Energy Efficient, Intelligent Public Street Lighting System

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Declaration

I declare that this thesis is my own work and has not been submitted in any form for another degree or diploma at any university or other institution of tertiary education. Information derived from the published or unpublished work of others has been acknowledged in the text and a list of references are given.

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Abstract

Power demand is increasing day by day. Minimizing power wastage to face for the future power demand has become a worldwide concern. People are inspired to find alternative approaches to deal with energy conservation. Public streetlighting system is one sub system which accounts for a considerable energy consumption from entire global energy. it takes approximately 40% of the entire energy consumption.

This research proposes a method to save energy through smart control of public streetlights. The proposed system uses Light Emitting Diodes over traditional bulbs. The system is combined with existing traffic management system to get the real time traffic information to control streetlights. Different lighting classes are proposed for Highways, Normal Motor ways and Walking Paths based on speed limits allowed on roads. One sided and both side light installation methods are used based on the type of road. Solar cells are used as primary power source and in the absence of solar energy secondary power backup source is used. Charging circuit can recharge the battery when the battery power gets low. Moreover, charge controller between battery and solar panel can save the lifetime of battery. Each streetlight is attached a light sensor, ultrasonic sensor connected to a microcontroller for collecting environmental data. Microcontroller connects to the server through network and sensor collected data is sent to the server. Real time light information is sent to the database and server instructs the immediate streetlights to be switched on based on the program written. Also, a prototype has been developed to evaluate the functionality of system.

Table of Contents

List of Figures

List of Tables

Chapter 1: Introduction

1.1 Introduction

This research study presents a novel approach of traffic based smart street lighting to optimize energy consumption. This chapter provides background information for the research and identifies the problem statement to move into the new system.

The chapter consists of six sections. 1.2 This introductory section is followed by a brief overview of the research background. In section 1.3 research problem is summarized. Section 1.4 presents the Aim and objectives. 1.5 presents the scope, this study supposed to cover. Finally, the chapter ends with a summary in section 1.6.

1.2 Research Background

Power demand is increasing day by day. Both, indoor and outdoor lighting consumes a significant amount of energy. According to statistics, approximately 70% of the world population will live in urban areas by 2050. The municipalities should ensure the existing and upcoming citizens a safer and secure infrastructure facilities. There are many services in urban areas consumes energy such as hospitals, buildings, transportations etc. Cities consume considerable energy from global energy usage. There are many elements contributing for significant energy usage in transport infrastructure such as Traffic signals, General outdoor lighting, Christmas lighting, Traffic lightings etc. Public street lighting system is one sub system of entire lighting systems which consume larger amount of energy. Streetlights are common along motor ways, local roads and highways. [1] Since the urbanization was not rapid in twenty years back, there were a smaller number of streetlights on roads. Due to the dramatic global rise of urbanization, people are travelling and looking for enjoying along roads without any danger. The present situation is, streetlights are switched on in the evening and they are switched off in the dawn, Occasionally, streetlights remain switch on in daytime as well. Since energy saving is a global concern, it is a requirement to manage energy effectively. Considerable energy wastage of manual lighting system motivated for a smart control of street lighting system.

[2]According to statistics, migration from conventional lighting system to new system saves three billion euros in Europe.

At the same time, smart city concept is becoming more popular due to the dramatic urban development. Nowadays, Internet of Things (IoT) is playing an important role in everyday life which can make human life better. Information and communication technology in collaboration with internet of things effectively manage the resources and assets of the city centers. City related data is collected using sensors and are processed and analyzed them in real time to manage the resources of the city such as, traffic and transport systems, cities waste disposal, etc. Among them effective and safer public street lighting system is an important facility required for the citizens. Smart control over street lightings can reduce operational and maintenance cost as well as lower energy consumption. The term smart refers to an intelligent system which collects environmental data and operates autonomously with the aid of wired or wireless communication protocols. It is vital to ensure the appropriate and enough public street lighting to ensure the attractiveness of the city. A well-designed street lighting system can guarantee the safety and comfort of the road users and it reduces the fear of night-time crimes and darkness. Moreover, it avoids a considerable environmental pollution and reduces the road accidents allowing the vehicles to drive safely providing visibility over great distance. [3] Lighting consumes 19% of the global energy usage and it leads for approximately 6% of environmental pollution. The production of electricity releases Carbon Dioxide (Co2, Greenhouse Gases) to the environment which leads for environmental pollution. Efficient street lighting system can protect the pedestrians and drivers from unexpected incidents occurring along the road. Above mentioned things motivated the municipalities for implementing proper solutions.

Municipalities contribute for ensuring safety of pedestrians and drivers on roads during dark hours. [3] Nevertheless, Municipalities are enforced to reduce light levels or switch off lights on roads due to unexpected energy wastage. It leads to increase accidents, reduce safety of pedestrians as well as the attractiveness of the city. Energy is considerably wasted in areas where pedestrians and automobiles are less common.

Research studies have focused on developing energy efficient smart street lighting systems. The author of "Energy Efficient Smart Street Lighting System in Nagpur Smart City using

IoT" has studied Smart Street lighting system of Nagpur city and older street lighting system is replaced by new system. Further, the study shows results after implementation of smart lighting technology. Various energy reduction methods are applied in this study. They have focused on replacing old fashioned fluorescent, mercury-vapor and sodium-vapor streetlights with LED lights and control them automatically. Operating light ON/OFF schedules, control streetlights through central management system, schedule-based dimming and motion allowing dimming are also implemented.

Light Emitting Diode (LED) has changed the conventional lighting which leads for lower power consumption as well as the environmental pollution. Sensor integrated smart control of luminaries also play a vital for energy saving in intelligent lighting system. Also, the networked, on demand lighting system guarantees safe and secure environment for pedestrians as well as optimal luminary operations. Wireless sensor network (WSN) integrated lighting system allows for easy monitoring, controlling and maintenance capability. Combination of sensors allows for identification of ambiguous environmental conditions and weather conditions for providing optimal lighting operations considering light intensity. Networked smart outdoor lighting system can conserve considerable energy with capability of centralized management.

The research "Energy efficient smart street lighting system with traffic and weather analysis" concept introduces a next level of intelligence for smart lighting. This research proposes a method to reduce considerable energy consumption of public streetlights while ensuring the safety for the pedestrians and drivers. The main concern of this research is for adjusting LED luminaries according to changing traffic volumes and thereby reducing power consumption while securing the drivers and pedestrians from unexpected accidents on roads. Another interesting part of this research is to change light intensity according to weather conditions.

This rest of the paper is organized as follows. In Chapter 2 the contribution of other researchers for the problem with their drawbacks are discussed. In Chapter 3, the methodology is made which describes the proposed architecture, design and technologies used in the research. Two sub systems are introduced for controlling street lighting and traffic management. This research presents a low power, more reliable and less complex smart lighting model. Chapter 4 describes practical implementation of the research. Subsequently, in Chape 5 and Chapter 6 discuss the results and conclusion.

1.3 Problem Statement

Street lighting is one of the main lighting systems which consumes a considerable energy in the world. Public street lighting provides citizens a safe secure life on roads, and it ensures the security of homes and cities as well. Therefore, municipalities are responsible for ensuring the secure environment for the citizens by ensuring on-demand lighting. studies show " [4]Public lighting can reduce crime by up to 20% and traffic accidents by up to 35%". Outdoor lightings operate on dusk to dawn. In some cases, they operate on once it rises again in the morning. Also, they remain lighting when there are no vehicles and pedestrians on roads. These outdated lighting systems lead for huge wastage of electricity.

Lighting is responsible for a staggering 19% of global electricity usage. According to statistics, powering streetlights accounts for 30% - 50% of city's electricity bill. According to the international energy agency, "[4] The demand for the lighting will be 80% higher by 2030 compared with 2005." Therefore, reducing overall system power consumption has become a worldwide concern.

Currently, various issues are associated with this outdated public street lighting system. Due to the increasing power demand, it is difficult to address power demand with existing conventional methods. Therefore, efficient power sources and control methods are required to address this issue. Possible solutions for optimal energy consumption are, use of energy efficient light sources, system design support for optimal glare, control time and period of lighting, control lighting in the absence of community, Quality design etc. In any case, it is vital to implement lighting systems for increasing economic growth together with community safety. Economic growth is achieved by allowing the people to spend their work even at dark.

There are various families of lamps which can be used for roadway lighting. Efficient light sources can achieve same luminaries with a smaller number of operational lamps. High pressure sodium lamps are mostly used for street lighting which emits a golden light.

Anyway, High pressure sodium Lamps (HPS) have high operating and maintenance cost since these sodium lamps can easily be damaged. Thus, the existing system used HPS lamps are inefficient and leading for wastage of manpower. [5]These are omnidirectional which leads for wastage of light. Also, it loses roughly 15% of the heat emissions. And they are relatively fragile.

There may be streets where travelling people and vehicle could be irregular. In that case, full intensity of the streetlight may not be required, and it leads for energy wastage. The conventional lighting system remain operate in the absence of vehicles or pedestrians on roads. Lighting should be operated on only when it is required.

The number of lamps on roads also matters for energy consumption. The number of lights necessary for roads depend on various parameters such as type of road, traffic volume, speed limits, weather conditions and surroundings. And also, Luminaries can be adjusted based on above parameters during night. The existing lighting system doesn't consider these parameters and lighting are operated manually in night.

Conventional lighting system is difficult to be maintained. Life span of sodium lamps are relatively low compared with LED lamps. The damaged lamps should be replaced manually when necessary. Smart control of networked lights can inform state of lighting system and its individual components. Therefore, savings can be claimed not only from electricity but also from maintenance.

The research conducted on Nagpur Smart City believes, high traffic is occurred from evening to midnight. Thus, the lights are always ON for 100%, after that motion-based dimming is activated. This proposed system introduces adaptive lighting system based on different street conditions. Moreover, the proposed research adopts for the weather conditions and emergency situations like fire. Thus, change its operation and activate energy saving modes.

Therefore, this research introduces a reliable, cost-effective model for achieving energy efficiency through identification and elimination of problems associated with conventional street lighting system and ensure optimal lighting for the citizens. Also, this research interest in automatic controlling of street lighting based on various parameters such as type of road, speed levels, traffic conditions, weather conditions so on.

1.4 Aim and Objectives

1.4.1 Aim

- Design and develop an energy efficient intelligent public street lighting model while ensuring the safety and comfort of the citizens.

1.4.2 Objectives

- Improve energy efficiency of public street lighting system by controlling luminous (ON/OFF/DIM) automatically, considering various parameters such as type of road, speed limits, traffic volume, surrounding light intensity, weather conditions and emergency situations like fire etc.
- Control light ON/Off based on people or vehicle movements.
- Minimize operation and maintenance cost through automatic light control via mobile portal.
- Identification and elimination of problems associated with conventional street lighting system.
- Future predictions of lighting system based on the current user behaviors.

1.5 Scope of Study

The proposed street lighting system introduces an energy saving mechanism ensuring optimal lighting, citizens safety and thereby reducing environmental pollution. The proposed system uses LED (Light emitting diode) instead of conventional sodium lamps which can reduce power consumption, environmental pollution and so on. Solar cell is used as the power source and if it is unable to do so, Li-lon battery storage is used as secondary backup to control the situation immediately.

The system observes the vehicle and people movements to control the on/off streetlamps accordingly. Improve energy efficiency of public street lighting system by controlling luminous (DIM) automatically, considering types of roads, speed levels, surrounding light intensity, traffic conditions, weather conditions and emergency situations.

Finally, energy consumed by streets and status of individual lighting components are sent to a mobile portal and can analyze the energy usage while controlling streetlights over mobile portal which leads for easy maintenance.

Proposed model of "Energy efficient, intelligent public street lighting system – based on detail analysis of traffic and weather conditions "shows an improvement over the existing work.

1.6 Summary

This chapter reviews the background study for the problem identified, research objectives, proposed solution, and scope of the proposed system.

Chapter 2: Literature Review

2.1 Introduction

This chapter reviews the literature of similar systems. The chapter presents, smart street lighting solutions to cut the unnecessary energy wastage of conventional lighting system and to conserve energy through novel methodologies. Many researchers have contributed for the mentioned problem so far. Moreover, this presents limitations of existing systems, proposed new systems and technologies use to overcome those limitations.

2.2 Literature Review

Various systems have been developed to ensure the efficiency and effectiveness of street lighting system to minimize unnecessary energy wastage. A study proposes an energy efficient autonomous intelligent street lighting system which uses an algorithm to control the energy of each lamp post [6]Lamp posts are grouped together, and they are equipped with various sensors for motion detection, illumination, voltage and current. The system can adopt for the weather conditions and in such situations ensures optimal lighting for the citizens. Proposed system groups three lamp posts together by electronic device. Each group is equipped with battery and control unit with solar module and sensors. Battery with control unit is located at the central lamppost and other two lampposts charge the central battery by power cables connected. Sensor collected data of central lamp post are sent to the control unit. Neighboring lamp posts send the data through simple cables. Then the control unit sends the data to a network coordinator via XBee 3 transceiver module. Network coordinator gets data from all the groups and store them in a database via internet. A web application is developed to remotely monitor and track the entire system.

