# IoT-based Efficient Streetlight Controlling, Monitoring and Real-time Error Detection System

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**ABSTRACT**

The challenge of meeting the escalating electricity demand has emerged as a significant concern for all nations, particularly for developing countries such as Bangladesh. Inadequate streetlight management in Bangladesh results in significant electricity wastage, causing substantial annual financial losses. Numerous significant endeavors have been undertaken by researchers across the globe to address this matter through the utilization of the Internet of Things (IoT), albeit with limited representation from Bangladesh. This study presents a proficient integrated streetlight framework that utilizes IoT technology to enable cloud-based monitoring and control. The system incorporates light dimming capabilities that respond to external lighting conditions and traffic detection, as well as a fault detection system to promote low power and electricity consumption. Data from Dhaka North and South City Corporation, Narayanganj City Corporation, and Chattogram City Corporation were analyzed to evaluate the efficacy of our proposed model. Our findings indicate that the proposed model can achieve a reduction in energy cost of approximately 60% compared to the existing system. This highly advanced and optimized system can be deployed in key urban centers throughout Bangladesh as a component of a smart city initiative, with excess electrical power being harnessed for residential and critical applications.

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## 1. INTRODUCTION

The utilization of fire played a pivotal role in the progression of human society, liberating mankind from the constraints of obscurity. This exerts a significant impact on the collective human population and enhances its overall efficiency. This phenomenon is commonly observed in urban areas. The primary differentiation between a town and a village lies in the installation of streetlights, which effectively illuminate urban thoroughfares by eliminating the absence of light. The inaugural streetlight was established in London during the winter season of 1417, marking a significant milestone in the history of public lighting. The initial introduction of Later in the United States can be attributed to Benjamin Franklin. In his efforts, he replicated the glass globes that were utilized in London and subsequently introduced his own version. It was during the Pennsylvania Assembly Circa 1757 that oil candles were first utilized. [1] The streetlight infrastructure underwent significant improvement following the advent of electricity. The Yablokov candles are a variant of electric carbon arc lamps that were invented by Pavel Yablokov, a Russian electrical engineer, in the year 1876. According to reference [2], the inaugural electric streetlight was installed in Paris, France on May 30, 1878. Consequently, it can be inferred that streetlights constitute a crucial component of a city's infrastructure.

The advent of the internet and information technologies has inaugurated a novel epoch. The Internet of Things (IoT) facilitates the interconnection of devices with the Internet, enabling seamless data transmission between devices to accomplish integrated tasks [3]. The implementation of IoT has proven to be successful in the realm of home automation. In addition, automation plays a pivotal role in contemporary society and our daily routines. Consequently, it is evident that legacy systems in our vicinity are undergoing rapid transformations to enhance user convenience. The observation has been made that a significant amount of energy, specifically electricity, is being squandered in the major urban centers of Bangladesh. As per the report, the power consumption of streetlights constitutes approximately 30%-35% of the total energy consumption of a city [4]. Despite the prevalence of information technology, conventional methods are still employed for the activation and deactivation of streetlights in Bangladesh. Based on our investigation of the streets in Chattogram, it has been observed that the streetlights remain illuminated until 12 p.m. After careful evaluation, it has been determined that the utilization of technology is imperative in the pursuit of establishing ecologically sound and sustainable urban areas in Bangladesh. Consequently, our objective is to construct intelligent and environmentally friendly cities by means of the Internet of Things (IoT).

Our proposal entails the implementation of an Internet of Things (IoT) powered streetlight monitoring and control system that incorporates cost monitoring, real-time detection of defective lights, and automated dimming of streetlights to 50% brightness in response to reduced traffic congestion. The primary objective is to achieve cost savings on electricity consumption. The advanced sensor technology is capable of detecting the presence of a vehicle or an individual in the vicinity of a streetlight electric pole, triggering the illumination of the lights to their maximum brightness level.

The subsequent sections of the document are organized in the following manner. Section 2 provides a literature review on the optimal methodologies for contemporary streetlight models and systems. Section 3 delineates the methodology employed in our proposed model. Section 4 is dedicated to examining the features that demonstrate the veracity of the proposed model in this study. The outcomes and analysis are presented in Section 5. The paper is ultimately concluded in Section 6.

## 2. LITERATURE REVIEW

Hannan et al. have developed a streetlighting system that utilizes LDR and ultrasonic sensors to gather real-time data. Their methodology for data collection and storage in the prototype was not explicitly stated in their publications [5, 6]. Alex and colleagues (2017) employed ZIGBEE technology and sensors to examine an energy-efficient intelligent street lighting system. ZIGBEE and sensors were implemented to enhance the efficacy of the streetlighting infrastructure. The utilization of ZIGBEE and sensors is accountable for the system's low power consumption. The ZIGBEE protocol has a communication range of approximately 50 meters. Consequently, its usability is compromised.

