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ORIGINAL ARTICLE **SCIENCE & ENGINEERING**

SELF-POWER DRIVEN IOT-BASED SMART STREET LIGHTING SYSTEM (SSLS)

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Abstract

Street lighting promotes safety by allowing pedestrians and vehicles to see each other and prevents accidents, robberies, unwanted theft, and other crimes that occur on the highway. But the electrical energy consumed for street lighting is a significant concern for developing countries, especially when the lights are on at night during the absence of objects. Also, maintaining the street lighting system is costly, and manually controlling and repairing the lights is unfeasible. Considering the above problems, this paper presents an IoT-based street lighting system that mitigates the above challenges by automating the system. The proposed system will run entirely on solar power systems, which draw clean, pure energy from the sun. As the object gets 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. The proposed smart street lighting system is low-cost, faster-response, eco-friendly, and energy-efficient. It aims to reduce active power loss while boosting energy efficiency, monitoring air quality, decreasing the cost of maintaining the street lighting system, and reducing the hard labor cost of controlling the system.

Keywords: IoT, Street Lighting, Air Quality, Arduino Uno, ESP8266, MQ-135

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Introduction

Street lighting may offer safety benefits at midblock and junction locations and boost pedestrian safety, particularly at crossing points. Lighting intersections may also aid drivers in navigating by letting them view the crossing road, turning automobiles, traffic queues, and other drivers on the route. Because of the inefficiency of the municipal office staff in switching street lights off and on, 420MW of power costing roughly Tk34 lakh is wasted every month, which could have been employed to satisfy the demand of 4,000 non-urban households or an entire district municipality in Bangladesh. Most streetlights are traditional fluorescent, halogen, and sodium, and very few of them are energy-saving. The research report advises that the conventional fluorescent and sodium lights should be replaced with energy-saving light-emitting diode (LED) bulbs. According to the report, one switchman turns on thirty-three lamps daily. It proposes boosting the number of a switchman and strengthening the monitoring to prevent large power waste In (Rasel, 2014).

Manually resolving the problems listed before was not possible. So, if we want to tackle the issue, we need to use an automated system as a tool. A loT-based system for remote monitoring and control of linked street lighting seeks to change cities by delivering energy-efficient smart street lighting and the means to provide smart city services that will favorably improve the environment, the economy, and inhabitants alike. This study proposes a "Self-Power Driven IoT-based Smart Street Lighting System (SSLS)" solution to overcome most of the issues described above. The system has many sensors as well as a microcontroller. The sensors gather data from the environment and transmit it to the central data system. The microcontroller is said to be the brain of the device. NodeMcu will serve as a conduit for data sent to the central database. The essential contributions of this study are summarized below.

1. We investigated the current options for fixing the street light issues. As a result, we have proposed a cost-effective, quicker, more efficient, user-friendly, low-energy-consumption system that intelligently manages streetlights and prevents energy loss. Furthermore, the suggested solution will aid in measuring ambient air quality.
2. We developed a system that detects the presence of cars, pedestrians, and levels, and measures the quality of air.
3. We've also included the capability to save different sensor data in the local database as well as a web server using the NodeMCU module.
4. Ultimately, we demonstrated the suggested device's performance using a simulation environment.

The rest of the paper is structured as follows: The second portion goes through prior smart street lighting research efforts. Section three outlines the suggested cure and the mechanism for applying it. Section four presents the proposed remedy and the technique for enforcing the experimental findings. Section five wraps up the paper.

Literature Review

The authors (Abdullah et al., 2018) offered a method by which they constructed a street light control system. They first utilize the LDR to measure light intensity and then the IR sensor to detect and quantify the presence and speed of the automobile. Then, the system controls the street light based on the measured values. In (Priyanka et al., 2019), the authors describe their suggested system as a web-based street light system. This project employs an

