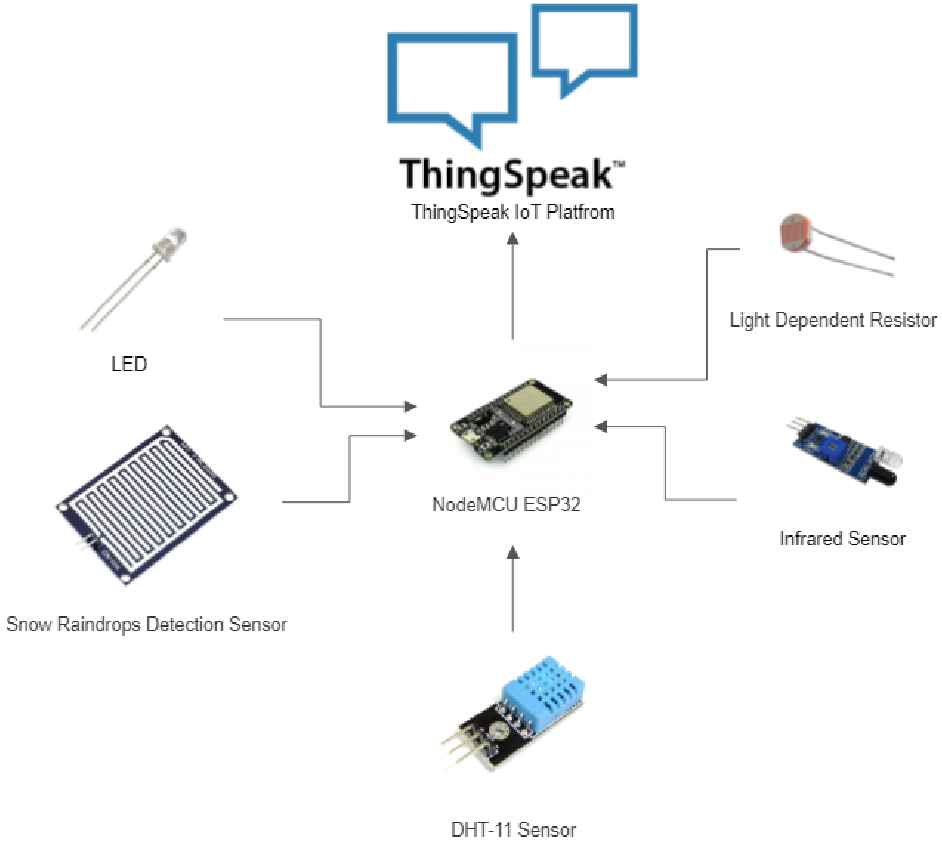


Figure 3. 1: The building blocks of the IoT Smart Street Lighting System

3.3 Technology Components

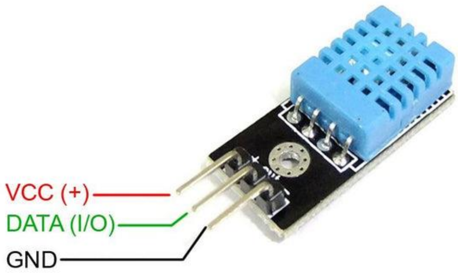


Figure 3. 2: DHT-11 Sensor

DHT-11 is a commonly used digital temperature and humidity sensor that provides accurate measurements in various applications. It is a low-cost sensor that is easy to use. Here is some information about the DHT-11 presented in a table format:

Property	**Description**
Sensor Type	Digital temperature and humidity sensor
Operating Voltage	3.3V - 5V
Temperature Measurement	Range: 0°C - 50°C (32°F - 122°F) Accuracy: ±2°C
Humidity Measurement	Range: 20% - 90% RH Accuracy: ±5% RH
Communication Protocol	One-wire digital interface (Single-bus)
Output Format	8-bit data for temperature and 8-bit data for humidity
Sampling Rate	Approximately 1 reading per second
Size	12mm x 15.5mm (0.47" x 0.61")
Pin Configuration	VCC, DATA, NC (No Connection), GND
Recommended Pull-up Resistor	5k ohms
Library Support	Available libraries for various microcontrollers (Arduino, etc.)

Table 3. 1: DHT-11 Specifications

The DHT-11 sensor utilizes a one-wire digital interface, meaning it requires only a single data pin to communicate with a microcontroller or other devices. It provides temperature and humidity readings as 8-bit data, which can be easily interpreted by the receiving device. The sensor has a relatively low sampling rate of approximately 1 reading per second.

In terms of measurements, the DHT-11 has a temperature measurement range of 0°C to 50°C (32°F to 122°F) with an accuracy of ±2°C. It also measures relative humidity in the range of 20% to 90% RH with an accuracy of ±5% RH. These specifications make it suitable for monitoring environmental conditions in various indoor applications.

The sensor operates at a voltage between 3.3V and 5V, making it compatible with most microcontrollers and development boards. It requires a pull-up resistor of around 5k ohms connected between the data line and the supply voltage to ensure reliable communication.