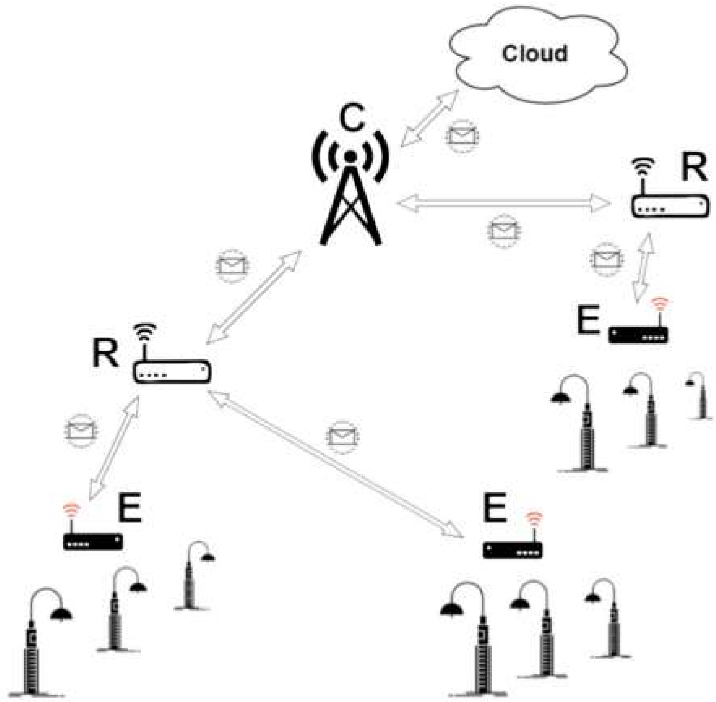


Figure 2.1:Wireless sensor network topology of the street lighting system

The most important feature proposed in this research is dynamic adoption for the weather conditions. Weather forecast API integrated with network coordinator can predict weather conditions for coming 3 days and activate different lighting modes for the operation. Different lighting modes operate on different algorithms designed for energy saving.

The architecture of the system consists of several levels such as end devices, router and control center. Sensor equipped lamp posts send transmit data to the router Via XBee. Then router transfers those data to network coordinator and store data in database. Then the system is managed online through website. A failed lamppost sends error message and service team fix the error for providing on demand lighting system for the citizens.

The main controller of the proposed architecture consists of sensors, micro controller and transceiver which is powered by 12V Battery. The controller is ATmega328PU, XBee 3.0 as transceiver and sensors such as infrared motion sensor to detect the presence and movements of pedestrians, illumination sensor which is an energy saving sensor for light dimmers, INA219 current and voltage sensor and Light sensor for determining the time of the day.

This system mainly proposes a weather adoptive algorithm to change light operations based on different lighting modes. It forecast the weather information for coming three days. The batteries of each lamp post group are charged by solar modules in daytime and charging information status is sent to the network coordinator. In night, weather information request is sent is sent to the network coordinator. If weather of next day is mostly sunny, the system looks for current day weather condition. If it falls sunny, it operates in mode A. If it falls cloudy, the system operates in mode B. If the weather of coming day is cloudy, it again requests climate for the day after tomorrow. If the climate of day after tomorrow is mostly cloudy, it changes the operation to mode C. If it is sunny, ask for the todays weather and if it is sunny operates on mode B and if not operate on mode C accordingly.

In Mode A, luminous is changed up to 100% based on movement of people and vehicles, otherwise intensity is reduced up to 50%. In mode B, the intensity of central lamp post is change up to 50% whereas the neighboring lamp post change the intensity up to 25%. The central lamp post lights up to 100% and neighboring lamp post remains same if a motion is detected. In mode C, turn off the central lamp posts and neighboring lampposts light up into 25%. Neighboring lamp posts change into 50% considering people and vehicle movements. Mode C is more energy efficient compared with other modes.

Also, they have represented energy genration by solar cells under different weather conditions. Experiments have been carried out on sunny and cloudy days. Solar tracker is placed at 43^0 angle int to the horizon. Here, the solar battery used is 40W. According to the observation, the average amount of energy generated in sunny days was 291.6Wh, in cloudy days it was 12.7Wh. This research has presented the energy consumption as well. Considering each three-lamp post as a single unit, energy consumption of entire system is determined. 7-Watt LED lamps are used as lighting lamps, and they can operate in accordance with all the four types of modes. Power consumption details are taken from the INA 219 voltage current sensor and resulted power consumption of each unit including three lamps are presented. Also, this system uses uniaxial solar tracker for increasing efficiency of solar cells.

As a result, this proposed system with intelligent predictive algorithm uses wireless module for remotely monitoring the device status to provide on demand lighting and can save the considerable energy wasted of public streetlights.

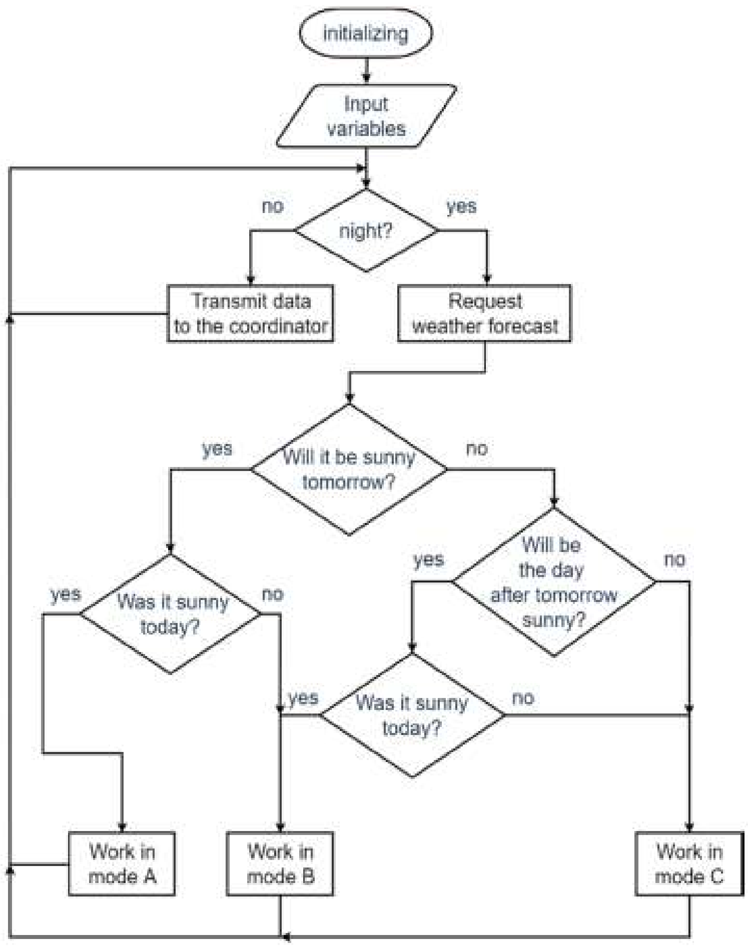


Figure 2.2:Proposed Lighting Algorithm

Another study presents [7]a case study of smart lighting system in Nagapur Smart city and mainly the purpose of this study was to reduce carbon dioxide by reducing unnecessary energy wastage. The goal is achieved through replacing conventional lightings to LED lights with motion detection functionality for controlling streetlights. Finally, the results represent reduced energy consumption of Nagapur smart city.

Smart city concept was relatively new for India. There are many services which consume energy in India and energy reduction can be achieved by smart control of streetlights. 2% of energy in Indian cities are consumed by streetlights and allocate 10% to 15% of municipal budget as well. Nagapur is considered as the third largest city of Indian state of Maharashtra. To reduce the energy wastage, they suggest the replacement of old standard fluorescent, sodium-vamper and mercury-vamper streetlights with LED lights.

The study explores the issues of existing street lighting system of Nagapur. In conventional lighting there is no proper system for operating streetlights, and they consider each single unit of streetlight for fault detection and replacement. Lack on information about real time status of streetlights is another issue faced in conventional lighting system.

There are three layers in the proposed lighting architecture. Sensor layer, Communication Layer and Management Layer working together for achieving energy efficiency. Lamps are equipped with various sensors which interact with external environment and collect data such as light conditions, motions etc. The collected data is passed to a gateway through communication protocols and gateway forward them for a management layer for decision making. Management layer with central management system analyzes data and take energy saving decisions.

Nagapur smart city uses wireless lighting controllers which control the operations of LED streetlights from a centralized platform. Centralized management platform creates all operational policies and push them on to the nodes. It sends the operational procedures to the controllers to operate themselves. Sensor layer equipped with motion sensors which operates when it detects a motion. LED control nodes equipped with sensors are connected to the gateway, through ZigBee protocol and the gateway is connected to the data center through cellular network, Wi-Fi, or Ethernet.

Further, this study presents the technologies used for successful implementation of smart street lighting system.

Light poles use 120W LED lights equipped with control node for motion sensing. Each node is integrated with a streetlight controller. It performs intelligent ON/OFF switching and dimming controls via remote management. Wireless gateway system integrates smart street lighting system and the central server through WI-FI or Ethernet. Web based system connected to the central server presents the real time status of lighting system and controls the lighting operations.

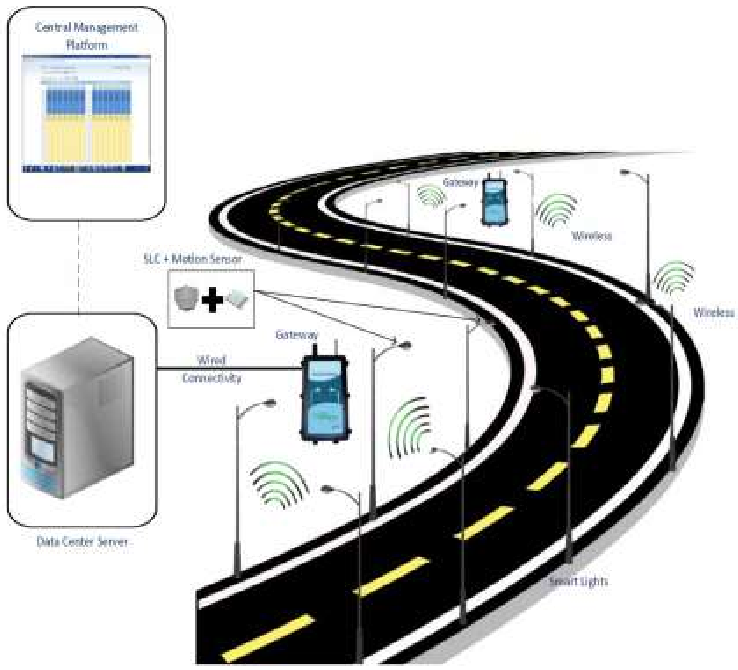


Figure 2.3:General Architecture of the system

Algorithm of the smart lighting system works on two modes. Manual mode and Mixed mode. Manual mode performs schedule-based dimming, ON/OFF is performed as per the specified time and does not operate based on motions. In this mode, streetlights are turned on after 6pm and switched off when the sun rises. This mode activates LEDs up to 6am. In mixed mode, streetlights remain switched on 100% from evening to midnight (6pm – 11pm) due to high traffic and then motion-based dimming is activated. When the system switched into motion-based dimming, all LEDs are set into 40%. When a motion is detected, streetlights are switched on 100% for 30 seconds. This mode works from 11pm to 5am.

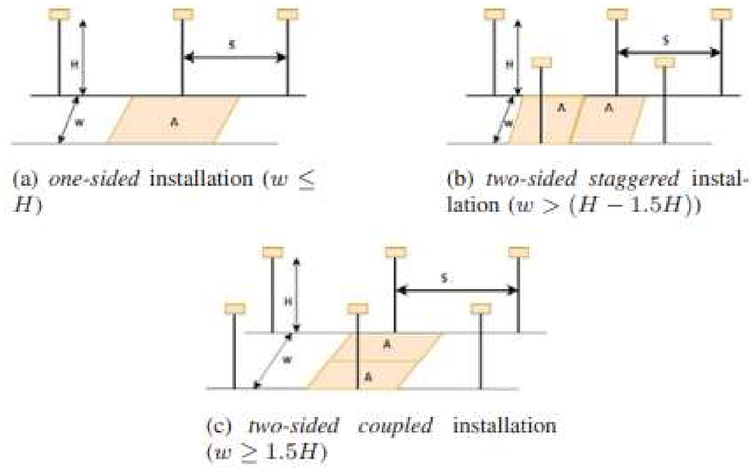
This study presents energy consumption sample data of conventional lighting system taken from online configurator and detailed electricity consumption for two months is presented.

After implementing smart lighting system in Nagapur city they have analyzed the total energy consumption of 349 smart lights. Finally, they have presented a significant energy saving in smart street lighting system of Nagapur city over conventional lighting system which replace the traditional luminaries.