The study conducted by Bhairi et al. [8] investigated a smart solar-powered Light Emitting Diode (LED) streetlight that is equipped with an automated mechanism to switch off during daylight hours and activate only during nighttime. In the event of inclement weather conditions, the luminescence intensity of the light source will be reduced to 30%. However, in the presence of a pedestrian or vehicular traffic, the light source will be triggered to operate at full capacity, i.e., 100% brightness. The absence of an error-detection mechanism is evident in this context.

Several investigations [9-12] have examined the LoD (Light of Demand) mechanism utilizing motion detectors, intensity control systems, AC voltage regulators, and controllers such as AC-AC buck converters, multi-taped autotransformers, and high-frequency switch converter dimmer systems. The studies have proposed solutions for reducing the usage of LED streetlights. Despite their efficacy in reducing the brightness of LED lighting, all of these approaches required the acquisition of costly components.

The study conducted by Saifuzzaman et al [13] delved into the implementation of streetlighting and traffic control systems utilizing IoT technology. The concept of integrating road traffic systems with streetlighting is being deliberated. Notwithstanding, its pertinence in Bangladesh is comparatively lower owing to inadequate inter-agency coordination among the governmental entities of Bangladesh. The Metropolitan Police Department holds jurisdiction over traffic management, whereas the city corporation bears the responsibility for the installation and maintenance of street lighting infrastructure. Furthermore, the aforementioned study [14] has presented a novel computer vision-driven approach for managing streetlights, which is a relatively nascent concept in the context of Bangladesh. However, it falls short of offering a comprehensive framework for concurrently monitoring, controlling, and detecting errors in streetlight systems, which is the primary focus of our research endeavor.


(a)


(b)

**Figure 1.** The mismanagement of streetlight controlling at Chittagong from our investigation, (a) night-time, (b) day-time.

The study conducted by Saifuzzaman et al [13] delved into the implementation of streetlighting and traffic control systems utilizing IoT technology. The concept of integrating road traffic systems with streetlighting is being deliberated. Notwithstanding, its relevance in Bangladesh is diminished owing to inadequate inter-agency coordination among governmental entities in the country. The Metropolitan Police Department assumes jurisdiction over traffic management, whereas the city corporation bears the onus of streetlighting maintenance. Furthermore, the model presented in reference [14] has presented a novel computer vision-driven approach for managing streetlights, which is a relatively new concept in the context of Bangladesh. However, the model lacks a comprehensive framework for simultaneous monitoring, controlling, and error detection of streetlights, which is the primary focus of our current work.

Each of the aforementioned studies exhibited exceptional quality. The researchers endeavored to furnish the most optimal techniques of their era. Nevertheless, none of the aforementioned works integrate the four essential characteristics of monitoring, fault detection, brightness control, and low power consumption. The objective of our study is to analyze the viability of implementing IoT technology for optimizing streetlight management in Bangladesh, with the aim of reducing financial waste. Located in Bangladesh, Chattogram is the country's second-largest city. Our residence and academic pursuits have enabled us to uncover the factual state of affairs, which is briefly illustrated in Figure 1. The data was acquired through observational means along Port Connecting Road and Agrabad Access Road in Chittagong city, between the hours of 5:25 p.m. and 8:30 p.m. on November 28th and December 1st, 2021, as depicted in Figure 1.a and b. An exhaustive report of our inquiry, encompassing multiple news articles, media accounts, and on-site investigations, has been included in Appendix I to facilitate comprehension for the readership of this study.

Our proposed system incorporates a Light Dependent Resistor (LDR) that functions as a photosensor, triggering automatic activation when ambient light levels fall below a certain threshold and deactivation when light levels exceed that threshold. Under the traditional approach, the governing body lacks a mechanism to ascertain the presence of any malfunctioning streetlights within the municipality. Our model has the ability to identify and address issues in real-time. Implementing a mechanism to regulate the luminosity of streetlights can effectively contribute towards reducing power consumption.

## 3. METHODOLOGY

The system we have developed consists of two fundamental constituents, namely hardware and software (admin panel). The system methodology is presented herein by means of hardware specifications, block diagram, and flowchart to illustrate the integration of software and hardware components.

### a) Technical Specifications of the Hardware

The Arduino Nano functioned as the hardware's central processing unit. The ATmega 326 microcontroller is equipped with a total of 14 digital pins and 8 analog pins, and operates at a clock speed of 16 MHz. Ultrasonic sensors were employed to detect the presence of any vehicular or pedestrian traffic on the roadway. The ultrasonic sensor comprises four distinct pins, namely positive, negative, trigger, and echo. The Light Dependent Resistor (LDR) is utilized to measure the luminosity of the streetlight and detect the existence of solar radiation. The esp8266 has been employed as a Wi-Fi module to establish a connection between our hardware system and the control room via the internet. LED bulbs represent the latest advancement in lighting technology. This lighting solution offers a 75% reduction in energy consumption compared to traditional lighting options, while also providing a lifespan that is 25 times longer. Current sensors were employed to monitor both AC and DC currents, providing electrical isolation between the sensor's output and the circuit under scrutiny. Additionally, a potential meter was utilized to divide a higher voltage by a predetermined ratio based on the electrical components, thereby generating a lower output voltage. Additional components were incorporated into our system, although the aforementioned ones hold the utmost importance.