To use the DHT-11 sensor, you can find libraries and example codes readily available for popular platforms such as Arduino, Raspberry Pi, and other microcontrollers. These libraries simplify the process of reading data from the sensor and integrating it into your projects.

In summary, the DHT-11 is an affordable and versatile digital temperature and humidity sensor. Its ease of use, low cost, and availability of libraries make it a popular choice for applications that require temperature and humidity monitoring.

Infrared proximity sensor or IR Sensor

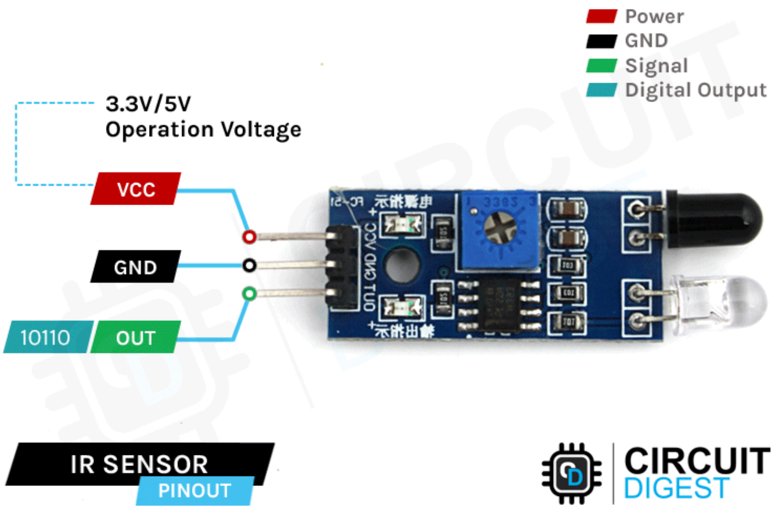


Figure 3. 3: Infrared proximity sensor or IR Sensor

An infrared proximity sensor, also known as an IR sensor, is a device that detects the presence or absence of an object within its range using infrared light. It is widely used in various applications such as robotics, security systems, automation, and gesture recognition. Here's some information about the IR sensor presented in a table format:

Property	**Description**
Operating Principle	Infrared reflection or interruption
Sensing Range	Typically, up to a few meters
Detection Type	Presence or absence of an object
Output Type	Digital (High/Low) or analog voltage
Supply Voltage	Varies, commonly 3.3V or 5V (depending on the model)
Output Voltage	Varies, typically High (Logic 1) or Low (Logic 0)
Response Time	Typically, in the range of microseconds or milliseconds
Angle of Detection	Varies, commonly 30° to 120° (depending on the model)
Operating Temperature	Varies, typically -20°C to +85°C (-4°F to 185°F)
Power Consumption	Varies, typically low power consumption
Applications	Object detection, proximity sensing, line following, gesture recognition, etc.

Table 3. 2: Infrared proximity sensor or IR Sensor Specifications

The operating principle of an IR sensor can be either based on infrared reflection or interruption. In the reflection mode, the sensor emits infrared light and detects the reflection from an object. In the interruption mode, the sensor emits infrared light and detects the interruption of the light beam caused by an object.

The sensing range of an IR sensor can vary depending on the specific model and its application. Some sensors can detect objects within a few centimeters, while others have a range of several meters.

The output type of an IR sensor can be either digital or analog. In digital output mode, the sensor provides a digital signal (High or Low) indicating the presence or absence of an object. In analog output mode, the sensor generates an analog voltage that varies based on the detected proximity.

IR sensors typically operate at a supply voltage of 3.3V or 5V, depending on the model and the system requirements. The output voltage of the sensor is typically high (logic 1) when an object is detected and low (logic 0) when no object is detected.

The response time of an IR sensor refers to the time it takes for the sensor to detect an object and provide a corresponding output. This response time is typically in the range of microseconds or milliseconds, depending on the specific sensor and its operating conditions.

The angle of detection determines the field of view of the sensor, indicating the range within which objects can be detected. It can vary from narrow angles, such as 30°, to wide angles, such as 120°.

IR sensors are designed to operate within a specific temperature range, typically from -20°C to +85°C (-4°F to 185°F). This allows them to be used in a wide range of environmental conditions.

IR sensors are generally low power devices, consuming minimal power during operation. This makes them suitable for battery-powered applications and energy-efficient systems.

In summary, infrared proximity sensors, or IR sensors, are versatile devices used for detecting the presence or absence of objects. They operate based on infrared reflection or interruption and provide either digital or analog output. With their wide range of applications and various features, IR sensors are popular components in many electronic projects.