[8]Another study has proposed an improved energy efficient street lighting system to reduce the power consumption through varying power range and the distance between light poles for different lighting classes. Due to the huge energy wastage of manual lighting system, they introduced this system considering various installation parameters for streetlights. Further, this study presents problems associated with manual system as well as the improper consumption of lighting in manual system. For better utilization of energy, LED lights with different power ranges and various inter distances among lights based on different street conditions for streetlight installation are proposed. They have presented a simulation of the proposed approach and minimum power supply required to operate streetlights to obtain energy efficiency has been validated through simulation model.

The study presented an adaptive street lighting model for the users of different roads.[8] P (Pedestrian and low speed areas) lighting class. This class is basically for the pedestrians and for the areas where there is a low traffic. C (Conflict areas) lighting class is designed for the crowded areas such as cities, cinemas, food courts, shopping streets where it is very common to see motor vehicles and huge crowed. M (Motorized areas lighting class) is designed for the vehicle drivers. These three basic lighting classes are classified into sub classes based on set of factors such as traffic conditions, speed of walkers or traffic flow etc. These classes are further categorized as P1 to P6, C0 to C5 and M1 to M6.

This system considers various installation parameters for lighting poles. One important parameter is [8] ratio of width (w) of the road to the height (H) of the luminaries. $r = w/h$. Based on the ratio value there are three lighting installation designs, one sided two sided staggered and two sided coupled.



(a) *one-sided* installation ($w \leq H$)

(b) *two-sided staggered* installation ($w > (H - 1.5H)$)

(c) *two-sided coupled* installation ($w \geq 1.5H$)

Figure 2.4:Light installation methods

The figure shows the three lighting installation designs. “A” denotes the area of each luminary. The area covered by each luminary (A) depends on road width(w), the distance between two lighting poles and installation design factor (k). The installation design factor (k) is k=1 if the selected lighting installation design is one sided. Similarly, if the lighting arrangement is two sided, then k=2. Based on this, value of r (ratio) is different for each installation design.

The proposed work of this study presents a simulation model which considers 100watt of power (P_c) and the distance of 40m between lighting poles (S). CIE (International Commission on Illumination) recommends the inter-distance of two lights should be between the range of [10-50] meters. The one-sided lighting arrangement where k=1 (installation design factor) is considered for the simulation which mainly focus on conflict areas. And MATLAB 9.4.0.813654 has been used to carry out the simulation.

Factors	Value
Width of the road (w)	7 meters
Height of each luminary (H)	10 meters
Installation design factor (k)	1
Power range (P_c)	25 – 125 Watt
Distance among lighting poles (S)	10 -15 meters

Table 2.1:Lighting installation parameters

The paper further presents the simulation results. The constant term Cn where $C_0 – C_5$ is categorized based on set of factors [8] in order to estimate E_{av}, E_{av} denotes the minimum value necessary for the respective light throughout its lifetime. E_{av} is evaluated based on the watt of power between the range of 25 – 125 and 10 -50 meter of the distances between two light poles. They have presented the average luminance for various power values and inter-distances.

Class	Pc (Watt)	S(meter)	Eav
C0	116	20	50.0953
C1	125	28	29.9900
C2	88	29	20.0018
C3	66	29	15.0013
C4	44	29	10.0009
C5	66	48	7.5007

Table 2.2: Results

Required minimum power is determined by validating the Pc value obtained from simulation using DIALUX. DIALUX is a leading lighting design software founded by German Institute for Applied Lighting Technology [8]. The DIALUX presents the validation results 44 as the minimum power necessary for the light. The simulation and the DIALUX presents the result, LED light for C5 lighting class.

[1] A research conducted on “Regulating solar LED array with vehicle detection to turn streetlight on or off to save energy” presents a mechanism to save energy focusing on the efficiency of streetlights and cost effectiveness. The author has discovered that today’s major concentration is going for Solar powered LED streetlights as the reliability, flexibility, low maintenance cost, easy implementation etc. This research uses Solar motion detector which can sense the object close to the sensor by 60 meters along one particular LED streetlight to be switched on and switched off in the absence of vehicles on roads to save energy by supplying it to a grid station. LED streetlamp arrays are used instead of conventional streetlights such as high-pressure sodium lamps, mercury vapor and so on. Further this study presents details comparison of high-pressure sodium lamps and LED array along the motor ways.

Region	Height Pole	High Pressure Sodium	LED Arrays	Power saving using LED for 5000 poles
Division/Sector	8m	80W	45W	175,000 Watts
Service Lane	14m	160W	90W	350,000 Watts
Highway / Motor Way	18m	250W	120W	

Table 2.3:Comparison of energy serving

A survey conducted on highway lighting system discovered, one high pressure sodium lamp is consuming 250 watts whereas LED is giving same luminous with 120 watts. HPS requires 160 watts for illuminating road while LED array needs only 90 watts. The research recommends the installation of 20,000 LED light poles for a particular city of Pakistan, can save a considerable amount of energy. As well as installation of solar power with LED arrays can solve energy crisis by filling the gap of energy shortfall. Finally, the study shows LED solar arrays are cost effective than traditional mercury or sodium lamps powered by electrical power supplied by a grid station.

Also, this research recommends using LDR (Light Dependent Resistors) sensors to switch on lights based on surrounding light. The sensor senses the light based on sun rays' intensity. When the solar rays' intensity is not present, it increases the LDR resistance and switch the light on. When the sun rays' hits into LDR sensor, it decreases the resistance and switch the life off.

The batteries attached to the streetlights are getting charged during daytime and it alights LED lights during nighttime. The extra power goes to a grid station so that it can be consumed for households or public. The invertor attached to LED arrays' batteries convert Direct current (DC) to Alternate Current (AC) in order to transport easily for the grid station.

Figure 2.5:Regulating solar LED array with vehicle detection

This research further presents, [1] the Solar panel angle should be adjustable from 10 to 30 degrees manually or automatically in parallel to the sun rays' intensity changes via direction. Smart streetlights are arranged in a way that it can detect the vehicle movement close to it by 60 meters and the corresponding streetlight get switched on while the vehicle crosses the streetlight. It remains unchanged until the vehicle moves 60 meters away from the streetlight. The installation of this system in Pakistan can save over 3 billion Pakistan rupees in case of installation of 200000 LED streetlights over 8000km. brightness of 110w LED array set is same as the shine of 250W High pressure sodium lamps. Energy saving of 20 years after installing LED array set over HPS bulbs is around 482 billion and it reduces the burden of energy crisis faced by Pakistan. Finally, this system utilizes energy efficiently via object and light detection sensors, Solar panels, batteries, LED arrays etc. and the results are shown in tables and figures which illustrates the energy saving.

"[3] A Traffic-Aware Moving Light System Featuring Optimal Energy Efficiency" focused on developing a new approach to control brightness of streetlights based on traffic volume on roads, providing on-demand lighting for the road users while showing the possible energy savings and real time light consumption. Moreover, this research motivates for CO_2 reductions and brings the concept of moving lights to activate lights when they need. The proposed system has been evaluated using Simulink simulator and practically implemented and tested to prove the concept.

SFH203 photo diodes are attached to each lamp to detect objects movements. Radar sensors are used to prevent from shadowing and occlusion. They can detect the motion, velocity and unaffected by snow, fog such environmental parameters. Several neighboring lamps together identifies traffic direction, and a new approach is used to detect direction and velocity. TTL value of IP packet is changed at each immediate station and TTL value gets decreased when the object distance is closer. TTL value is increased when the vehicle is moved away from the station. Object direction is determined by the first and last of saved packet. Space difference is divided by time difference, vehicle requires to pass two lamps which is used to determine the velocity. [3] "n_{Obj} is a number of traffic elements or objects. n_L is the number of lamps. The total energy requirement E of the lighting system for all traffic elements n_{Obj} and all lamps n_L is the sum of the energy consumption of each lamp in the automated system."

$$E = \sum_{i=1}^{nl} E\ auto\ i$$

It activates the lamps before and after object without dimming function.

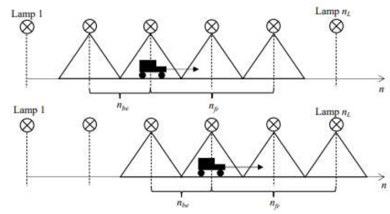


Figure 2.6:Traffic aware moving light system

[9]"Design and Implementation of Smart Solar LED Street Light" proposes an energy efficient street lighting system to save energy in rural areas, urban areas, and smart cities. The study recommends using LED lights instead of High-pressure sodium lamps or fluorescent lights and it highlights the advantages of LED lights in various ways such as economic, performance, environmental and so on. Intelligent sensor attached street lighting system controls light intensity based on various parameters. Also, this solar based system can be operated using auto change over technique to switch into utility supply in case of insufficient charge in batteries. Motion detection sensors can control streetlight intensity. The battery charges daytime and LDR attached streetlights automatically switch on for 30% of intensity in the night. When it detects object movements light intensity will be increased from 30% to 100%. Again, the intensity reduces gradually to 30%. Arduino microcontroller receives light information from LDR sensor, Passive infrared sensor for motion detection information and system operate according to the program uploaded into it. Charge controller between solar panel and battery arrays protects from battery overcharging which enhance the lifetime of battery bank. This system ensures on-demand lighting.

Arduino microcontroller operates on the Arduino program uploaded into it. The program starts with reading LDR value followed by PIR motion sensor value and charge controller. When the sufficient light is present, LED lights turn off. During nighttime LED lights operate based on set of conditions. The light intensity is 30% during nighttime and light intensity increases up to 100% when it detects motion.

[10]B. G. Shivaleelavathi, M E Vinay and V Sucheeth together published "Solar Based Smart Street Lighting System" with the intension of developing a street lighting system which can change the slope of solar cells perpendicular to the sun to get the maximum use

of solar rays. Moreover, it combines LED dimmer circuits to save energy by switching off lights in situations where the road users are not present. Also, the PWM based solar charge controller can avoid overcharging the battery to protect the battery. The focus of this study is to bring a solution to get the maximum use of solar irradiation under any seasonal or weather conditions and to present a solution to get rid of unnecessary energy wastage.

To achieve energy efficiency, the system consists of, battery, charge controller, relays, set of sensors, motors, cloud server, light dimmers etc. The solar panel combines with time-based tracker and geared motor powered by motor driver IC (L293D). The tracker and the motor together maintain the angle of solar cells. Time based tracker tracks the sun for 8 hours and return it to the original position at the next dawn. Voltage sensor attached to solar cells detect the real time voltage and update the cloud server. The relay attached between charge controller and battery limit the charge based on the voltage value detected at battery terminal. Once the battery reaches 100% of charge, microcontroller disconnect the battery and charge controller so that it protects from getting overcharged which leads to enhance the battery life. During night-time, LDR resistance is increased, and it is triggered by the controller thereby switch on the relay between battery and load. Once the relay is activated, dimmer circuit takes the input from ultrasonic sensor connected to the microcontroller. Ultrasonic sensor detects the object presence. Object presences change the luminosity of lamp post to 100% whereas absence of object dims the light to 30%.

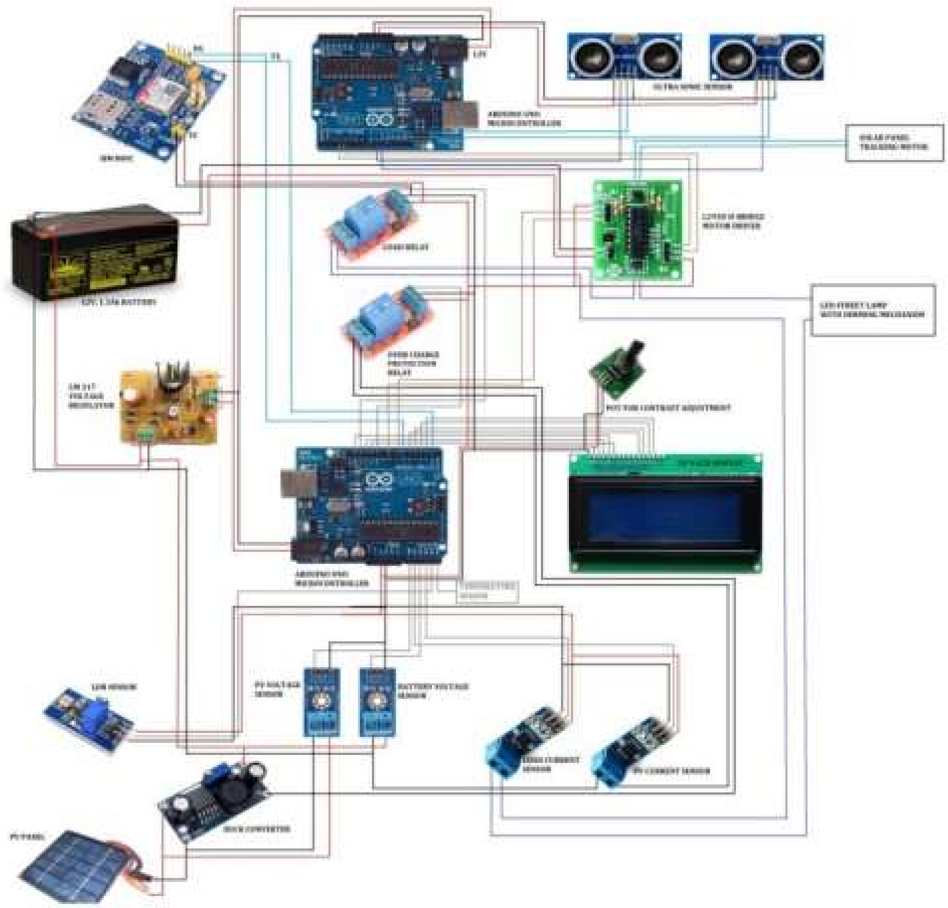


Figure 2.7:Solar based smart street lighting system

PWM (Pulse Width Modulation) pulses are provided from controller to the dimmer circuit at two different duty cycles to control the brightness of lamp posts. These two duty cycles can control the voltage across the load which affects for the current through the load. The sensor collected data is sent to the cloud through GSM or GPRS module. Moreover, the status of the lamp is sent to the registered mobile number.