### b) block diagram and flowchart depicting the model are presented.

As illustrated in Figure 2's block diagram, the Arduino Nano serves as the primary system or central processing unit. The battery can be charged via either a solar or grid source, which serves as a power supply input and enables monitoring of power consumption, light intensity, ultrasonic sensors (No.1-6), and thermistor input data to the Arduino Nano. The Arduino Nano acquires the aforementioned data and manages the bulbs through switchable sockets.

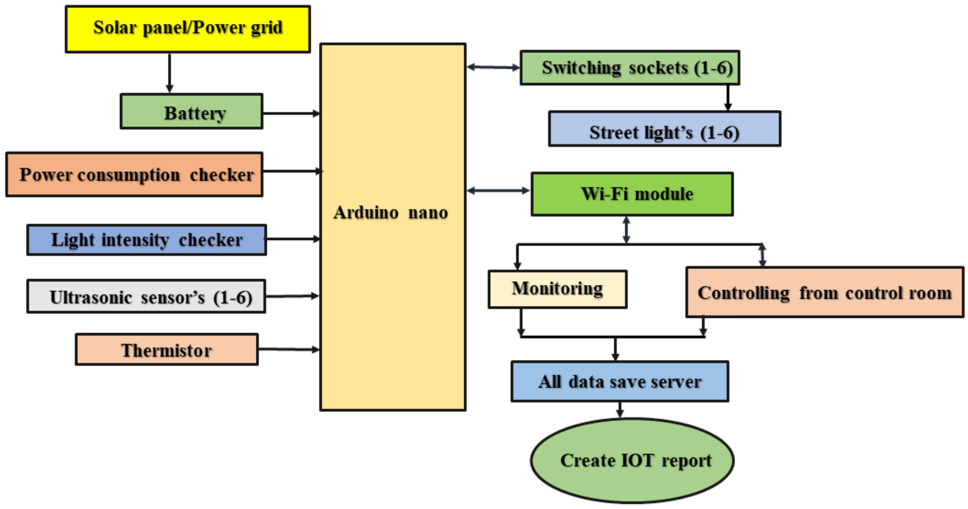



**Figure 2**. Block diagram of the system we proposed.

Furthermore, the information is transmitted via Wi-Fi to the system for the purpose of monitoring. If deemed essential, it acquires input from the supervisory control and data acquisition (SCADA) system and transmits it to the Arduino Nano via wireless fidelity (Wi-Fi) communication. The Arduino Nano receives instructions for the streetlights from the control room through a switching connector. An Internet of Things (IoT) report is generated through the transmission of data to servers and utilizing state-of-the-art monitoring and control mechanisms.