Light Dependent Resistor LDR

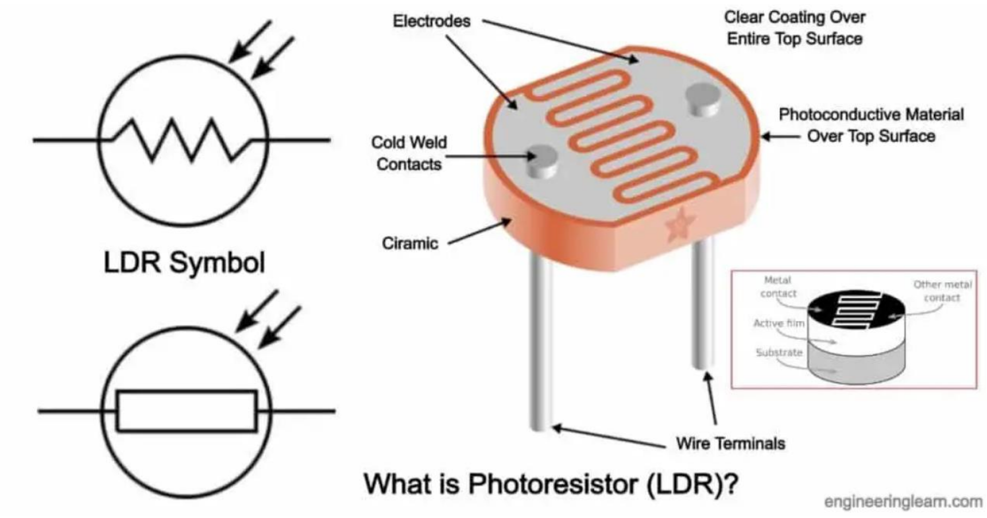


Figure 3. 4: Light Dependent Resistor LDR

A Light Dependent Resistor (LDR), also known as a photoresistor or photocell, is a type of passive electronic component that exhibits a change in resistance based on the intensity of light falling on its surface. It is widely used in various applications that require light sensing or control.

The construction of an LDR typically involves a semiconductor material, such as cadmium sulfide (CdS) or lead sulfide (PbS), which has the property of becoming less conductive when exposed to light. The resistance of an LDR can range from a few hundred ohms in bright light to several megaohms in darkness.

The behavior of an LDR is based on the principle of the photoelectric effect. When light photons strike the surface of the semiconductor material, they excite electrons, causing them to move from the valence band to the conduction band, thus increasing the conductivity of the material. Consequently, the resistance of the LDR decreases as the intensity of light increases.

LDRs are commonly used in light sensing circuits, where they provide a means of converting the amount of light into an electrical signal. For example, in automatic lighting systems, LDRs can be employed to detect ambient light levels and control the activation of artificial lights accordingly. When the ambient light is low (e.g., at night), the resistance of the LDR increases, triggering the circuit to turn on the lights.

Conversely, when the ambient light is bright (e.g., during the day), the resistance decreases, and the circuit turns off the lights.

LDRs can also be utilized in applications such as camera exposure control, solar-powered devices, burglar alarms, and light-sensitive switches. Their simplicity, low cost, and versatility make them popular choices for light sensing purposes.

However, it's important to note that LDRs have some limitations. They are relatively slow to respond to changes in light intensity, and their sensitivity can vary depending on factors like temperature and wavelength of light. Additionally, LDRs are not suitable for precise light measurements or applications that require rapid light detection.

In conclusion, Light Dependent Resistors (LDRs) are passive electronic components that exhibit a change in resistance in response to the intensity of light. They find widespread use in various light sensing and control applications, offering a simple and cost-effective solution for converting light into an electrical signal.

Light Emitting Diode (LED)

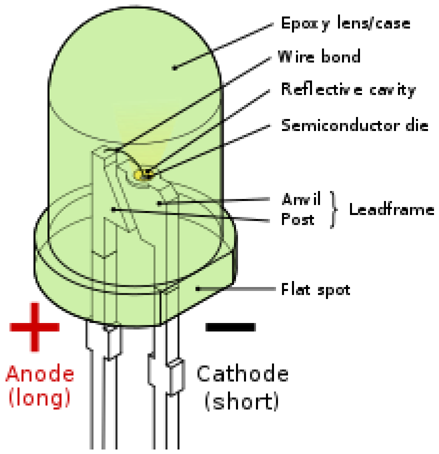


Figure 3. 5: Light Emitting Diode (LED)

LED (Light-Emitting Diode) refers to the standard type of LED commonly used in various lighting applications. LED technology has revolutionized the lighting industry by providing efficient, durable, and versatile lighting solutions. Conventional LEDs are widely utilized in residential, commercial, and industrial settings due to their numerous advantages over traditional lighting sources.

The fundamental principle behind conventional LEDs is electroluminescence. When an electric current passes through a semiconductor material, it stimulates the emission of light. In the case of LEDs, the semiconductor material is typically composed of a combination of elements from groups III and V of the periodic table, known as compound semiconductors. The most commonly used compound semiconductor for LEDs is gallium nitride (GaN).

Conventional LEDs have several distinct features that make them highly desirable for lighting applications. One of the primary advantages is their energy efficiency. LEDs are significantly more efficient than traditional incandescent or fluorescent bulbs since they convert a higher percentage of electrical energy into visible light. This efficiency leads to substantial energy savings and reduced electricity consumption, making LEDs an environmentally friendly choice.