LDR sensor to detect light intensity and a CCTV camera to catch any panic situations in the street. The authors suggested a smart street light system driven by footfall (Ahmad et al., 2019). The system is powered by a piezoelectric sensor and a DC generator. The created energy functions as a signal and is linked to light. The authors described a solution for smart cities that uses IoT to create intelligent, energy-efficient street light management systems. The writers have discussed three units for regulating streetlights (Mary et al., 2018). The authors describe a system that uses solar panels to generate energy to power the device (Nyemba et al., 2019). Solar panels cut energy usage and expense by collecting energy and using it to light up the street light. The main purpose of this project is to analyze and integrate these methods to efficiently reduce the consumption of power in street light systems. The three methods available to minimize energy usage caused by street lights are Part Night Lighting, Variable Lighting, and Light Trimming (Harrow Council., n.d.). Advancement in technology has brought many methods like brightness dimmer or controller (which reduce the intensity of light), and systems based on Wireless and ICT have been proposed (Beeraladinni et al., 2016). The ON/OFF of the street lights is accessed through the internet. The actions performed on the roads are tracked by a camera placed on top of the street lights and footage is saved on the server. In case of any emergency or danger, the panic button is placed on the pole, and any person caught in danger can press this panic button which raises an alarm to the nearby police station. The manual operation is completely eliminated to ensure safety and to prevent energy wastage in the system (Abinaya et al., 2017). The development of a smart street light system in this paper is to control the street light. This paper proposes that by using the IoT energy conservation and manpower are reduced and the saved energy can utilize efficiently for other purposes. The traditional HID lamps are replaced by LED to save more amount of energy. the calibrated digital signal output of the temperature and humidity is sensed by the DHT11 sensor. A Programmed Arduino board is used to provide the required intensity of the light at various times (Dheena et al., 2017). Development of the Urban IoT system proposed by the paper mainly focused on the sustenance of the smart vision of the city, it aims at abusing the further most innovative technology to support the added values for the management of the city and for the citizens. It provides a wide-ranging survey of the enabled technology protocol for an inner-city IoT (Zanella et al., 2014). The mentioned paper declares that can make decisions for light control. The LDR sensor identifies the daylight, and an IR sensor controls the street lights. Here solar cells are used as a battery to power up the system. The critical part of this project is monitoring the traffic and watching the entire system using cameras on the street light connected through the internet (Saifuzzaman et al., 2020).

In our paper, we proposed an IoT-based smart street lighting system with a self-powered mode. The system reserves solar energy into a battery which will later be used to power the light at night. The system can detect the objects running on the road, and the lights will increase their brightness as soon as the objects get closer to the light, otherwise, the lights will give low brightness to conserve the energy. The system also can measure the air quality from time to time to comprehend whether the surrounded environment is suitable for the health or not. Another notable characteristic of the proposed system is the capability to identify the faulty lights, whether the light needs repairing, replacing, or not. The system cleans up the light lamp at regular intervals by using a servo motor to remove the dust and dirt. The proposed system is automated, economical, environment-friendly, resource-efficient, etc. and it decreases the cost and hard labor of maintaining the street lighting system.

Proposed System

In the beginning, the system utilizes a single LDR sensor to determine the ambient light intensity. During the day, the light levels are usually high. The LDR will not enable the lamps to be turned on in direct sunshine. In the absence of the sun, we utilize an ultrasonic sensor with each street light pole to detect the movement of the objects. If ultrasonic sensors detect objects, the light intensity is proportional to the distance between the sensors and the objects. We employ solar panels on each lighting pole in our system to power the lights at night. We use an extra LDR sensor with each light bar to ensure that the lights operate correctly. If the lights aren't functioning correctly, send the data to a central database through an Esp8266 NodeMCU so that responsible personnel can respond fast. Once a week, we clean the street light poles using a servo motor. For a given distance, we employ two IR sensors to determine the speed of the cars. Each bar has an MQ135 sensor that collects data on the air quality surrounding the poles and sends it to ThingSpeak, where we can view the processed data graphically. The Arduino Uno is employed as a processing unit in our system. This section discusses the components that comprise the overall system. Figure 1 shows the proposed system architecture and figure 2 illustrates the various hardware components used in the system.

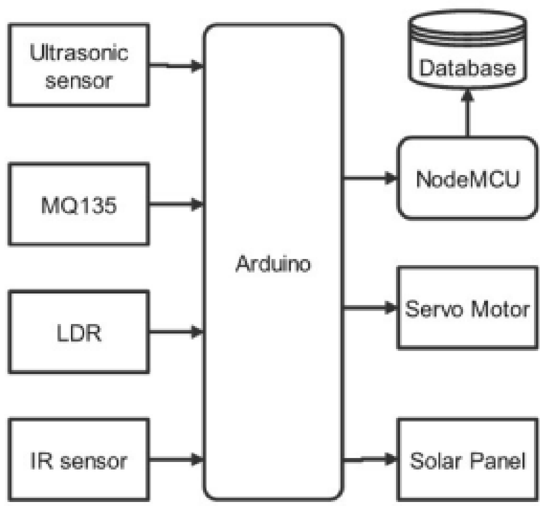

Figure 1. The proposed system's architecture.