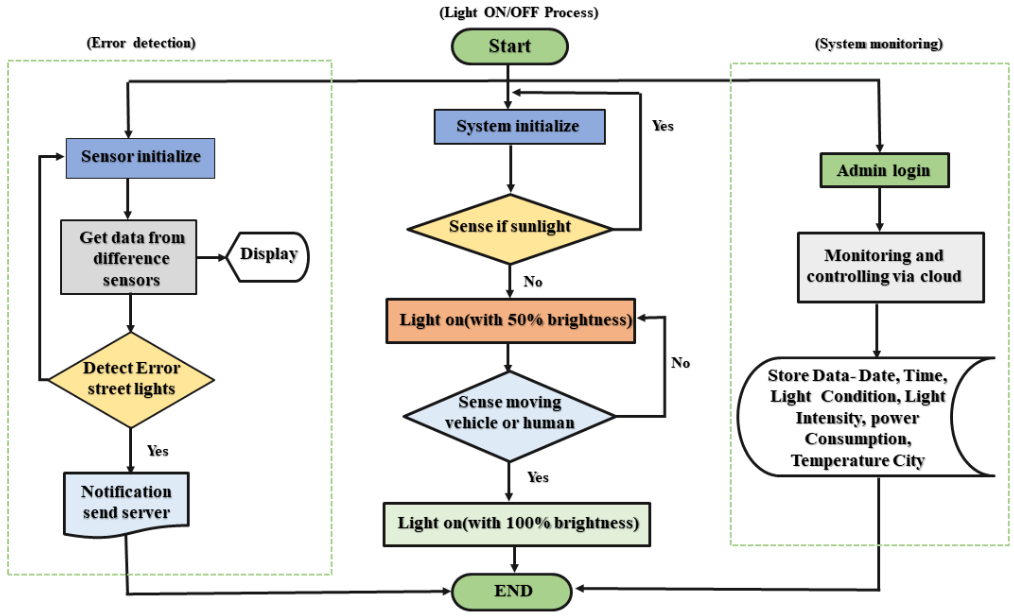



**Figure 3**. Flowchart of the system we proposed.

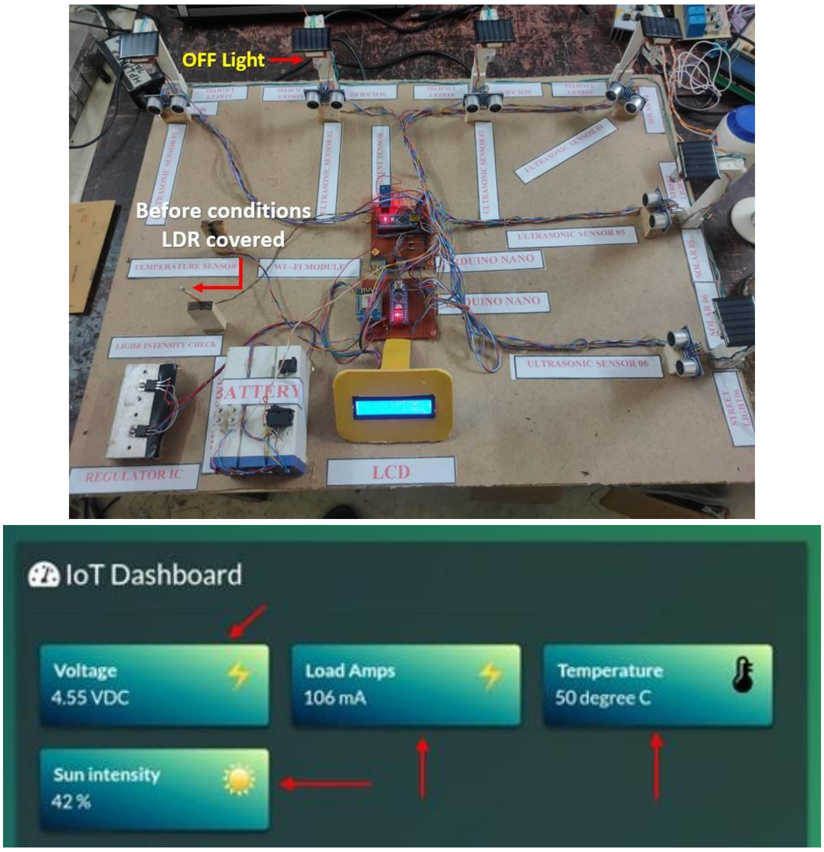
As illustrated in Figure 3, our system operates via three distinct modes. The branch located at the extreme right is dedicated to the acquisition of data and the monitoring of the system. The process of error detection is initiated in the event of identifying any inconsistencies, as depicted in the branch situated on the far left. The central component is accountable for executing the activation and deactivation of the illumination system in accordance with the specified conditions. The system will commence with a monitoring procedure. Upon authentication, the system administrator panel will present a comprehensive overview of the system's data for retrieval. A system for emergency control can be accessed from this location.

The software will oversee a diverse range of hardware sensors within the system that has been formulated. In the event of a streetlight malfunction, our server will generate a notification. If no anomalies are detected, monitoring will persist for the duration of the streetlight's operational state. At the third tier, our system shall quantify the amount of solar radiation prior to activating the streetlamp. The streetlight will be activated when the level of solar irradiance is low or absent, and deactivated when there is sufficient solar irradiance. The subsequent procedure involves conducting an assessment to determine the presence of vehicles or pedestrians in the vicinity of our street lighting infrastructure. In the presence of pedestrians or vehicles, our automated system will activate the streetlights and set them to full luminosity. In the absence of human or vehicular presence in the vicinity of the streetlights during nighttime, the system commands a reduction in brightness to 50%. It will perform its intended function. Upon the expiration of the designated timeframe, the illumination level will be reduced by half as per the 50% brightness protocol. This approach will be employed to accomplish all three work forms or phases.