Snow Raindrops Detection Sensor

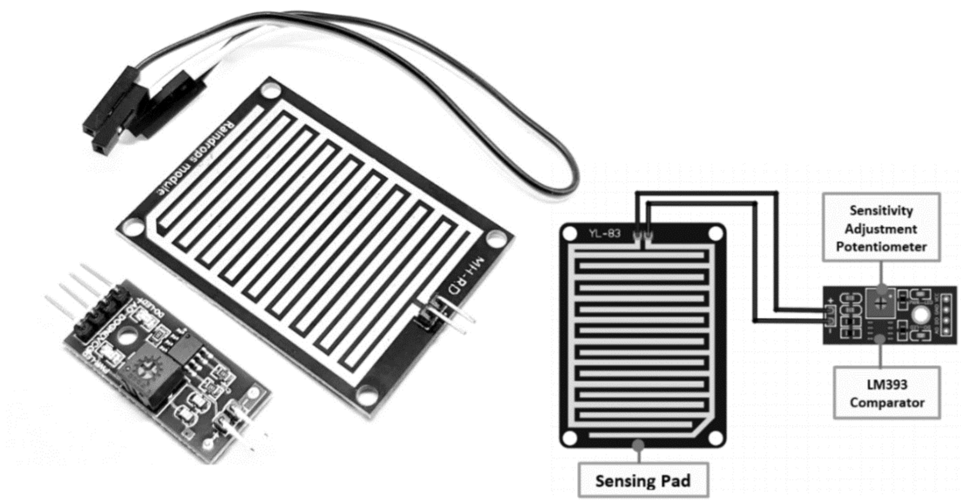


Figure 3. 6: Snow Raindrop Detection Sensor

Snow Raindrops Detection Sensor is an advanced technology used to detect and measure the presence and intensity of snowfall or rainfall. This sensor plays a crucial role in various applications such as weather monitoring, hydrological studies, agriculture, and environmental monitoring. It provides valuable data for meteorologists, researchers, and decision-makers to understand precipitation patterns and make informed decisions.

S.No:	Name	Function
1	VCC	Connects supply voltage- 5V
2	GND	Connected to ground
3	D0	Digital pin to get digital output
4	A0	Analog pin to get analog output

Table 3. 3: Snow and Raindrop Sensor Pin Layout

Raindrop Sensor Features:

Feature	**Description**
Working voltage	5V
Output format	Digital switching output (0 and 1), and analog voltage output AO
Sensitivity adjustment	Potentiometers to adjust the sensitivity
Comparator type	LM393 comparator
Clean waveform	Comparator output signal with clean waveform, good driving ability
Output driving capability	Over 15mA
Anti-oxidation and anti-conductivity	Long use time
Easy installation	Bolt holes provided for easy installation
PCB size	Small board PCB size: 3.2cm x 1.4cm

Table 3. 4: rain drop sensor specifications.

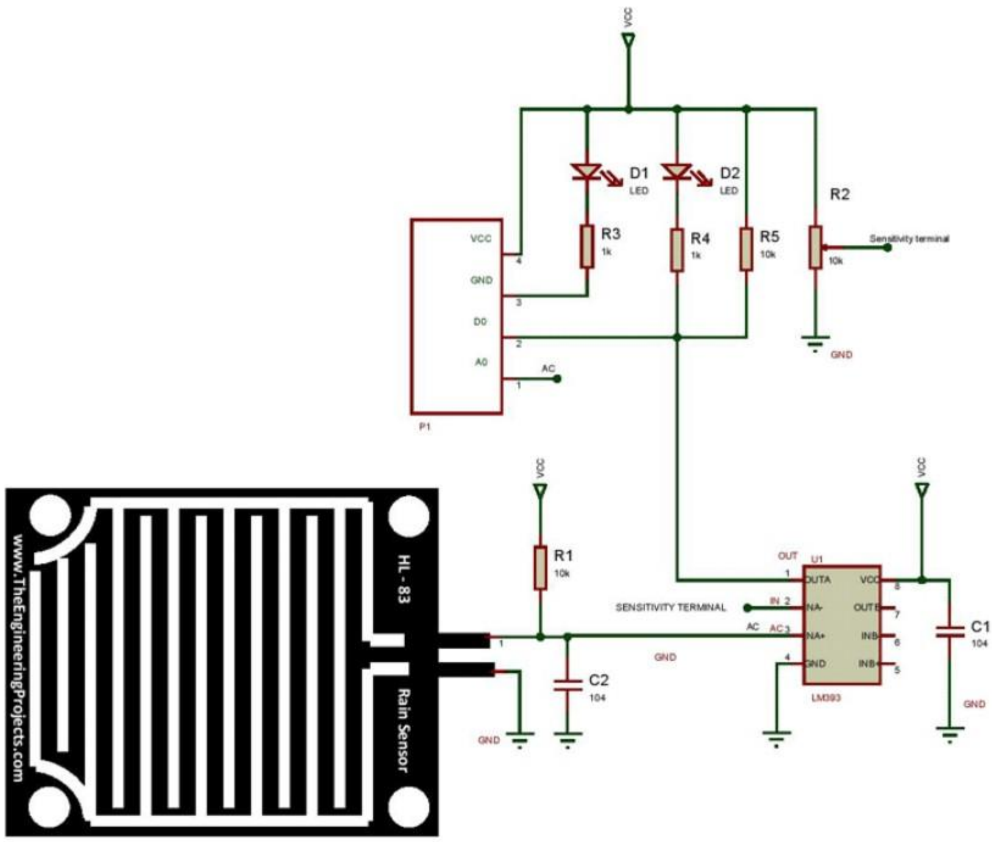


Figure 3. 7: The circuit for rain drop sensor.