Hardware components

Arduino UNO: Arduino is a programming microcontroller that includes a physical, electronic circuit and a software ecosystem (B_E_N., n.d.). The processing unit of our system is Arduino, and it was used to gather sensor data and operate a variety of actuators.

NodeMCU: The ESP8266 Wi-Fi system is at the heart of NodeMCU, an open-source IoT platform. Version 3 is based on the ESP-12E (ESP8266MOD) module, a user-friendly development board featuring analog and digital pins, a USB-to-serial converter found on the CH340g module, and a micro-USB connector (Loginov, 2020). The NodeMCU in our setup will transfer data from Arduino to the data server.

LDR: A Light Dependent Resistor (LDR) is a light-sensitive sensor. It's constructed of high-resistance semiconductor material. When light shines on semiconductors, the material's resistance reduces (Electronics-notes, n.d.). LDR is used in our system to detect light levels and identify damaged lights.

Servo motor: A servo motor is an actuator that efficiently turns a machine component. A servo motor is made consisting of a motor and a sensor that is linked to it. The servo motor employs a closed-loop system to manage

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the motor's rotational or linear speed and position (Realpars, 2022). In our method, we use a servo motor to clean the street lights automatically once a week.

MQ135 Sensor: MQ135 is a gas detector that detects the presence of hazardous gas. It detects dangerous gases such as NH3, NOx, Alcohol, Benzene, smoking, and CO2 (Components101, n.d.). MQ135 is used in our system to monitor the air quality of the street.

Ultrasonic Sensor: By producing ultrasound waves, ultrasonic sensors detect the existence of an item. It sends out ultrasonic waves, detects reflected ultrasound from objects, and transforms the signal into an electrical signal. Ultrasonic sensors measure time and determine the distance between two points in space (Jost, 2019). We employ ultrasonic sensors in our system to detect the presence of an item.

IR sensor: The infrared sensor monitors and detects infrared radiation in the surroundings. It detects movement within a specific range (Wikipedia., 2005). To measure vehicle speed, we employ two infrared sensors in our system. When cars pass over the two infrared sensors, we divide the constant distance by the time to pass through these infrared sensors.

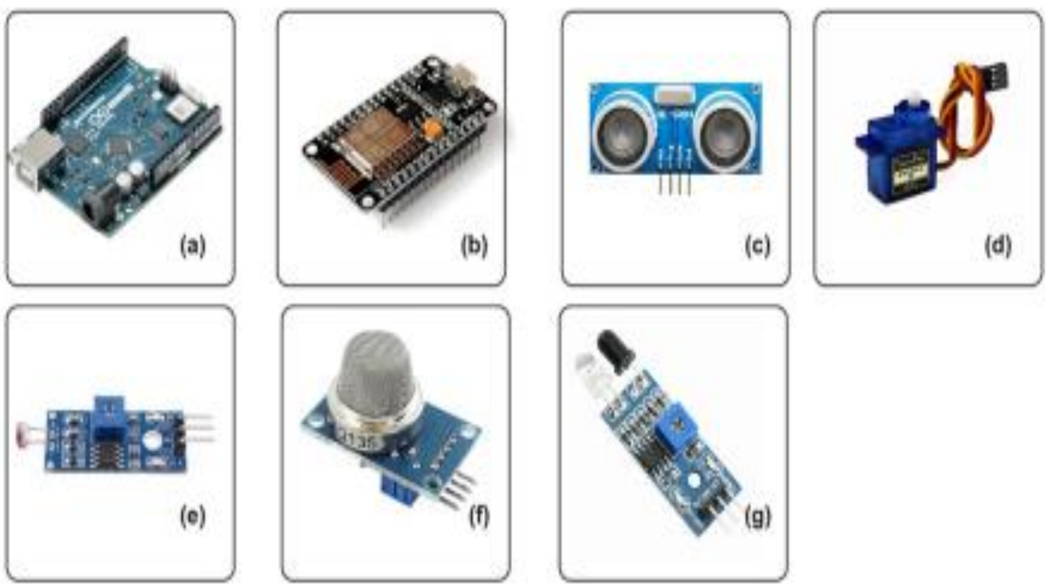

Figure 2. List of Components (a) Arduino Uno (b) NodeMCU (c) Ultrasonic Sensor (d) Servo Motor (e) LDR (f) MQ-135 Sensor (g) IR Sensor.