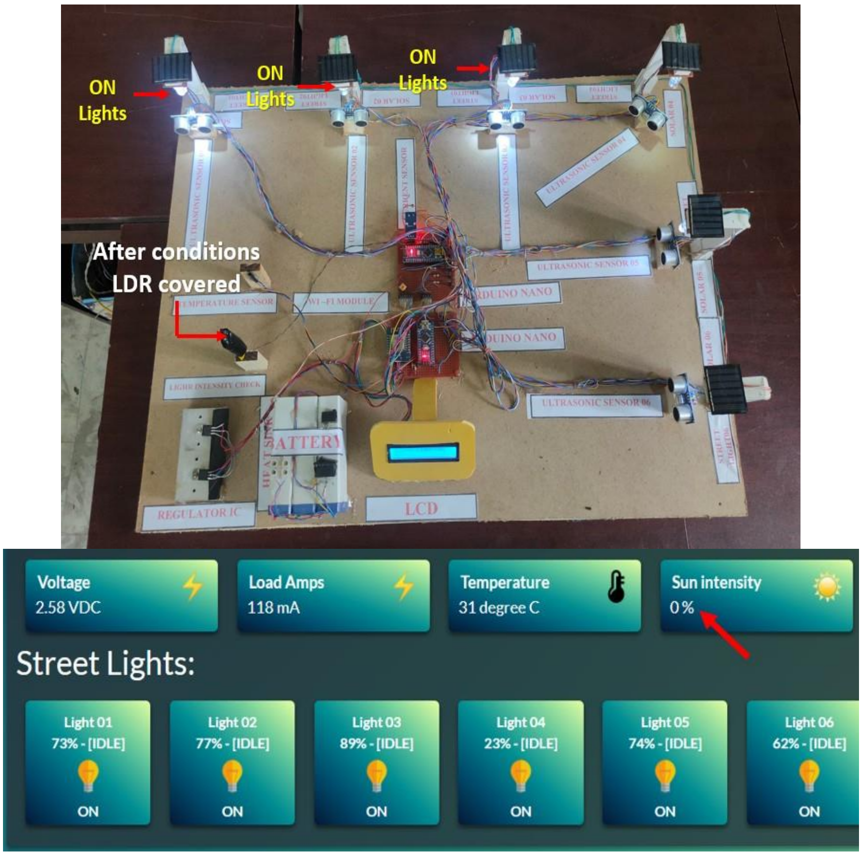
## 4. FEATURES OF THE PROPOSED MODEL

The laboratory prototype was engineered to address a diverse array of practical challenges. The proposed model exhibits a range of features, including:

**Sunlight diagnosis:** The initial phase of the experiment involved testing the system's ability to detect solar radiation.




(a)




(b)

**Figure 4**. Sunlight detection with the help of LDR

Figure 4(a) illustrates the capability of the Light Dependent Resistor (LDR) sensor to detect the electric light in the laboratory, as demonstrated in the model. Consequently, the entire set of streetlights in our model has been deactivated. Furthermore, it is noteworthy that the administrator interface is exhibiting the current luminous flux, measuring at 42%, to facilitate the simulation of a nocturnal environment. Following that, we proceeded to place an obstacle over the Light Dependent Resistor (LDR) as depicted in Figure 4 (b). The current solar irradiance level has been observed to be at 0%, as per the readings displayed in the administrative interface. Consequently, all the streetlights have been successfully activated through automated means. The luminosity of individual lights can be observed through the administrative interface.

**Determine real-time current consumption of all sensors:** Figure 5 depicts the power consumption of our system during operation, along with the prevailing ambient temperature.

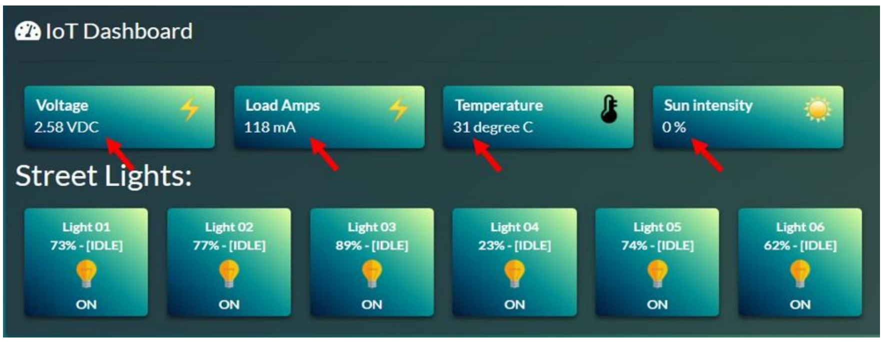
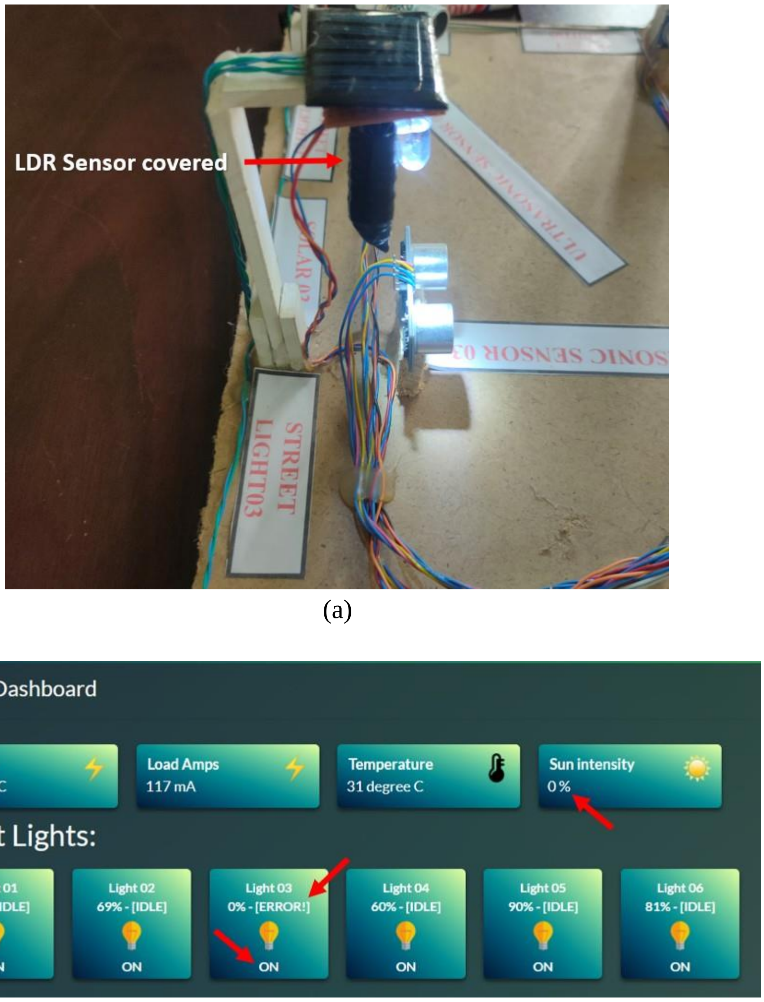