R1 resistor and rain board module will act as voltage dividers in the figure above. C1 and C2 serve as biasing elements. R1 and the rain board module are connected to the non-inverting terminal. The A0 terminal of the control module receives another point from this connection.

The potentiometer (R2) is used to input the inverting terminal of the LM393. By varying R2, the sensitivity of the control module can be modified by varying the voltage input to the inverting terminal. When not in use, resistors R3 and R4 will act as current limiting resistors, while resistor R5 will act as a pull-up resistor.

By varying the potentiometer, the input to the inverting terminal is set and the sensitivity is adjusted. If the rain board module's surface is exposed to rainwater, it will be wet, offering minimum resistance to the supply voltage. Thus, the minimum voltage of the LM393 Op-Amp appears at its non-inverting terminal. Inverting and non-inverting terminal voltages are compared by the comparator. The Op-Amp output is digital LOW when the input of the inverting terminal is higher than the input of the non-inverting terminal. A digital HIGH output will be produced by the Op-Amp if the inverting terminal's input is lower than the non-inverting terminal's input. ADC circuits are used when the A0 pin is connected to the microcontroller.

NodeMCU ESP32 Microcontroller

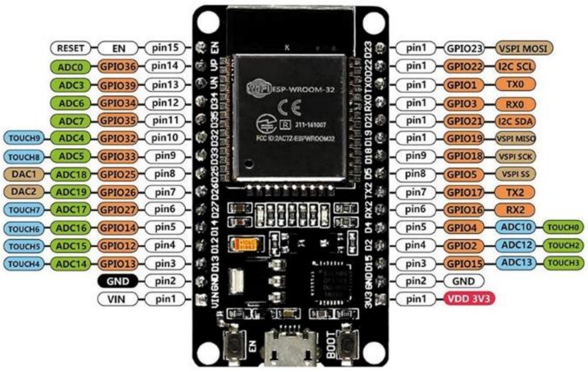


Figure 3. 8: NodeMCU ESP32

NodeMCU ESP32 is a popular development board that combines the power of the ESP32 microcontroller with the convenience of built-in Wi-Fi and Bluetooth connectivity. It is widely used in various Internet of Things (IoT) applications due to its versatility and ease of use. Let's explore its key features, specifications, and capabilities using a table format:

Feature	Description
Microcontroller	ESP32 dual-core Tensilica LX6 processor
Clock Frequency	Up to 240 MHz
Wi-Fi	802.11 b/g/n 2.4GHz (supports station, access point, and mesh modes)
Bluetooth	Bluetooth Classic and Bluetooth Low Energy (BLE)
GPIO Pins	36 general-purpose input/output pins (GPIO)
Analog Inputs	18 ADC channels (12-bit resolution)
SPI	4 SPI interfaces
I2C	2 I2C interfaces
UART	3 UART interfaces
Flash Memory	4MB onboard flash memory
Operating Voltage	3.3V
Programming	Lua scripting language support with NodeMCU firmware
	Arduino IDE support with ESP32 core
	Micropython support
	C/C++ programming using ESP-IDF framework

Table 3. 5: NodeMCU ESP32 Microcontroller Specifications

The NodeMCU ESP32 offers an extensive range of features, making it suitable for various IoT applications. With its dual-core processor and high clock frequency, it provides ample processing power for running complex applications. The built-in Wi-Fi and Bluetooth capabilities enable seamless connectivity with other devices and networks.

The GPIO pins allow interfacing with a wide range of external sensors, actuators, and modules. Additionally, the board offers multiple communication interfaces such as SPI, I2C, and UART, enabling easy integration with external devices.

One of the notable advantages of the NodeMCU ESP32 is its compatibility with different programming languages. It supports the Lua scripting language with the NodeMCU firmware, allowing rapid development of IoT applications. It also works well with the Arduino IDE using the ESP32 core, making it accessible to a large community of Arduino developers. Moreover, Micropython can be used for programming the board. For more advanced applications, the ESP-IDF framework provides a C/C++ programming environment.