Software requirements

Arduino IDE: Arduino Software (IDE) is open-source, cross-platform software for Arduino that makes it easy to write a program and upload it to the Arduino board. It is a text editor and links to the Arduino hardware components to communicate with them. It uses the C/C++ language to program the Arduino board.

ThingSpeak: ThingSpeak is an open-source IoT analytics web service platform written in Ruby to collect real-time data. The data also can be preprocessed, visualized, and analyzed in the cloud by this platform. It includes a Web Service (REST API) that allows to collection and storage of the sensor's data in the cloud and builds the IoTs applications. The important benefit of this platform is it provides instant visualizations of data sent by different devices to ThingSpeak. It is often utilized for prototyping and proof of concept Internet of Thing (IoT) systems that need analytics. ThingSpeak is unrestricted for small non-profitable projects. However, in the proposed system, the data from MQ135 sensors are sent to ThingSpeack to monitor the air quality data. Besides, ThinkSpeak also helps to monitor the vehicle's speed in our system.

Workflow of the Proposed System

The suggested system automatically runs and maintains the streetlights with little human intervention. First, an ultrasonic sensor was put to detect the items and their distance from the sensor.

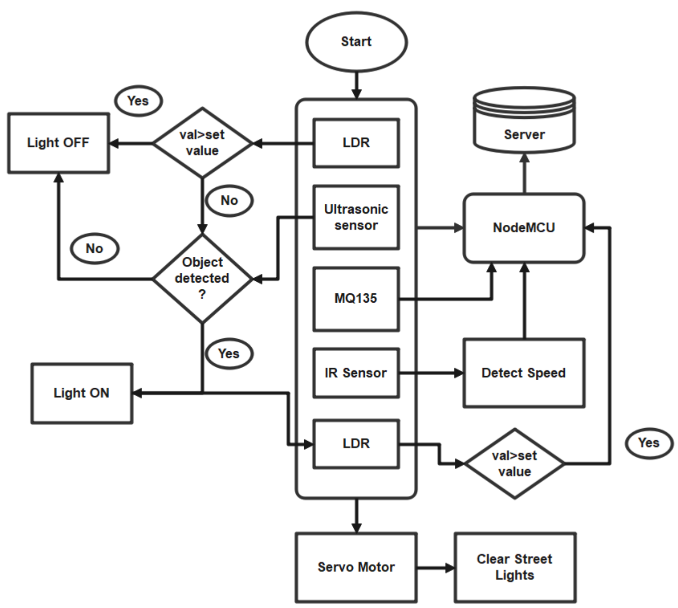

Figure 3. The proposed system's flowchart.

An LDR sensor is used to measure light levels. During the day, the LDR detects sufficient light and does not turn on the streetlights. However, ultrasonic sensors detect the items during the night and turn the lights on and off according to their distance. We utilize a solar panel to power the lights. Then, we use an extra LDR for each pole to see whether the lights are working correctly. If the light level from the sun does not provide the correct value, we send an alarm message to a centralized server through an ESP8266 NodeMCU. The air quality is

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measured using MQ135 and stored in the' ThingSpeak' cloud. Finally, we employ two infrared sensors to determine each vehicle's speed. Figure 3 depicts the system's process.

Experimental Setup and Result

We worked with the experimental outcome in this section. We explained the experiment setting first and then tested the performance of the ultrasonic sensor, the LDR sensor, to switch on the light inefficiently. We also included a servo motor to maintain the light with a good cleaning system, air quality monitoring with MQ135 of the experimental environment, vehicle speed detection with two IR sensors, a solar module for an efficient energy source, and a solar module for an efficient energy source.

Simulation environment

We've chosen the Arduino Uno board for this experiment as our project motherboard. We connected some sensors and actuators to this board for experimentation. We develop a sketch Arduino IDE, written in the c programming language, to control all the sensors and actuators and upload it for testing the device after connecting all of the essential components with Arduino Uno.