**Figure 5.** Electricity consumption data in admin panel

**Real-time error detection**: Due to the laboratory setting in which the experiment was conducted, the system generated an error in an artificial manner. Upon examining our model and admin panel, it is evident that the condition was assessed prior to the intentional generation of the error depicted in Figure 6(a). We have implemented a mechanism on our Streetlight 3 that triggers a simulated error in the event of the LDR sensor's inability to detect the streetlight. Subsequently, the administrative interface will indicate that the system has effectively exhibited the malfunction of streetlight number 3, notwithstanding the illumination of the light in Fig.6 (b).

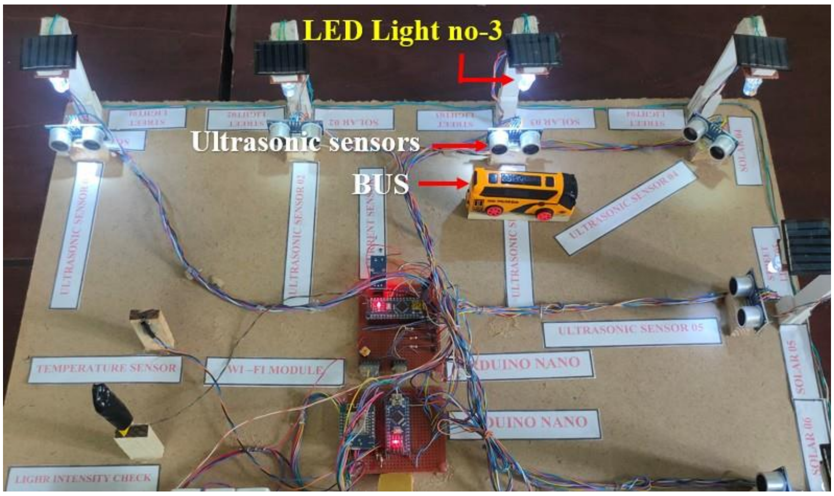



(a)

(b)

**Figure 6.** (a) Light 3 has turned on after LDR sensor is artificially covered (b) Shown in admin panel

**Testing ultrasonic sensors**: Our system employs ultrasonic sensors to detect the presence of vehicles within the vicinity of the road lights. The luminosity of the streetlights in the vicinity will experience a substantial increase upon the arrival of an automobile. The aforementioned observation is visually represented in Figure 7. In the absence of automobiles, the streetlights were deactivated. As evidenced by the data displayed in the administrative interface, the act of parking a bus in close proximity to an ultrasonic device results in a significant increase in the luminosity of the adjacent streetlights, as depicted in Figure 7(b). By implementing this method, it is feasible to decrease power consumption.




(a)


(b)

**Figure 7.** Ultrasonic sensor in Light 3 detects a car (a) and the brightness of the Light 3 has instantly increased (b)

**Data storage**: The system has the capability to capture and store data in tabular format, which includes timestamps, as illustrated in Figure 8. This feature can facilitate subsequent analysis of power usage.

Data Table RESET

| Date | Time | Volt | Amp | Temp | Sun | Light 01 | Light 02 | Light 03 | Light 04 | Light 05 | Light 06 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 13/02/2022 | 01:47:22pm | 5.00 | 99 | 21 | 66 | 0@36 | 0@45 | 0@57 | 0@34 | 0@58 | 0@51 |
| 13/02/2022 | 01:47:38pm | 5.00 | 117 | 21 | 32 | 1@43 | 1@49 | 1@45 | 1@36 | 1@52 | 1@53 |
| 13/02/2022 | 01:47:53pm | 5.00 | 113 | 21 | 31 | 1@41 | 1@48 | 1@51 | 1@34 | 1@45 | 1@65 |
| 13/02/2022 | 01:48:10pm | 5.00 | 112 | 21 | 64 | 0@42 | 0@48 | 0@58 | 0@35 | 0@54 | 0@57 |
| 13/02/2022 | 01:48:27pm | 5.00 | 133 | 21 | 34 | 1@40 | 1@44 | 1@67 | 1@30 | 1@47 | 1@44 |
| 13/02/2022 | 01:48:42pm | 5.00 | 106 | 21 | 66 | 0@36 | 0@46 | 0@57 | 0@34 | 0@58 | 0@51 |
| 13/02/2022 | 01:49:43pm | 5.00 | 109 | 21 | 68 | 0@39 | 0@48 | 0@60 | 0@37 | 0@61 | 0@54 |
| 13/02/2022 | 01:49:58pm | 5.00 | 101 | 21 | 68 | 0@39 | 0@48 | 0@60 | 0@37 | 0@61 | 0@54 |