3.4 Hardware & Software development

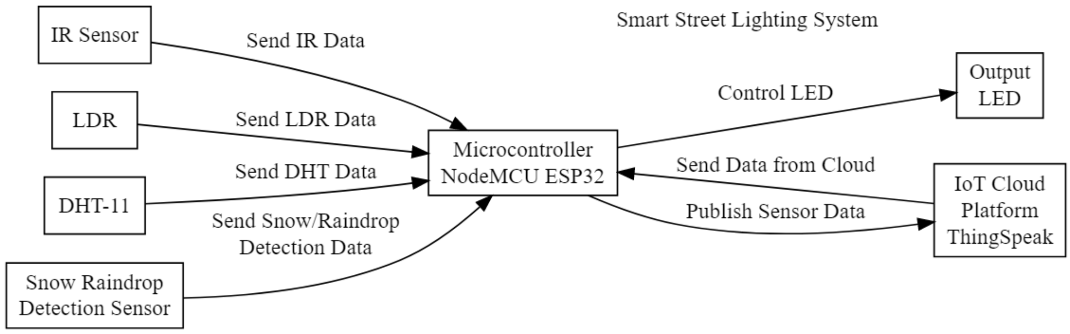


Figure 3. 9: System architecture

The system architecture diagram for the IoT Enabled Smart Street Lighting System provides a visual representation of the various components and their interactions. At the center of the diagram is the "Smart Street Lighting System" cluster, which encompasses all the essential elements of the system. The main component within this cluster is the NodeMCU ESP32 microcontroller, which acts as the central control unit for the entire system.

Surrounding the microcontroller are two additional clusters: the "Input Sensors" and "Output Devices." The "Input Sensors" cluster consists of four sensors: the IR Sensor, LDR Sensor, DHT-11 Sensor, and Snow/Raindrop Detection Sensor. These sensors serve as the primary sources of input data for the system. The IR Sensor detects the presence of objects, the LDR Sensor measures ambient light levels, the DHT-11 Sensor captures temperature and humidity data, and the Snow/Raindrop Detection Sensor identifies the occurrence of snow or rain.

On the other hand, the "Output Devices" cluster contains a single component, the LED. The LED represents the street lighting units that are controlled by the system. The microcontroller communicates with the LED to control its behavior based on the data received from the input sensors.

Connecting all these components is the IoT cloud platform, ThingSpeak. The platform serves as the bridge between the physical system and the digital world. It receives data from the input sensors, such as the IR, LDR, DHT-11, and Snow/Raindrop Detection

Sensor, and facilitates the processing, storage, and analysis of this data. Additionally, it enables the microcontroller to send control signals to the LED, allowing for dynamic adjustments in lighting based on the sensor inputs.

The arrows in the diagram indicate the flow of data and control between the various components. For instance, the microcontroller interacts with each of the input sensors to gather relevant information, while also communicating with the LED to control its operation. Moreover, the input sensors transmit their data to the IoT cloud platform for further analysis and potential integration with other systems or applications.

Overall, this system architecture diagram provides a clear visualization of the key components and their interactions within the IoT Enabled Smart Street Lighting System. It helps to understand the flow of data and control, highlighting the role of the microcontroller, input sensors, output devices, and the IoT cloud platform in facilitating an efficient and intelligent street lighting system.