Result analysis

This section discussed our device's performance in light switching depending on obstructions and LDR. We tested the capacity to identify whether light is defective or not and pollution monitoring, vehicle speed detection, lamp cleaning, power sources identification, etc.

Uses of Solar Energy: We proposed to use a solar panel to collect solar energy during the day. A battery is used to store the solar energy to power up the whole system at a time when needed. The system will be able to get full power from solar energy.

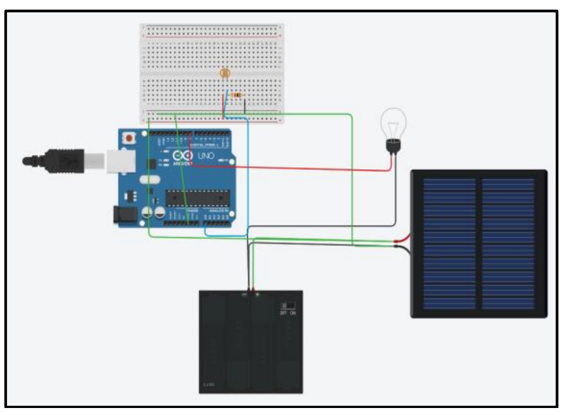

Figure 4. Connecting solar panel with Arduino Uno.

Figure 4 demonstrates the connection of the solar panel with Arduino Uno in Tinkercad. In Figure 4, solar cells are connected to the input of the lithium battery, whose output is connected to the Arduino Uno. We can