**Figure 8**. Data of streetlights in admin panel

## 5. RESULTS AND DISCUSSION (10 PT)

Subsequent to our laboratory experimentation, our primary objective is to elucidate the feasibility of substituting the conventional streetlighting infrastructure with the system we have developed, with the aim of achieving cost and energy efficiency. As per the information available on the website of Chittagong City Corporation (CCC), the organization employs a diverse range of street lighting solutions, including sodium lights, 100-watt bulbs, halogen bulbs, metal halide bulbs, and tube lights. The cumulative count of incandescent streetlights utilized by CCC is 33,750. Additionally, the LED streetlight count for Dhaka North City Corporation (DNCC), Dhaka South City Corporation (DSCC), and Narayanganj City Corporation (NCC) are 46,410, 54,966, and 2,474, respectively, as reported in references 16, 17, and 18. Energy consumption and cost are calculated and compared across four city corporations in three distinct scenarios.

**Scenario 1**: We conducted an estimation of CCC's 33,750 streetlights, assuming a power rating of 100 watts (W) for sodium lights, in order to determine the cost of the current system. Typically, streetlights are operational for a duration of 12 hours per diem.

The power rating of the sodium streetlight is 100 watts, and its energy consumption over a period of 12 hours is 1.2 kilowatt-hours. The unit cost is 7.70 TK/kWh as per reference [12]. The daily electricity expenditure for a solitary 100W sodium streetlight is calculated as (1.2 kWh*7.70) = 9.24 TK. Therefore, the aggregate energy utilization equals the product of 1.2 and 33750, resulting in 40500 kilowatts or 40.5 megawatts.

The current streetlight systems of DNCC, DSCC, and NCC do not incorporate sodium lights. Therefore, Scenario 1 is not applicable to the aforementioned three city corporations.

**Scenario 2:** By substituting the current 100W sodium lights utilized by CCC with 40W LED lights, the energy consumption for a duration of 12 hours would amount to 0.48 kWh, resulting in a daily electricity cost of 3.70 TK.

Hence, total energy consumption with 100% brightness,

For 33750 units LED light in CCC is 16.2 MW

For 46410 units LED light in DNCC is 22.3 MW

For 54966 units LED light in DSCC is 26.4 MW and

For 2474 units LED light in NCC is 1.2 MW

**Scenario 3:** Our proposed model entails the implementation of a dimming mechanism for LED streetlights during periods of reduced traffic congestion. Specifically, the lights would operate at a reduced brightness level for 50% of their total active time during the midnight to dawn hours. Given a 40W LED Streetlight in CCC, with a dimming condition of 50%, the power consumption of the light is expected to be reduced by half, resulting in an approximate power consumption of 20W per light.

Hence, consumption for 12 hours is 0.24 kWh, daily Electricity cost is 1.85 and the total energy consumption with 50% brightness,

For 33750 units LED light in CCC light is 8.1 MW.

For 46410 units LED light in DNCC is 11.15 MW

For 54966 units LED light in DSCC is 13.2 MW and

For 2474 units LED light in NCC is 0.6 MW

Table 1. Energy consumption comparison in CCC

| Lighting option | Per day (TK) | Per month (TK) | Per year (TK) |
|---|---|---|---|
| For 100W sodium light | 311850 | 9355500 | 113825250 |
| For 40W LED light (with 100% brightness) | 124875 | 37 46250 | 45579375 |
| For 40W LED light (with 50% brightness) | 62438 | 1873125 | 22789688 |
| Total Save [100W - 40W] (100% brightness) | 186975 | 5609250 | 68246125 |

Table 1 presents a comparative analysis of the electricity consumption of the current 100W sodium streetlighting system and two alternative options discussed in CCC, as per our proposed model.

Table 2. Energy cost comparison in CCC

| For 100W incandescent light/day | For 40W LED light (with 100% brightness)/day | For 40W LED light (with 50% brightness)/day |
|---|---|---|
| 40.5 MW | 16.2 MW | 8.1 MW |

Table 2 presents the energy expenditures associated with the aforementioned scenarios across daily, monthly, and annual timeframes.