3.5 Flow chart

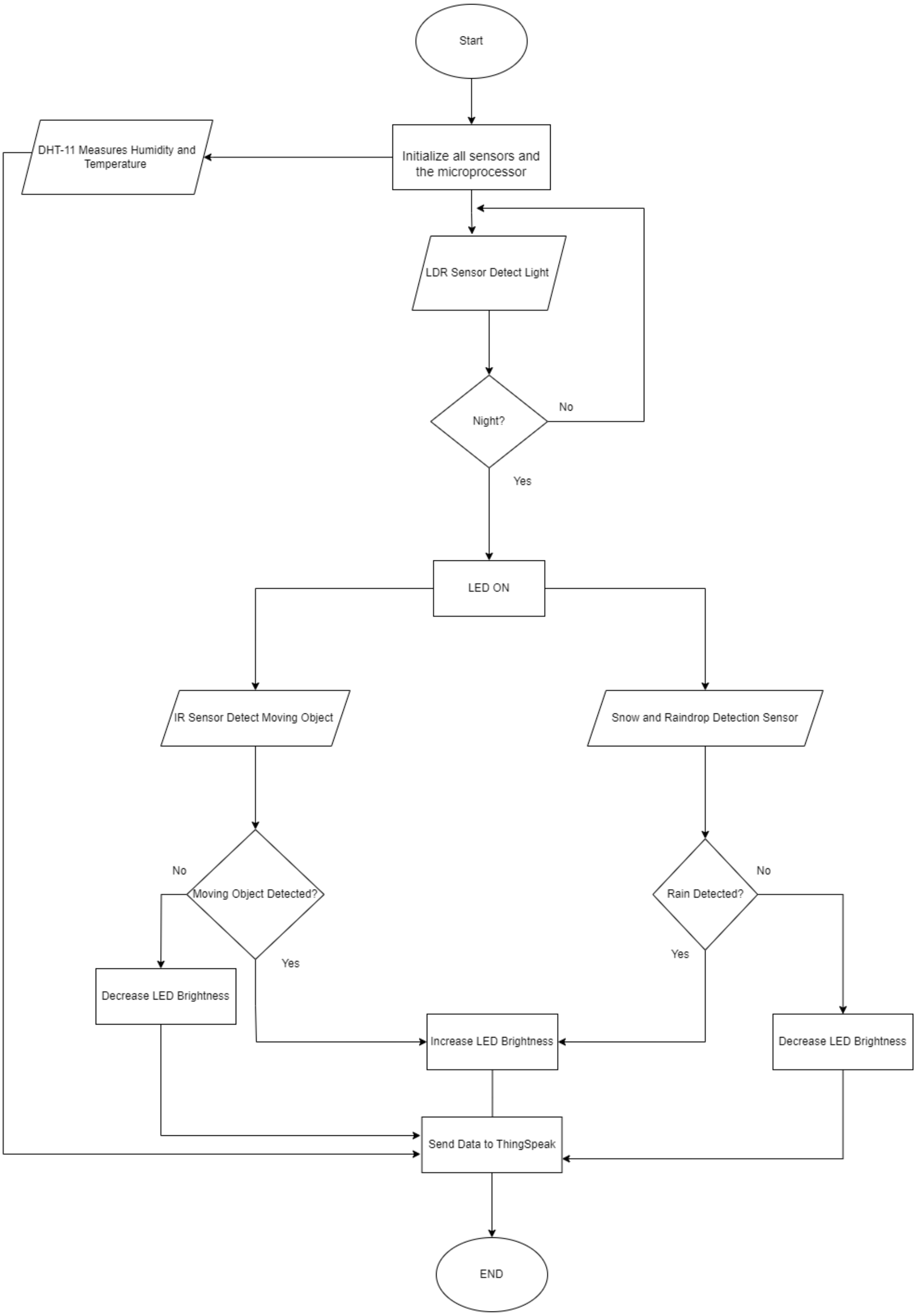


Figure 3. 10: Project Flowchart for IoT Enabled Smart Street Lighting System

An IoT-enabled smart street lighting system is a sophisticated solution that leverages several sensors and technologies to provide efficient and adaptable lighting. This system is environmentally conscious, uses energy effectively, and enhances public safety.

The first critical component of this system is a light-dependent resistor (LDR). The LDR is a sensor that detects the presence or absence of light, effectively differentiating between day and night. During the day, when the sunlight is ample, the LDR sensor sends a signal to the microprocessor, resulting in the LED street light being switched off. Conversely, as night falls, the reduction in natural light triggers the LDR to signal the LED light to switch on, ensuring the illumination of streets and public spaces during the dark hours.

At night, the system takes into account more factors to adjust the brightness of the LED. An infrared (IR) sensor plays an essential role here, detecting the movement of objects in the vicinity. When the IR sensor identifies moving objects, such as vehicles or pedestrians, it signals the microprocessor to increase the LED's brightness. This ensures better visibility for moving entities, enhancing safety. However, if no movement is detected, the system dims the lights to conserve energy.

In addition to movement, this smart street lighting system is designed to account for weather conditions. A specialized sensor for snow and raindrop detection is installed within the system. In instances of rainfall or snowfall, the sensor detects the precipitation and signals the LED light to increase its brightness, counteracting the reduced visibility that comes with inclement weather. When the weather is clear, the brightness decreases, striking a balance between visibility needs and energy efficiency.

The DHT-11 sensor, another important element in the system, measures the ambient temperature and humidity. While this data does not directly influence the LED's brightness, it can provide valuable context for the system's other sensor responses and is beneficial for analyzing weather conditions and their impact on the system's performance over time.

Finally, a central microprocessor functions as the system's brain, receiving sensor data, making decisions based on it, and controlling the LED lights accordingly. This microprocessor also sends all the data it collects to the IoT platform, ThingSpeak. This platform serves as a repository and analysis hub for the collected data, allowing for remote monitoring, performance analysis, troubleshooting, and further improvements to the system based on real-world data and feedback. This integration of various sensors, efficient data processing, and IoT connectivity is what makes this system truly smart, efficient, and highly adaptable.

3.6 Project Activities

This section outlines the timeline and activities related to the IoT-Enabled Smart Street Lighting System project. The initial proposal writing and fundamental research findings associated with IoT solutions for smart street lighting systems were accomplished in week 6 of trimester 2, 2022/2023. Following this, a thorough literature review on smart street lighting systems was conducted over a six-week duration, from week 3 to week 9 of trimester 2, 2022/2023.

Simultaneously, from week 3 to week 8 of trimester 2, activities related to devising an IoT algorithm for smart streetlights and procurement of necessary research materials were carried out. An additional six-week period, from week 10 to week 13 of trimester 2, was allocated to developing the IoT-based solution for smart street lighting system. The preparation of presentation slides focusing on the integrated IoT solutions for smart streetlights was slated for week 12 of trimester 2, 2022/2023.

In the second semester, the activities primarily concentrate on the actual implementation of the IoT for the smart street lighting project as well as the finalization of project inputs and results. From week 1 to week 4 of trimester 1, 2023/2024, the preparation and development of IoT kits for the street lighting control and security system will be executed. Prior to the actual deployment of the IoT project, activities on the integration of the IoT solution for smart street lighting will be conducted from week 5 to week 6 of trimester 1, 2023/2024.

Lastly, thesis writing, as well as the publication, presentation, and demonstration of the thesis, will take place over a six-week period, from week 7 to week 12 of trimester 1, 2023/2024. These activities are summarized and represented in Table.