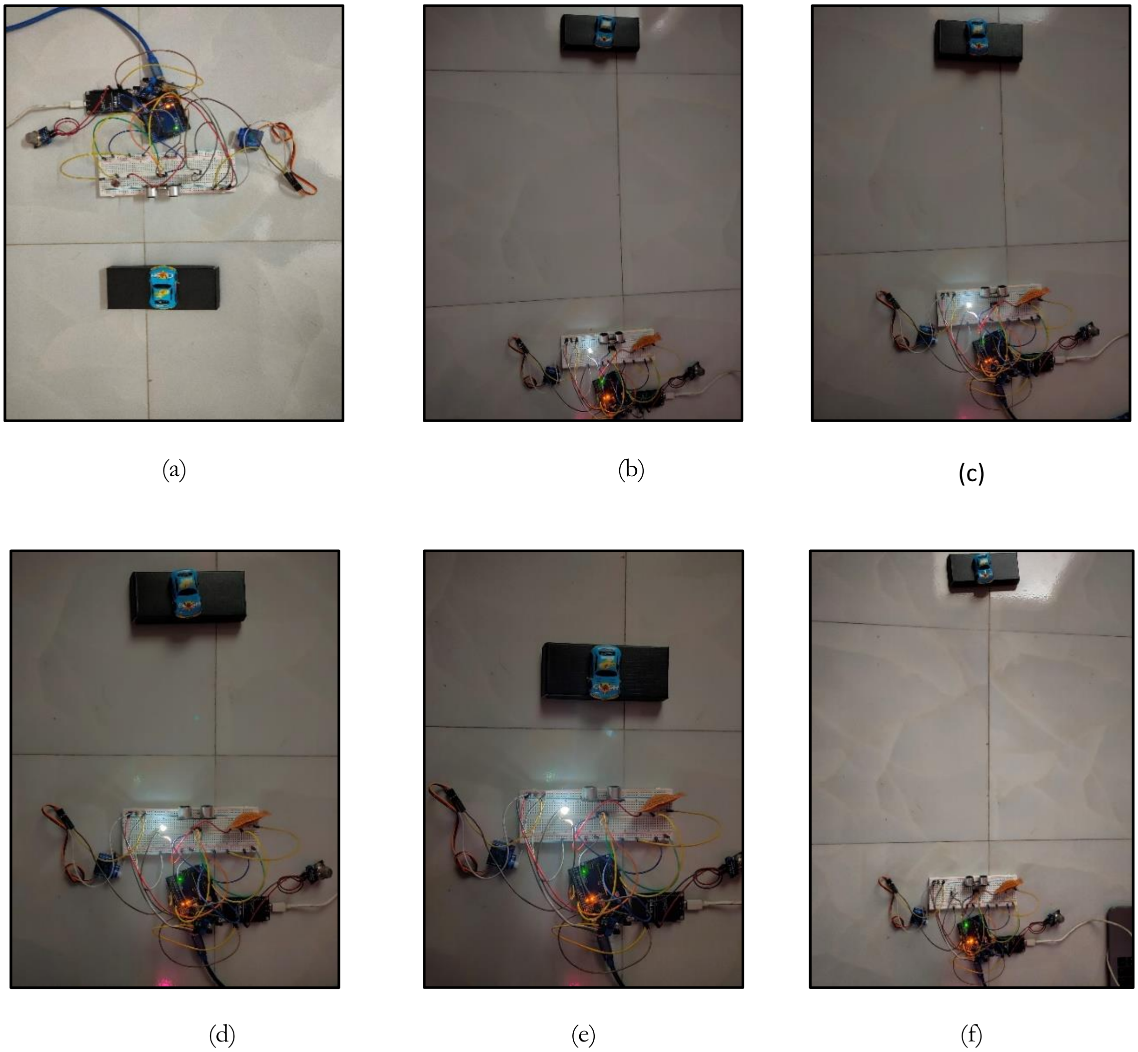

Figure 5. Light's brightness is (a) 0 (turn off) on the day (b) 50 when the object's distance is 50 units away at night (c) 100 when the object's distance is 35 units away at night (d) 180 when the object's distance is 25 units away at night (e) 255 when the object's distance is 15 units away at night (f) when the object's distance is far away at night.

now power the Arduino Uno by connecting the Vin pin to the positive terminal of the battery and the ground pin to the negative terminal of the battery, and the Arduino will function until the battery runs out. When there is enough sunshine, the battery will begin to charge automatically.

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Light's Brightness Change in presence or Absence of Objects: Figure 5 demonstrates the changes in light brightness in the presence or absence of objects. From Figure 5 (a), we see that when the system detects there is enough light in the environment, it turns off the light. However, in night mode, the system increases the light's brightness as soon as the object gets closer to the lamp pole and decreases the brightness when the object moves away from the pole.

Monitoring the Street Lights: Table 1 displays the state of each light contained in the database, indicating whether it is fully operational or not. When a vehicle passes through the sensor area yet the street light does not illuminate, it is deemed defective. After a certain period of time, the status of the lights is saved in the local database system, and the list is transmitted to the authorities for maintenance.In Table 1, the state column indicates whether the light is perfectly working or not. On means good, off means faulty. For example, row 1 indicates light no. 1 is perfectly working, whereas row 2 indicates light no. 2 is faulty.

Monitoring Air Quality: The proposed system can monitor the surrounding air quality. The system can show the air quality value on the PPM parameter. We tested the value at different times. Those values from the sensors are sent to the ThinkSpeak web service platform for displaying graphically. Therefore the system is able to detect air quality in different circumstances. Figure 6 shows monitoring air quality using the ThinkSpeak web service platform. Here, X-axis represents time and Y-axis represents Air Quality Index (AQI). In general, if the AQI value is less than 50, it is generally considered healthy air.

Detecting Vehicle's Speed: This system can monitor the speed of the vehicles on the street. Figure 7 shows that the system measures every car on the road at different times. Here, X-axis represents the time and Y-axis represents the vehicle speed. The system can send notifications to the central authority if any vehicles cross the speed limit.

Light cleaning: Our system can clean the street lights every week. Here, we use servo motors to clean up the light to get the proper brightness from the lights. This method helps to increase the durability of light as well as performance. Generally, a cleaner wiper is attached with the servo motor and the servo motor rotates the cleaner wiper 180 degree to remove dust, smoke, Fogg, etc.

Table 1. Status of the street light

No	Light Number	State	Time	Date
1	First	on	00:48:51	2022-05-18
2	Second	off	00:40:11	2022-05-18
3	Second	off	00:35:31	2022-05-18
4	Second	off	00:29:23	2022-05-18
5	First	on	00:27:17	2022-05-18
6	Second	off	00:23:59	2022-05-18
7	Second	off	00:12:00	2022-05-18
8	First	on	00:09:07	2022-05-18
9	Second	off	00:05:34	2022-05-18
10	Second	on	00:03:41	2022-05-18
11	Second	on	00:02:29	2022-05-18
12	First	on	00:01:50	2022-05-18