The main components such as track sun rays based on time, dimmer circuit, PWM based charge controller and cloud data storage together creates a powerful solution. This has been developed as an eco-friendly, cost effective and a practical solution for commercial and domestic lighting applications.

[11]IoT based street lighting and traffic management system proposed an automated lighting system which can control the brightness considering surrounding light intensity.

Moreover, this study introduces a solar based power supply and inability to supply power activates secondary DC current to control the situation immediately. This proposed system works on dimming the lights to 20% when the traffic level is decreased significantly around 1.00am to 6.00am. Also, the proposed solar technology can save 30% of electricity wastage. This study suggests installing road barriers such as traffic bollard or spikes. Surveillance cameras are installed on roads to monitor and control the whole system and data is stored in a database. Basically, the system works on light intensity, lights remain switch off during daytime and in the night, lights intensity is reduced for some streets with no vehicles and adjust the luminous for maximum for the streets where vehicles are moved. At the time of the red light in traffic signals, a barrier is appeared automatically, which is done by a servo motor and the barrier is disappeared when the green light is visible. Yellow signal allows the vehicles in barrier zone to stay away immediately and warns the vehicles behind the barrier zone to stop immediately. This solution is proposed to maintain the traffic light signals as well as to save energy. There are two separate parts of the system, streetlight system and traffic management system. A prototype has been developed to find the effectiveness of the street lighting system. The street lighting system and traffic management system is combined with another application which is accessible through internet to achieve cost effectiveness, easy maintenance and many more. The lighting system uses LED lights which can decrease the energy wastage. IR sensor modules are used to detect the object presence and when the vehicles pass through the modules, light intensity is increased. Also, the solar cells are used as primary power source and in the absence of solar energy secondary DC power backup source is used. Traffic management system uses three types of signals to manage the traffic without support of the traffic police. If necessary, manual system can be activated. Lighting system and traffic system is connected to the monitoring system through internet data is stored in a database. Surveillance cameras are installed for the monitoring purposes.

A prototype has been developed to evaluate the entire system. The system has been installed in the real environment for several months to verify its functionality in real environmental conditions. Finally, the study presents “a huge amount of power near about 30-40% can be saved and the curse of traffic jam can be deprived because of obeying the traffic rules”.

[12] Another study published on “Energy-Efficient Intelligent Street Lighting System Using Traffic-Adaptive Control” proposed a smart control of public lighting system. This study consists of smart control of LED streetlights for adoptable illumination and monitoring system to achieve energy efficiency. Moreover, the study presents a new approach of smart lighting based on traffic.

Less power consumption, environmental pollution and increased lifetime are the main drivers to move into LED streetlights from conventional lighting system. Sensor integrated system performs intelligent luminaries, and which is controlled by variety of interfaces. Nowadays, Wireless Sensor Network (WSN) is the backbone of applications in every domain [13]The ubiquitous nature, easy monitoring and control of Wireless Sensor Network are the added advantages for the networked LED luminaries which can save considerable amount of energy, centralized management, power management and many more. [14]The low power, less complex and more reliable WSN offered by ZigBee has emerged as a preferable choice for energy efficient indoor and outdoor lighting”. The combination of LED with Zigbee protocol in smart street lighting can adjust the dimming in ambient conditions.

The focus of this study is to adjust the brightness of smart LED lights based on the traffic volume on roads. Streetlights are equipped with various sensors such as temperature, light, and power metering sensors. They are networked together in a ZigBee mesh network which offers reliable communication among connected devices. ZigBee streetlight controller works as the gateway. The gateway translates messages in either way. Sensor collected data of ZigBee packets are translated into TCP/IP network packet format and LED status sent through a remote user is translated into Zigbee packet. Current system status is updated in Premise energy management software (PEMS) through internet, and it allows the remote operators to observe and manage the system. This system runs on a server machine connected to the gateway through internet. The software controls the scheduled dimming levels as well as PEMS can bypass the pre-defined scheduled to control streetlights based on demand. The remote operator can control the streetlights individually or as a group. Also, the system can monitor light, temperature, and power consumption. The software interface with traffic sensors installed on roads or the vehicular communication system to observe traffic volume and thereby adjust the light intensity. Temperature sensors are soldered on the controllers which can read the temperature level inside lamps and the remote users are notified when the safe limit is exceeded. Power consumption of streetlights are periodically monitored to observe power consumption as well as to indicate malfunctioning due to power failure.

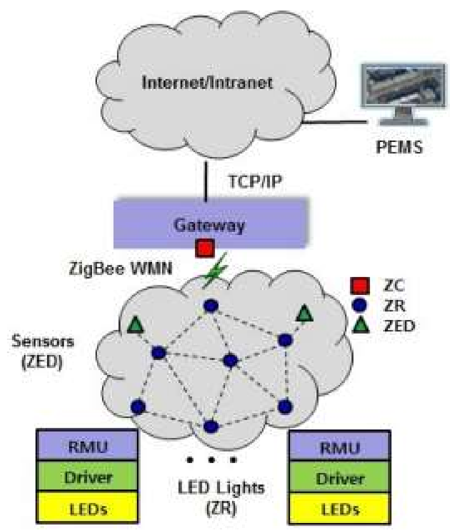


Figure 2.8:Traffic adaptive control lighting system

2.3 Summary

This chapter presents the literature of existing street lighting systems to reduce growing energy consumption through different methodologies.

Chapter 3: Methodology

3.1 Introduction

This chapter discovers the conceptual framework of proposed smart streetlighting system with Software and Hardware requirements, their usage for the proposed lighting system. Also, the system architecture and communication architecture of the proposed system is discussed, Since the proposed system is adaptive to traffic conditions, the algorithm of the system has different modes of operation. Novel concept of control unit algorithm is also presented in this chapter.

3.2 Hardware Requirement

3.2.1 Ultrasonic sensor

Ultrasonic range detection sensor is used to measure the distance for the objects. [15]This module sends ultrasonic pulse at around 40 KHz, which can travel through air. Then wait sometimes to listen the pulse to echo back. The sensor can send pulse as fast as 20 times a second. The module automatically sends 40 kHz square wave and automatically detect whether it receives the returning pulse signal. Based on travel time and speed of sound, distance for the object can be measured and thereby movements of vehicles or people can be detected to turn on streetlights to reduce unnecessary energy wastage. It can sense the objects regardless of material or color. The range it can travel is up to 3 meters. This requires 5v power supply to be connected.

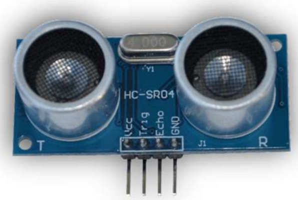


Figure 3.1:Ultrasonic Sensor

3.2.2 LDR (Light Dependent Resistor) sensor module

The resistance is dependent on the surrounding light intensity. [16]During daytime, light hits into LDR sensor and lead to decrease the resistance offered by the sensor. During nighttime, LDR resistance gets high. The sensor can be used to present intelligent luminaries based on surrounding light intensity. Streetlights can be turned on and off automatically through detection by LDR from evening to morning.

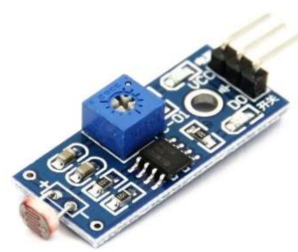


Figure 3.2:LDR Sensor Module

3.2.3 NodeMCU

NodeMCU is an open-source prototyping board with open-source firmware support for IoT applications. [17]Wi-Fi integrated prototyping board can be programmed through Arduino IDE, and which integrate a processor and USB controller. In the proposed lighting system, microcontroller (NodeMCU) receives input signals from sensors and charge controller attached to it and control streetlights based on the program uploaded to it. ESP8266 is a low cost NodeMCU board with full TCP/IP stack is used as the microcontroller for the proposed lighting system.

Figure 3.3:NodeMCU

3.2.4 Voltage sensor

Voltage sensor is used to measure the external voltages which can sense 0 – 25 DC voltage. Analog output pin of the voltage sensor is connected to analog input pin of the microcontroller and the sensor works on the voltage divider principle.

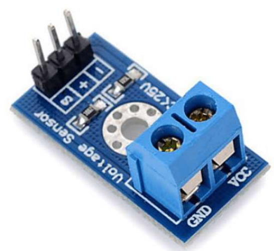


Figure 3.4:Voltage Sensor

3.2.5 LED (Light Emitting Diode)

LED lights are made up with non-toxic material. [18]The conventional lights with toxic gas can harm for the environment as well as for people. LED lights are accepted worldwide for any lighting applications due to many reasons. LED bulbs are durable, and which can last from 10 to 15 years [18] which minimize the installation, operational and maintenance cost. They are an economical choice which can save up to 90% of electricity cost. This study uses 230V LED streetlights.

3.2.6 Solar panels

[19]solar systems are based on photovoltaic technology (PV Technology) which can convert the solar irradiation falls onto the solar panel into electricity. Monocrystalline Silicon Panels consist of single silicon panel with higher silicon content can convert more energy into electricity. These types of solar panels are more efficient than other types of panels.

3.2.7 Li-ion Battery (Lithium-ion Battery)

[20]Li-ion battery is a popular type of rechargeable battery which contain high energy density, low self-discharge and loss of charge is slow when the battery is not in used. Since

these batteries contain flammable electrolytes, incorrectly charged may lead for fires. Solar panel is used as the primary power source and inability to provide power will change the power supply to battery.

3.2.8 Charge Controller

[21]Charge controller is placed between solar panel and battery which can protect the battery from overcharging or over discharging lead to enhance the battery performance and life span. Among different types of charge controllers, this research uses shunt controllers to monitor the maximum level of battery charging. Shunt controller can separate solar cells once the battery is fully charged.

3.3 Software Requirement

3.3.1 MySQL Database

MySQL is an open-source Database Management system that is used by many organizations. It has become more popular due to various features. Work with many operating systems, support for many languages like PHP, PERL, C, C++, and work with large data set are the popular features of MySQL database management system. It supports for large databases with large data sets like 50 million rows in the table. The default limit size for a table is 4 GB. Therefore, Sensor collected data is stored in MySQL database.

3.3.2 Nodejs

Nodejs is an open-source run time environment for executing JavaScript code to build backend services called APIs (Application Program Interface). This environment communicates with some services setting on the server to send data, send emails so on. Node contains v8 JavaScript engine, additional modularity which are not available inside browsers. It's non-blocking asynchronous architecture allows for a single thread to handle multiple requests. Node is continuously monitoring Event Queue in the background. If there is an event, take it out and execute it. This helps to serve many clients which make the Nodejs scalable.