Project Activity	MMU Academic Calendar
Proposal writing and fundamental research findings	Week 6, Trimester 2, 2022/2023
Literature review on smart street lighting systems	Week 3-9, Trimester 2, 2022/2023
Devising an IoT algorithm and procurement of research materials	Week 3-8, Trimester 2, 2022/2023
Development of IoT-based solution.	Week 10-13, Trimester 2, 2022/2023
Preparation of presentation slides on IoT solutions	Week 12, Trimester 2, 2022/2023
Preparation and development of IoT kits for street lighting control	Week 1-4, Trimester 1, 2023/2024
Integration of IoT solution for smart street lighting	Week 5-6, Trimester 1, 2023/2024
Thesis writing, publication, presentation, and demonstration	Week 7-12, Trimester 1, 2023/2024

Table 3. 6: Project Activities Summary

3.7 Milestone

This section provides a detailed account of the project deliverables aligned with the designated milestones. The initial tasks, including writing the literature review and purchasing the necessary research materials, are projected to be finished by May 15, 2023. The next major milestone involves the completion of the breadboard prototype, targeted for completion by June 5, 2023. The Final Year Project 1 (FYP1) report and presentation are slated to be completed by June 15, 2023.

Following these stages, the characterisation and result analysis of the project are expected to be completed by December 3, 2023. The final stages of the project involve the presentation and demonstration, as well as the writing and publication of the thesis, all of which are expected to be submitted by Jan 28, 2024.

The table below presents a summarised overview of the project milestones and their corresponding descriptions.

Milestones	Description	Deadline
1	Completion of literature review writing and purchasing of research materials	May 15, 2023
2	Development of breadboard prototype	June 5, 2023
3	Finalization of FYP1 report/presentation	June 15, 2023
4	Completion of characterisation and result analysis of the project	December 3, 2023
5	Final presentation and demonstration, thesis writing, and publication	June 28, 2023

Table 3. 7: Project Milestones Summary

3.8 Gantt Chart

Task	Week																									
	Trimester 1 (FYP part 1)												Trimester 2 (FYP part 2)													
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Overview																										
• Literature review																										
• Project Proposal																										
2. Hardware 1																										
• Purchase component																										
• Build and code the prototype system																										
• Prototype testing and debugging																										
• IoT development																										
3. Analysis 1																										
• FYP 1 presentation																										

4. Hardware 2																										
• PCB design																										
• 3D printing																										
5. Analysis 2																										
• Thesis Writing																										
• Journal Writing																										
• Thesis Publication																										
• Presentation and demonstration																										
• Hardcover report submission																										

Table 3. 8: Gantt Chart for The Project

3.9 Project Budget

Obtaining most of the required parts locally is the preferred approach for this project, given the benefits over sourcing components from overseas. Importing parts internationally can lead to increased costs and extended shipping times, making the local procurement a more advantageous option. Additionally, making online purchases from selected vendors eliminates the need for physical store visits.

The shortlisted local vendors for sourcing the necessary parts include Cytron Technologies (www.cytron.io), Lazada (www.lazada.com), and Shopee (www.shopee.com). The majority of the components are expected to be procured from Cytron Technologies and Shopee. This is due to their superior product quality, seller reliability, and adherence to RoHS standards, ensuring that all parts are genuine. All these parts come with an attached proper datasheet.

The forthcoming table provides an estimated budget for the IoT enabled smart street lighting system.

Component	**Quantity**	**Shipping (RM)**	**Unit Price (RM)**	**Total Price (RM)**
NODEMCU ESP32	1	29	5	34
LED	1	0.4	5	5.4
Light Dependent Resistor (LDR)	1	0.4	5	5.4
Infrared Sensor Module	1	1.9	5	6.9
DHT-11 Temperature and Humidity Sensor	1	4.9	5	9.9
Snow Raindrops Detection Sensor	1	4.63	4.9	9.53
Breadboard 16.5x5.5cm (830 Holes)	2	5.9	5	15.9
40-Way 30cm Dupont Jumper Wire	1	3.8	5	8.8
Total				**95.87**

Table 3. 9: Estimated Budget for IoT Enabled Street Lighting System

CHAPTER 4: Deliverable

Summarizing the project proposal, by the conclusion of this project, we aim to deliver a low-cost IoT solution specifically tailored for smart street lighting systems over small areas. The hardware deliverable would comprise of a printed circuit board with the necessary sensors soldered to it, all housed within a protected enclosure and powered by solar energy.

Our approach for the IoT-enabled Smart Street Lighting System will not only involve the physical assembly of components but will also require a significant amount of software engineering. We would ensure that the necessary sensor data is collected, transmitted, and analysed effectively to regulate the operation of the streetlights.

Finally, it is also our goal to complete a technical thesis on the development and execution of this project and have it published in a well-known online journal platform such as Elsevier or IEEE Xplore. This would detail the approach taken in developing this project.

In essence, the project deliverables are simplified as follows:

Smart Street Lighting System enabled with IoT connection.

Thesis writing and publication.

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