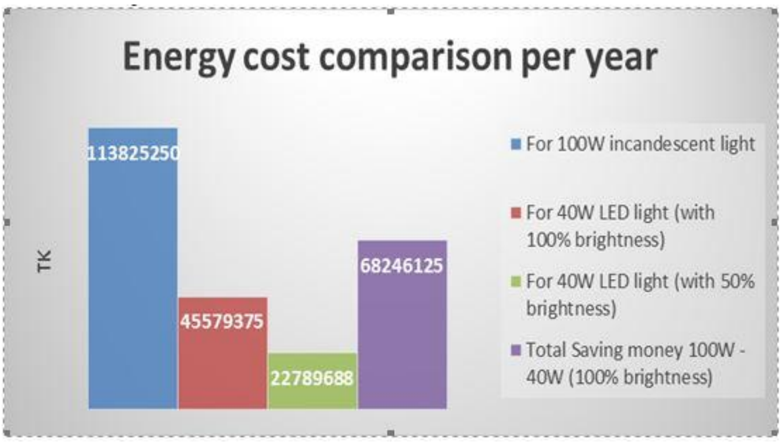



**Figure 9**. Cost comparison of three different streetlight systems in CCC.

Based on our computations, the utilization of LED lighting set at maximum luminosity for a duration of 12 hours can yield an estimated 60% reduction in electricity consumption compared to the conventional system currently in place at CCC. This translates to a power savings of 24.3MW (40.5MW - 16.2MW), which is equivalent to 60% of the original power consumption. Consequently, this approach can also result in a 60% reduction in expenses. Due to the presence of a brightness control system in our system, it is feasible to achieve energy and cost savings of up to 5% - 8%. The graphical representation depicted in Fig.9 showcases the cost comparison analysis conducted in CCC. The study reveals that by replacing 100W sodium light with 40W LED under 100% brightness condition using the proposed system, an estimated annual saving of approximately 60 million TK can be achieved. The findings of reference [19] indicate a monthly expenditure of 3.4 million TK being wasted, which is consistent with the outcomes derived from our own computations.

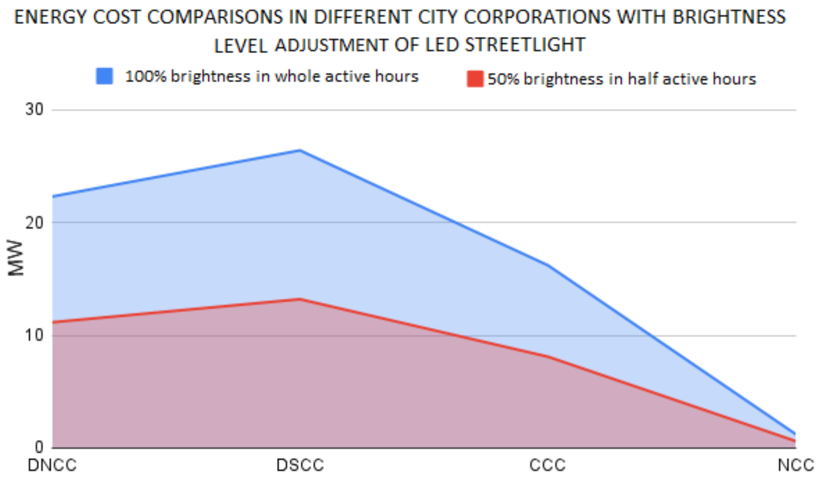



**Figure 10**. Cost comparison of four different city corporations in Bangladesh with different brightness combination of streetlights.

By integrating dimming protocols during late night hours and full brightness protocols during peak hours, the energy expenditure across four city corporations in Bangladesh has been notably reduced (Fig.10) in comparison to the full brightness protocols implemented throughout the entirety of active hours. This approach has proven to be a viable solution in addressing the substantial energy crisis faced by the country in the aftermath of the COVID-19 pandemic in 2022.

Our project was implemented using an Arduino Nano microcontroller, although an alternative solution could involve utilizing a Raspberry Pi single-board computer. In contrast, we opted for the utilization of Arduino Nano in order to reduce costs, given its intended purpose of evaluating its compatibility. In our experimental setup, an ultrasonic sensor was utilized. However, it is worth noting that an infrared sensor may yield favorable outcomes when the distance of the road exceeds that of the streetlight. ZIGBEE has been employed by numerous individuals to address identical issues. ZIGBEE technology may not be suitable for deployment in large urban areas where the communication range is limited to less than 50 meters. As a result, it exhibits a positive impact in low-density residential zones.

## 6. CONCLUSION

The feasibility of an Internet of Things (IoT)-based system for monitoring, controlling, and detecting errors in streetlights was presented and discussed. This system was specifically designed for implementation in major cities in Bangladesh. The proposed system exhibits significant promise in addressing the substantial electricity wastage resulting from the current deficient and defective streetlight infrastructure. It offers an advanced approach to oversee the entire city's streetlight administration. By implementing such a system, we can guarantee the construction of a sustainable urban environment in the foreseeable future.

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