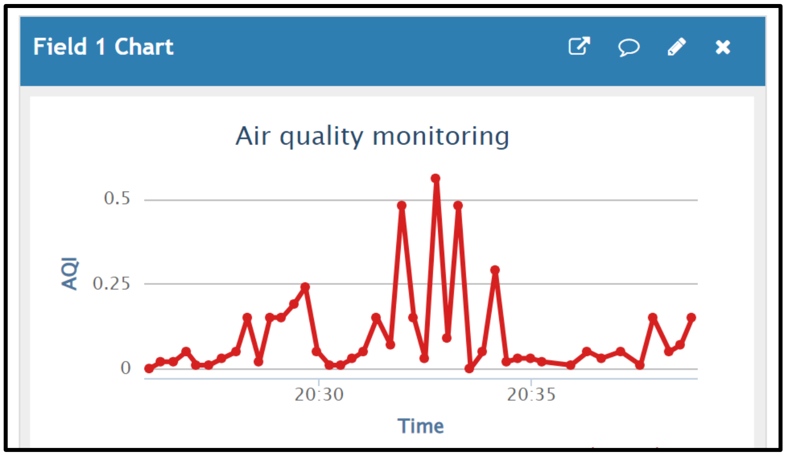

Figure 6. Air quality monitoring using ThinkgSpeak.

Figure 7. Detecting car speed and visualizing it through ThinkSpeak.

Comparative analysis: The below Table 2 clarifies the comparison of the key features of the proposed system with numerous existing systems. Most systems, it is apparent, utilize minimal power and have self-activated features. A few systems additionally include self-power and speed detecting features. On the other hand, our suggested system consists of all the previously listed functionality and unique features such as auto cleaning lighting, environmental air pollution monitoring, and detection of faulty lights.

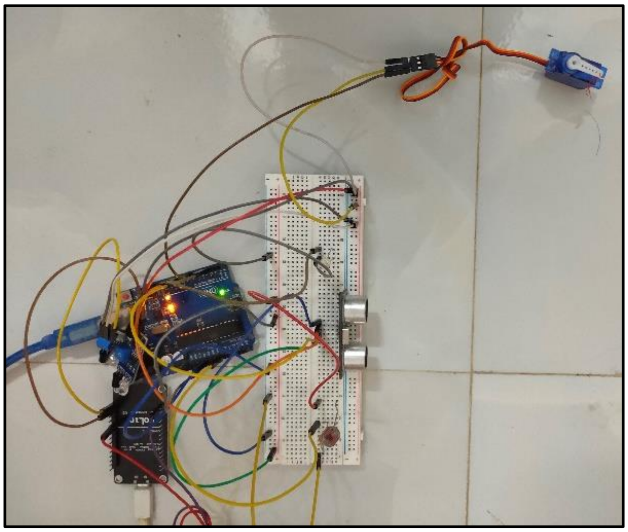

Figure 8. Servo motor connected to the system

Table 2. Comparative Analysis with other existing works

Sl no.	Author's	Self Power	Auto Cleaning	Self-activated street lights	Air Pollution Monitoring	Speed Detection	Faulty Light Detection	Low Power Consumption
1	Abdullah et al., 2018	Yes	No	Yes	No	Yes	No	Yes
2	Priyanka et al., 2019	No	No	Yes	No	No	No	Yes
3	Ahmad et al., 2019	Yes	No	Yes	No	Yes	No	Yes
4	Mary et al., 2018	No	No	Yes	No	No	No	Yes
5	Nyemba et al., 2019	Yes	No	Yes	No	No	No	Yes
6	Dheena et al., 2017	No	No	Yes	No	No	No	Yes
7	Saifuzzaman et al., 2020	Yes	No	Yes	No	No	No	Yes
8	Proposed System	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Conclusion

In this research, we proposed a smart solution to the many issues encountered in the street lighting system, transforming the following system from traditional to IoT-based. To detect the value of the surroundings in many criteria, the system includes an Ultrasonic sensor, an MQ135 sensor, two LDRs, and an IR sensor. The microcontroller unit accepts the sensor value and executes actuation depending on the system's conditions. When light is damaged, the NodeMCU transmits a message to the central server. Manually resolving the problem is very difficult, and it is easily remedied by using automation. The proposed approach would help reduce energy use and is easy to maintain. The project is cost-effective, can offer live data, and responds quickly, guaranteeing an innovative solution to the challenges of street lighting with minimum human work.

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