3.4 Proposed System Architecture

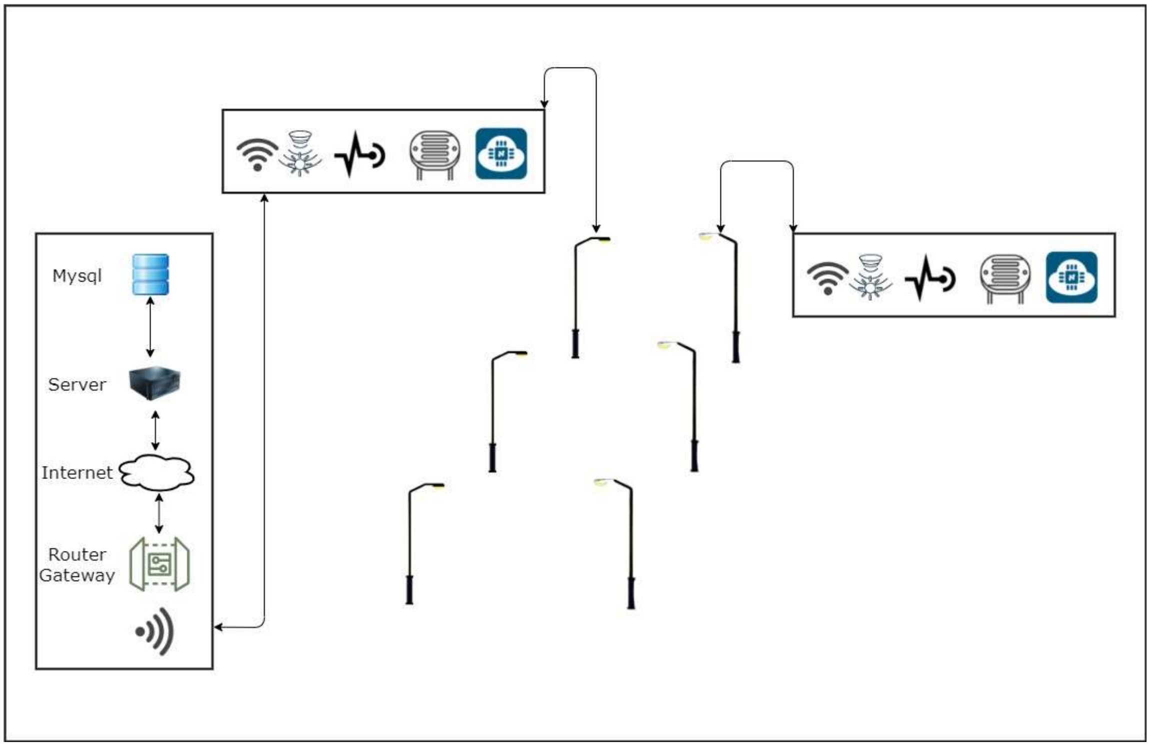


Figure 3.5: General Architecture of the system

The proposed system is designed for efficient utilization of power through eliminating unnecessary energy wastage. To achieve this the lighting system works on surrounding light and object presence. Motion detection sensors and light sensors work on the program uploaded into the controller and send the data to server for decision making. Based on the data, the server determines to activate different lighting modes according to the lighting algorithm.

The proposed intelligent public street lighting system combines with three inter- related layers.

- Sensor Layer

Sensor Layer consists of lamp posts integrated with Light sensors, ultrasonic sensors and voltage sensors which interact with external environment to collect surrounding light intensity, movement of vehicle and people, the voltage level of lamp post.

- Communication Layer

Collected data is sent to a gateway through web socket secured (WSS) protocol and forward data to management layer through internet.

- Management Layer

Management layer consists of server which analyzes received data and take the decisions. Also, the data is stored in MySQL database.

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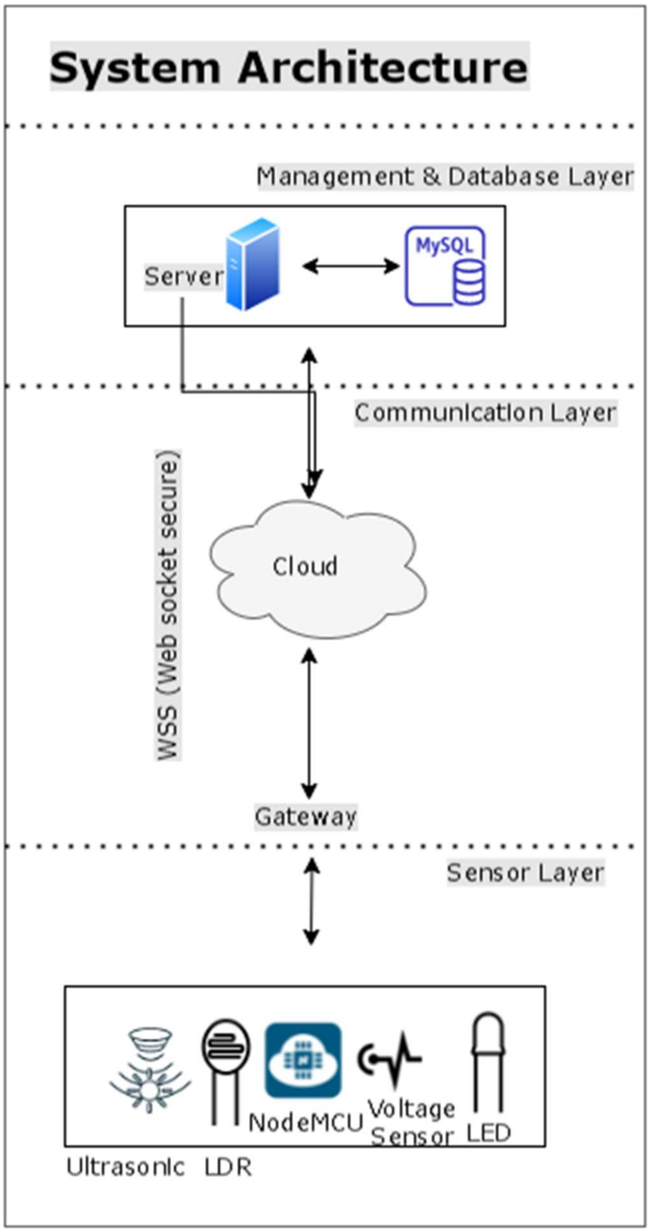


Figure 3.6:Proposed System Architecture

3.5 Control unit Algorithm

The innovative part of the proposed system is different lighting modes are introduced based on the type of road and traffic volume of the road.

The main categorization is performed based on the type of road. Different lighting operations are proposed for Highways, Normal Motor ways and Walking Paths. This classification is performed based on speed limits allowed on roads and light poles installation method. (One side installation or two side installation)

3.5.1 Highways

Highway lighting operations are further classified based on traffic volume such as High Traffic, Low traffic, and No vehicles on roads. Since, the speed limit allowed on highways are 100km/h, approximately a vehicle can travel 30m per second. Since the vehicles travel only one side of the rode, all the lamps are installed on one side of the roads. The speed limit on highways and the lamp poles arrangement is the main reason for introducing this lighting mode.

First take the input from light sensor. During daytime, streetlights are switched off and the light status is sent to the sever and update database. During nighttime, traffic volume information is obtained from the traffic management system and change the mode of lighting operations to switch on all lamps for 80% in a high traffic situation. Absence of vehicles in highways, choose the lighting operational mode to reduce the luminary of all lamps for 10%. In normal situations where there is no traffic on roads, obtain the input from motion detection sensor. If the sensor detects the presence of object, it activates another operational mode, switch on all lamps to its maximum for 200m, switch on all lamps 60% for next 200m and switch off all lamps after 400m of the particular lamp post. Finally, light status is sent to the cloud through server.

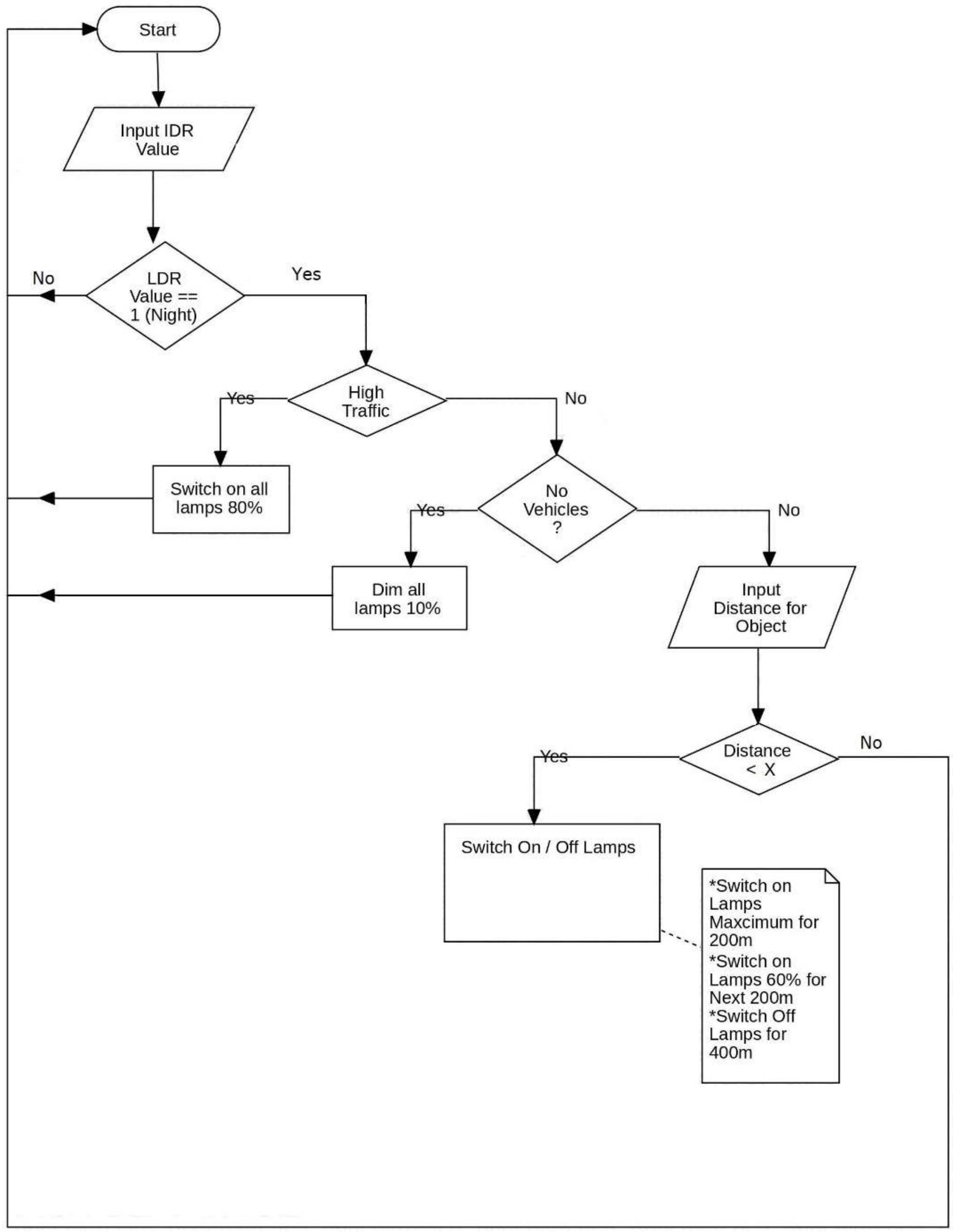


Figure 3.7:Algorithm for Highways

3.5.2 Normal Motor Ways

Normal motor ways are also classified based on traffic conditions on roads as high traffic and low traffic. The speed limit on normal motor ways is around 70km/h and lights remain switch on for a percentage during nighttime since vehicles are coming from both sides of roads. Also, lamp posts are installed on both sides of roads.

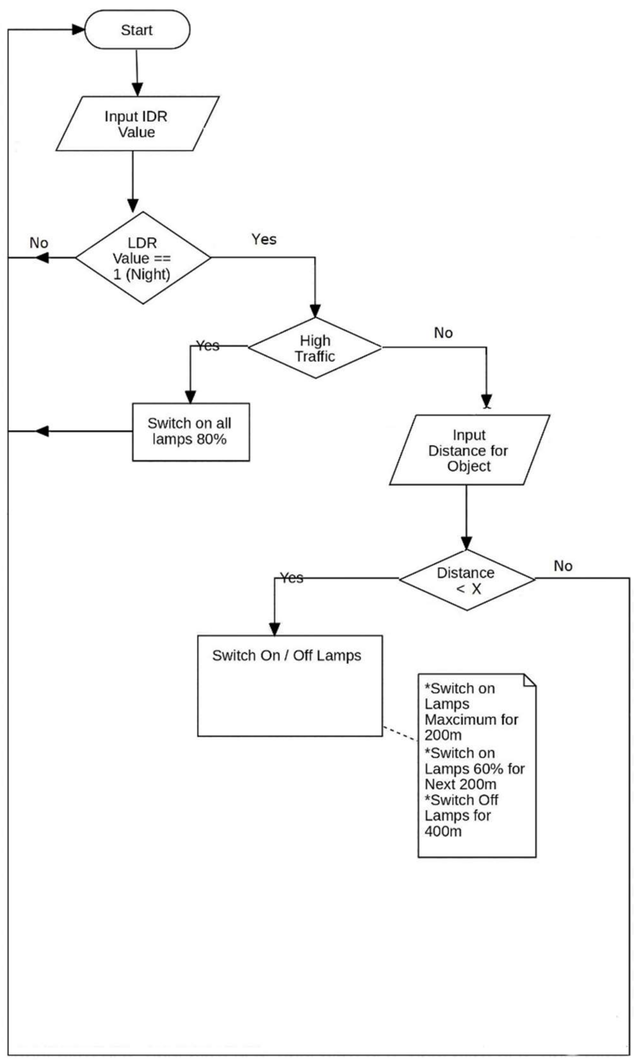


Figure 3.8:Algorithm for Normal Ways

Considering all these factors, Switch on all lamps for 80% during nighttime in a high traffic situation. In a low traffic situation, motion detection sensor activates and measure the distance for the object to determine the presence of objects. Movement of objects on roads activates a different lighting mode, switch on lamps 80% for first 100m, switch on lamps 50% for next 100m, decrease the luminary for 10% after 200m onward. Absence of vehicles on roads reduces the luminary for 10% and the light status is stored on cloud.

3.5.3 Walking paths

Streetlight installation in walking path is based on the width of road and height of the lamp post. Area covered by each lamp post is important for walking paths to ensure the safety of pedestrians by providing optimal lighting. Area covered by each luminary is dependent on width of road, light density, distance between two lighting poles and the lighting arrangement (one-sided or both sides).

Based on above parameters lamp posts are installed on walking paths and the lighting arrangement is designed to provide optimal lighting for the road users. Streetlights are installed on said locations in way that the area of each luminary spread as shown in the figure which ensures enough lighting for the road users.

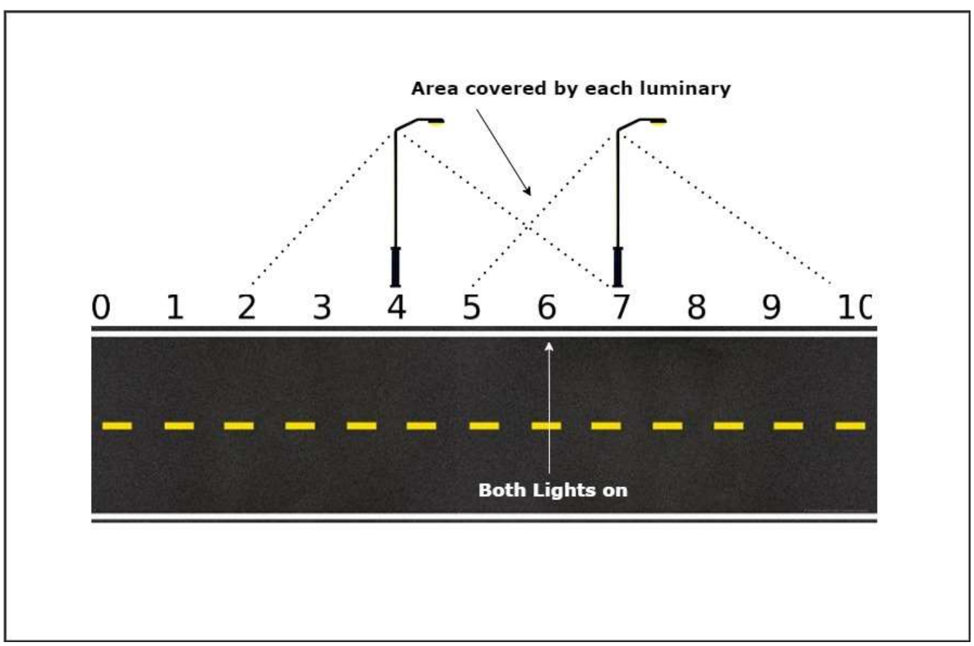


Figure 3.9:Algorithm for Walking Paths

3.6 Summary

This chapter presents the Technologies used to develop the system, the architecture of the system, control unit algorithm for different types of roads (Highways, Normal Motor ways, Walking paths).

Chapter 4: Implementation

4.1 Introduction

This chapter demonstrates how the proposed system has been implemented. Moreover, the chapter presents the implementation of sensor layer, communication layer and Management and Database layer. A prototype has been developed to evaluate the operations of proposed system. In addition, this chapter provides the results which are received by implementing it.

4.2 Prototyping Model

A prototyping model has been developed to evaluate the execution of proposed system. As the figure shows a low budget prototyping model is developed. During the development of prototype, 3mm Light Emitting Diodes as streetlights and ESP8266 NodeMCU is used as the microcontroller, its inbuild Wi-Fi manager can be used in the program to connect to Wi-Fi network. Also, LDR light sensor module to detect light intensity, 5 pin Ultrasonic sensor module for motion detection, 20A current sensor module to measure voltage, 9v battery, DC-DC Buck Converter Step Down Module to convert voltage levels are used in this prototype system.

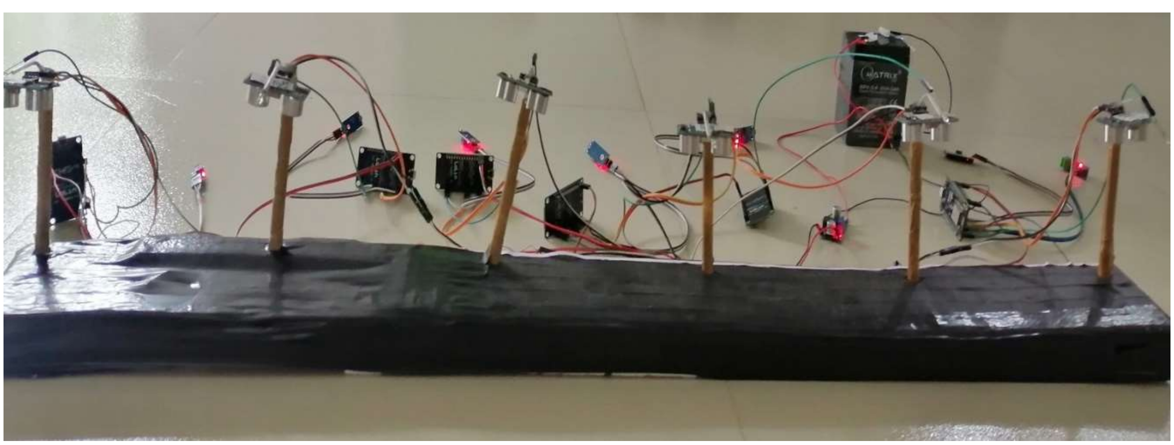


Figure 4.1:System Prototype

4.3 Sensor Layer Implementation

Sensor layer equipped with LDR Light sensor, Ultrasonic sensor and Voltage sensor is connected to NodeMCU. Microcontroller works according to the program uploaded into it. 9V battery is used to supply power to the prototype. As the figure shows, DC-DC Buck Converter Step Down Module converts the input voltage into 5v and supply 5v for NodeMCU and ultrasonic sensor. Ultrasonic sensor operates on 5v. Since LDR sensor can operate on 3.3v, sensor is connected to NodeMCU to supply power.

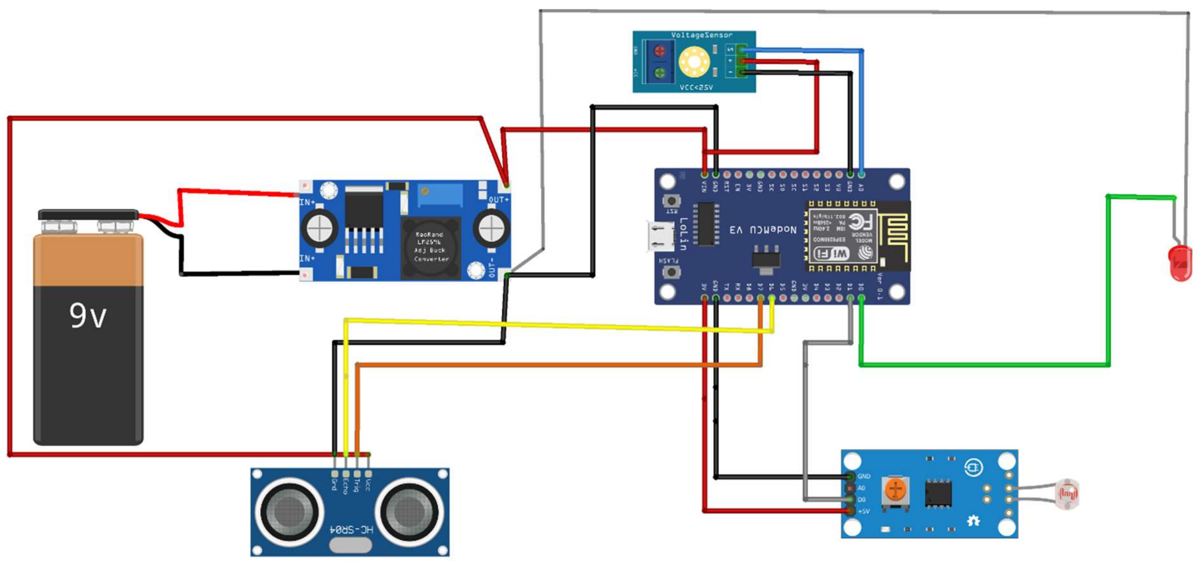


Figure 4.2:Sensor Layer

NodeMCU board is programmed using Arduino IDE and the program is uploaded into the board. System begins with the surrounding light intensity detected by light sensor attached to microcontroller. if the surrounding light intensity is low, ultrasonic sensor detects the movement of objects and switch on the particular light streetlight. The system has been extended to connect to a server and database, discussed in communication and management layers.

4.3.1 Pin connections

Ultrasound	
GND	NodeMCU - GND
Vcc	5v
Echo	NodeMCU – D7
Trigger	NodeMCU – D6

Table 4.1:Ultrasound – NodeMCU

LDR	NodeMCU
GND	GND
Vcc	3V
D0	D1

Table 4.2:LDR – NodeMCU

Voltage Sensor	NodeMCU
GND	GND
Vcc	Vin
Out	A0

Table 4.3:Voltage Sensor – NodeMCU

The prototype can be extended to connect solar panel to save energy. Solar panel is connected to charge controller to protect the lifetime of Li-ion battery connected to it being overcharged. Once the solar rays fall on to solar panel, battery attached to the charge controller is charged and battery supplies power to the system. Moreover, a charging circuit can be connected to automatically recharge the battery when the power gets low.

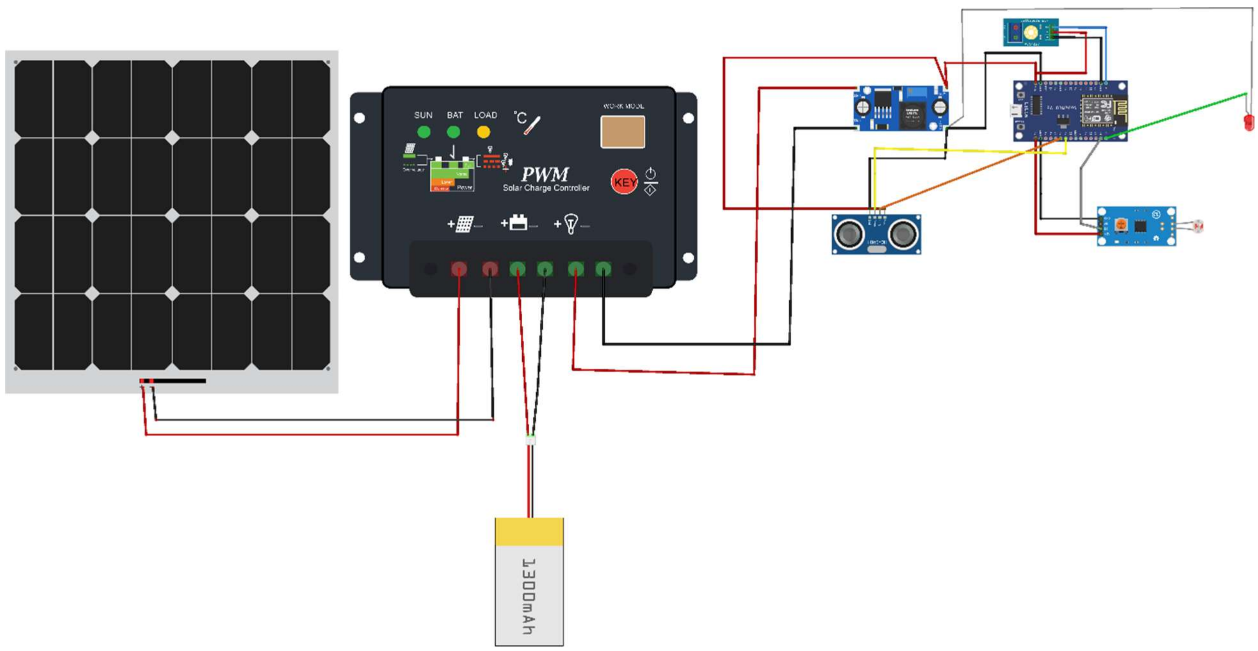


Figure 4.3:Solar Energy for Sessor Layer

4.4 Communication Layer implementation

Built-in Wi-Fi functionality of the NodeMCU allows to connect with the gateway (router) wirelessly. ESP8266WiFi.h library should be included to the program to connect NodeMCU board to the router through WIFI. Also, SSID and password of router should be set up in the program. Once the NodeMCU board is connected to the router through network, a local IP is assigned for the NodeMCU by the router.

Moreover, NodeMCU board connects with the server through internet.

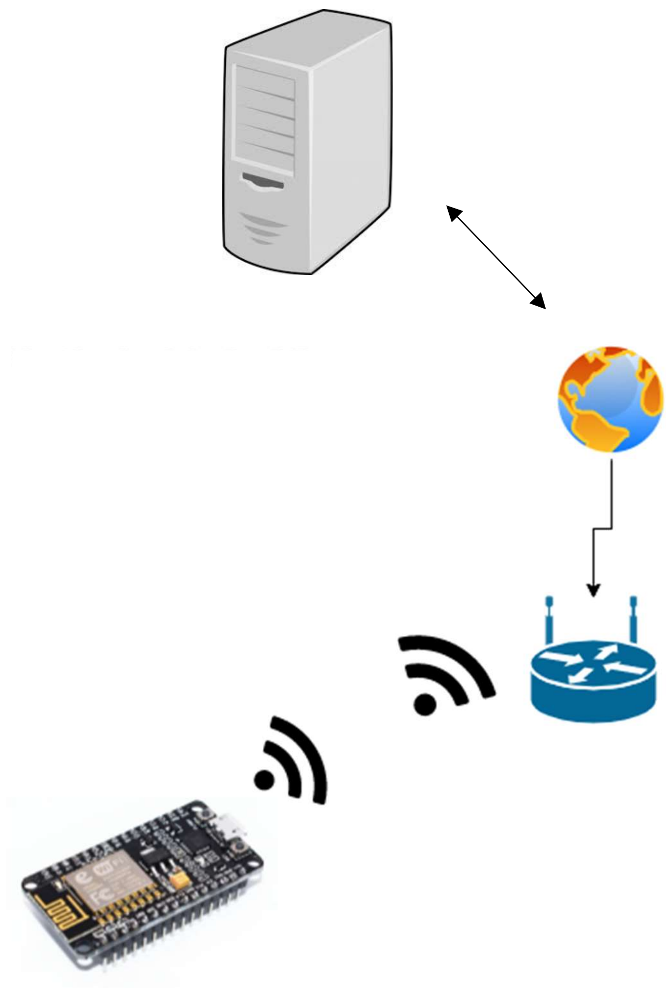


Figure 4.4:Communication Layer

4.5 Management and Database Layer implementation

Management Layer consists of the server and the database. The server has been implemented using NodeJS. It is an open-source run time environment for executing JavaScript code. This is used as the API for building backend services which uses set of modules, MySQL module to connect with MySQL database, Web socket module to create a connection for sending messages from client to server, or server to client at any instant. The communication happens through Web Socket Secure Protocol. Web socket object will automatically open a connection for the server through a specific port.

Client (microcontroller) sends a request for web socket server and the server act upon the program written on the API. Then the server sends the real time data to MySQL database while communicating with the client at the same time.

Figure 4.5:Management and Database Layer

4.5.1 Execution of Management and Database Layer

Each client (NodeMCU) is assigned a unique ID which contains the program to control sensor layer and client (NodeMCU) sends a request for the web socket server through the port (8000) to send sensor collected data to database. Server decode the request and read the device id of the client who sent the request.

Then the server responds the client, and the client sends its status (online/offline) to the server every 60 seconds to avoid disconnections. Moreover, the server updates the database with the last online time of the particular light.

Also, obtain the device ID form the message sent by the client and retrieve the device IDs of next two streetlights to send a command for the immediate two streetlights to be switched on.

4.6 Summary

This chapter describes how the system has been built. The implementation of sensor layer, communication layer, management and database layer are further demonstrated in detail.

Chapter 5: Results and Evaluation

5.1 Introduction

This chapter demonstrates the results of prototype system developed to evaluate the functionality of proposed smart street lighting system. Sensors are controlled by the algorithm uploaded into microcontroller (NodeMCU) and the outputs are displayed accordingly. Sensor network connects with the server and send real time sensor collected data to the server. This chapter presents the results of server implemented using NodeJS and the data stored in MySQL database server.

5.2 Sensor Layer

LDR sensor attached to particular streetlight detects the surrounding light intensity and display “bright” when the light intensity is high.

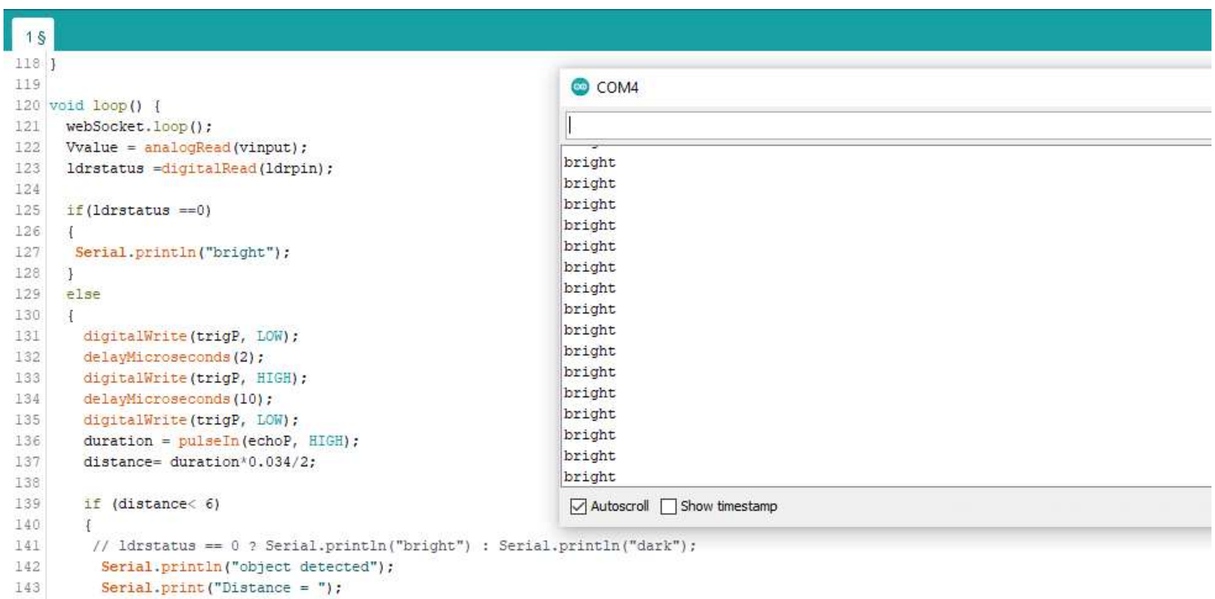


Figure 5.1:Surrounding Light intensity is high

If the surrounding light intensity is low, ultrasonic sensor detects the object movements based on the distance to the object. If the distance is not less than 6cm, display the message “No object Detected”.

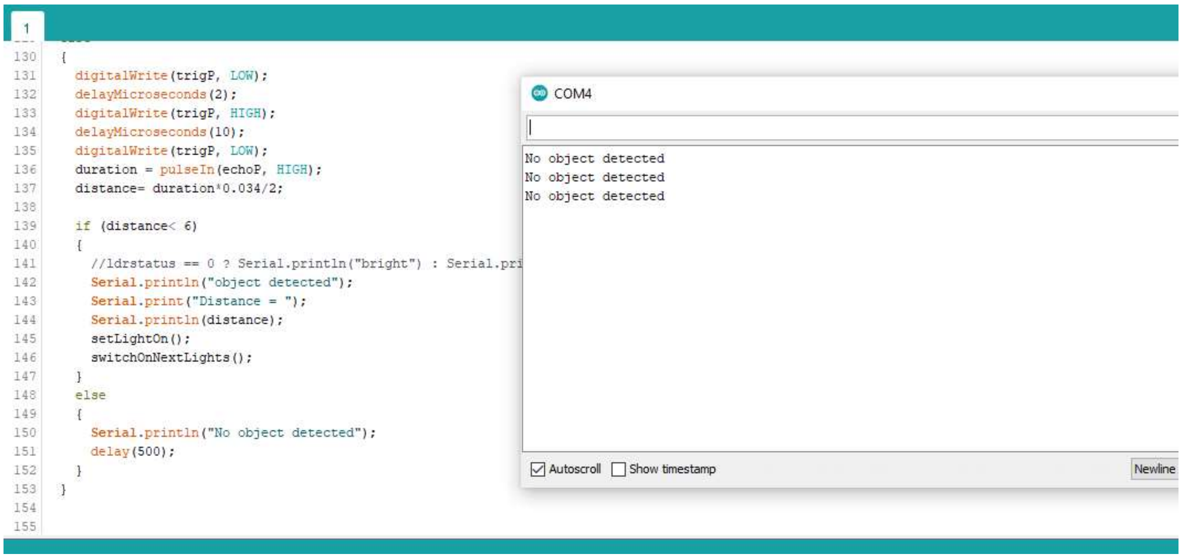


Figure 5.2: No object Presents

If the distance is less than 6cm, the system displays the message “Object Detected”.

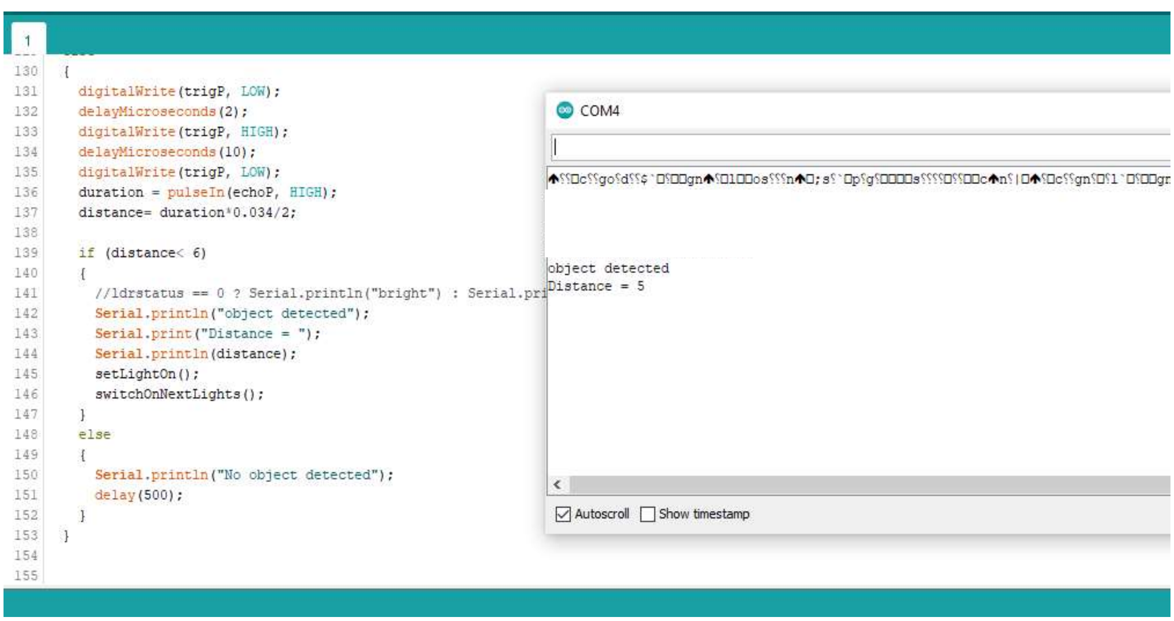


Figure 5.3:Presence of Objects

The streetlight connects to the router through WIFI. SSID and Password should be setup in the microcontroller attached to each streetlight. Router issues an IP address for each client.

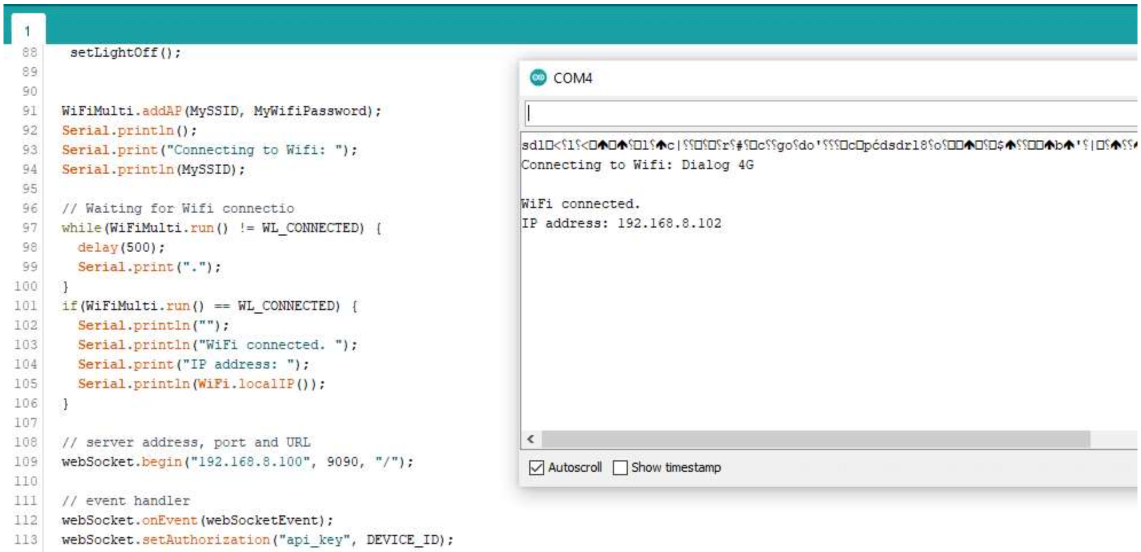


Figure 5.4: Connect to the network

5.3 Communication Layer

Streetlight (Client) sends a request to the server.

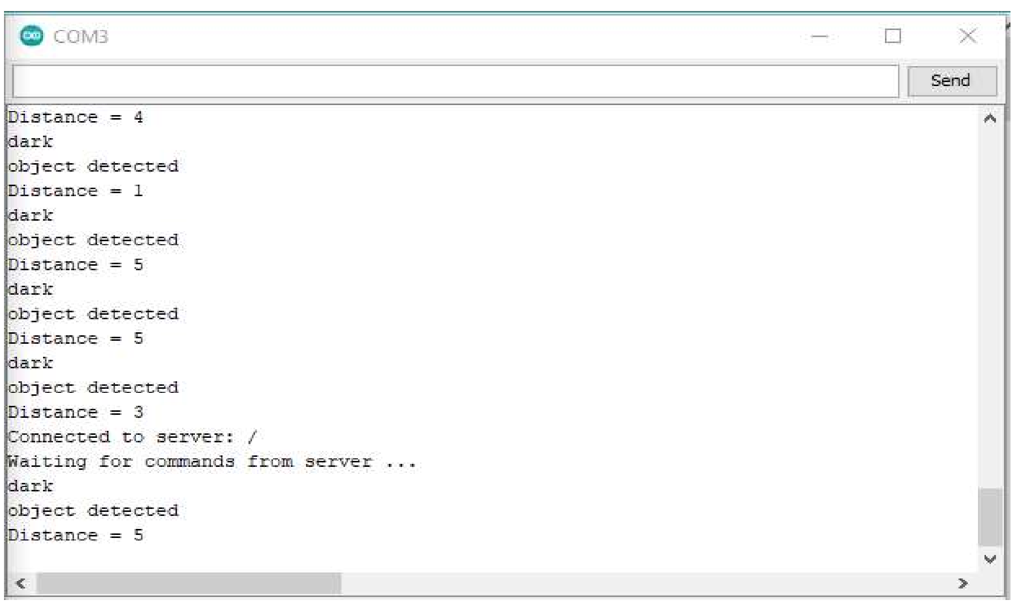
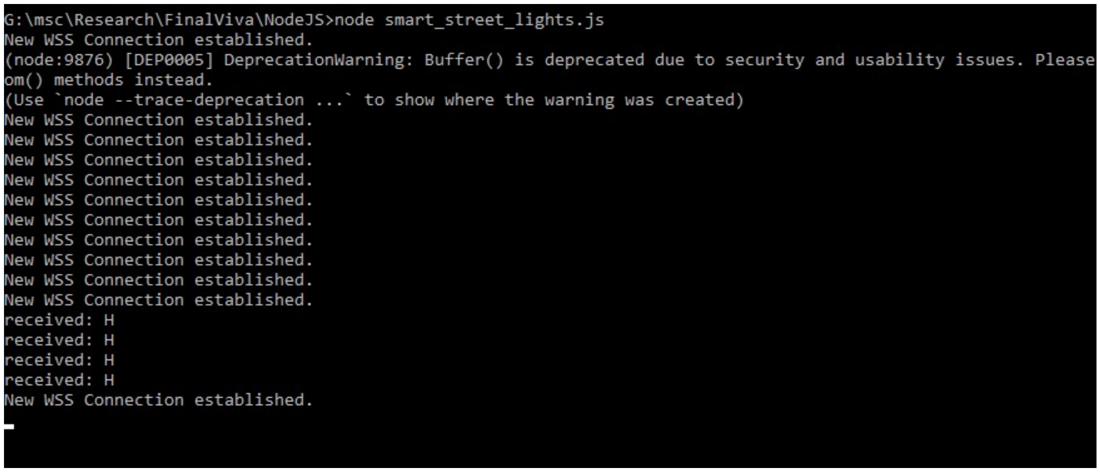


Figure 5.5:Client request

The server is listening to the port 8000 and each Client sends a heartbeat value at each 60 seconds to avoid disconnections.

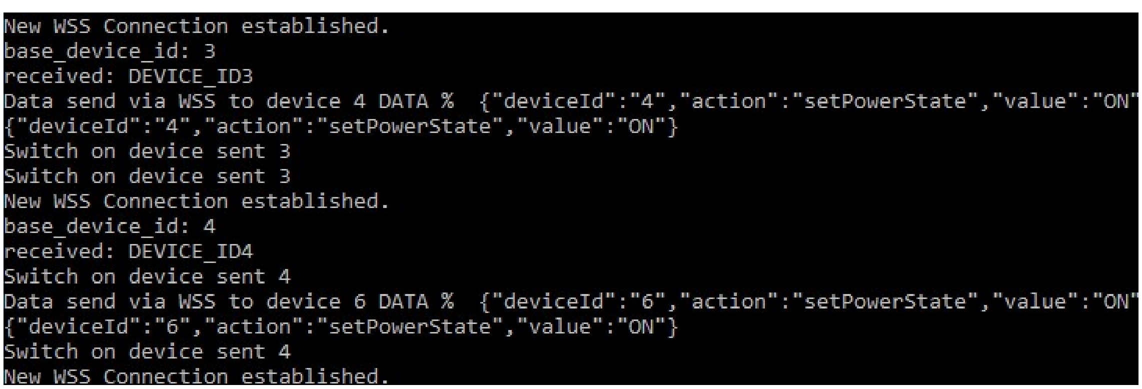


```
G:\msc\Research\FinalViva\NodeJS>node smart_street_lights.js
New WSS Connection established.
(node:9876) [DEP0005] DeprecationWarning: Buffer() is deprecated due to security and usability issues. Please
om() methods instead.
(Use `node --trace-deprecation ...` to show where the warning was created)
New WSS Connection established.
New WSS Connection established.
New WSS Connection established.
New WSS Connection established.
New WSS Connection established.
New WSS Connection established.
New WSS Connection established.
New WSS Connection established.
New WSS Connection established.
New WSS Connection established.
received: H
received: H
received: H
received: H
New WSS Connection established.
```

Figure 5.6:Establish connection with server

5.4 Management and Database Layer

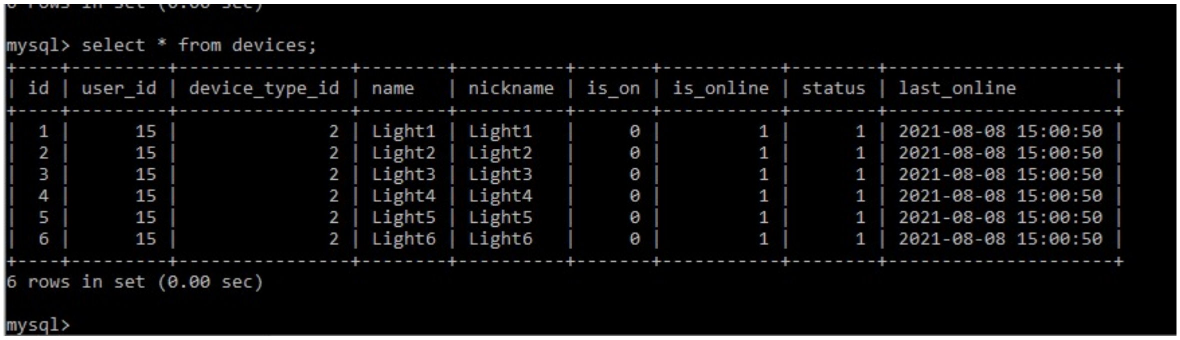
Each streetlight is assigned a unique ID and when the streetlight is switched on, the server displays a message. At the same time, the next two streetlights are switched on. The following figure shows, the streetlight 3 is switched on and a command is sent to the next two streetlights (4,5) to be switched on.



```
New WSS Connection established.
base_device_id: 3
received: DEVICE_ID3
Data send via WSS to device 4 DATA %  {"deviceId":"4","action":"setPowerState","value":"ON"
{"deviceId":"4","action":"setPowerState","value":"ON"}
Switch on device sent 3
Switch on device sent 3
New WSS Connection established.
base_device_id: 4
received: DEVICE_ID4
Switch on device sent 4
Data send via WSS to device 6 DATA %  {"deviceId":"6","action":"setPowerState","value":"ON"
{"deviceId":"6","action":"setPowerState","value":"ON"}
Switch on device sent 4
New WSS Connection established.
```

Figure 5.7:Execution of Server

The real time data (online status of each streetlight) is updated in the database.



```
mysql> select * from devices;
+----+---------+----------------+--------+----------+-------+-----------+--------+---------------------+
| id | user_id | device_type_id | name   | nickname | is_on | is_online | status | last_online         |
+----+---------+----------------+--------+----------+-------+-----------+--------+---------------------+
|  1 |      15 |              2 | Light1 | Light1   |     0 |         1 |      1 | 2021-08-08 15:00:50 |
|  2 |      15 |              2 | Light2 | Light2   |     0 |         1 |      1 | 2021-08-08 15:00:50 |
|  3 |      15 |              2 | Light3 | Light3   |     0 |         1 |      1 | 2021-08-08 15:00:50 |
|  4 |      15 |              2 | Light4 | Light4   |     0 |         1 |      1 | 2021-08-08 15:00:50 |
|  5 |      15 |              2 | Light5 | Light5   |     0 |         1 |      1 | 2021-08-08 15:00:50 |
|  6 |      15 |              2 | Light6 | Light6   |     0 |         1 |      1 | 2021-08-08 15:00:50 |
+----+---------+----------------+--------+----------+-------+-----------+--------+---------------------+
6 rows in set (0.00 sec)

mysql>
```

Figure 5.8:MySQL Database

5.5 Evaluation of the system

Different conditions are applied to represent the possibilities that effect for the output.

- Ultrasonic sensor uses sound instead of light to detect objects. The color of the object (vehicle) is not affected for the result and ultrasonic sensor can measure the accurate distance for the objects that it is faced.
- The sensor is not affected by environmental changes. The sensor works accurately not only inside but also outside. As well as they function accurately in rainy days.
- The proposed system is an effective low-cost solution for achieve considerable energy consumption through different lighting classes based on traffic volume and speed limit allowed on roads.

5.6 Summary

This chapter presents the results of entire system which consist of sensor layer, communication layer and management and database layer.

Chapter 6: Conclusion

6.1 Introduction

This chapter presents the findings of the research. Moreover, It provides a brief discussion of the overall research and the prototyping system developed.

6.2 Limitations

There are several challenges of this system. The distances between ultrasonic sensor attached to streetlight and the road. Minimum distance that the ultrasonic sensor can detect is 2cm whereas maximum range is 400cm. Distance between ultrasonic sensor and the road should be in between the mentioned range to get the correct result.

Ultrasonic sensor should be installed perpendicular to the object to get the accurate result. If the object's reflective surface is in a shallow angle, the sound that echo back would not reflect to the sensor.

The LDR light sensor requires a few milliseconds to adopt for the changes in light intensity. Also, the sensor collected data is sent to the server through network. Data packets send from client (streetlight) to server should be encrypted when it is transmitted over the network.

6.3 Future works

Previous section pointed out the limitations of the proposed system and they should be addressed when the system is installed in the real environment. Moreover, the results and knowledge gained from this research can be used as a contribution for future research.

In future, the system should be implemented on a larger scale to evaluate the system functionality using high performance sensors.

The system can be extended to produce intelligent dimming profiles based on weather conditions. Weather can be predicted using machine learning techniques and it can be used to maintain different dimming profiles.

Analysis of appropriate dimming levels for each lighting class is another future work which can enhance this study further.

6.4 Summary

Power demand is increasing day by day. There are many services in urban areas which utilize huge amount of power such as hospitals, buildings, transportations etc Among them, Lighting both indoor and outdoor consume a considerable energy from the entire global energy. Public street lighting system is one sub system of entire lighting system used by humans and it represents nearly 40% of total energy consumption.

Smart control of efficient street lighting system can save considerable energy to face for future growing energy demand. However, the municipalities should ensure enough lighting for the pedestrians and drivers to ensure their safety and comfort on roads.

The purpose of this proposed study is to save energy through smart control of street lighting while ensuring appropriate and enough lighting for the road users.

The smart city concept is becoming a more popular concept due to the dramatic urban development with Internet of Things. Information and communication technology in collaboration with internet of things effectively manage the resources and assets of the city centers. City related data is collected using sensors and are processed and analyzed them in real time to manage the resources of the city. City related data can be sent into cloud storage through internet so that they can be saved in later analysis.

A prototype has been developed in this study to evaluate the proposed system. The proposed system uses LED lights over conventional streetlights and renewable energy to achieve energy saving and green growth. The system is combined with existing traffic management system to get the real time traffic information to control streetlights based on traffic on roads. Also, different lighting operations are proposed for Highways, Normal Motor ways and Walking Paths based on speed limits allowed on roads. One sided and both side light installation methods are proposed based on the type of road. Solar cells are used as primary power source and in the absence of solar energy secondary DC power backup source is used. Charging circuit can recharge the battery when the battery power gets low. Moreover, charge controller between battery and solar panel can save the lifetime of battery. Each streetlight is attached a LDR light sensor, ultrasonic sensor connected to a microcontroller for collecting environmental data. Microcontroller connects to the server through network and sensor collected data is sent to the server to analyze them for decision making. Real time light information is sent to the database and server instructs the immediate streetlights to be switched on based on the program written.

This study has presented a clear comparison between conventional lighting systems and ICT enabled smart lighting system.

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