IOT-IntegratedStreetlightMonitoring System For Low-Latency Operations

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ABSTRACT:

This paper proposes the implementation of an IoTbased smart streetlight monitoring system that addresses the issues of real-time monitoring and data storage consumption in current smart streetlight systems. The proposed system uses sensors and actuators to provide intelligent outdoor lighting whilealso gathering data and processing it in real-time to ensure efficient maintenance. A data filtering algorithm is also utilized toprevent redundancy and reduce data storage usage. The implementation results indicate that the proposed system can provide real-time monitoring with minimal time execution and significantly reduce data storage consumption. This system has the potential to improve the efficiency of smart streetlight systemsand reduce energy consumption.

Index terms: Data filtering, Internet of Things (IoT), low delay, real-time monitoring, smart streetlights.

I. INTRODUCTION

The primary objective of streetlights is to illuminate dark areas,thereby ensuring a safe environment for pedestrians and drivers [1]. Traditional streetlights effectively fulfill this role, mitigating the risk of accidents. However, challenges such as power consumption extend beyond the basic functionality of streetlights. These challenges efficiency can be addressed by integrating smart systems, which upgrade conventional streetlights to smart streetlights. Smart streetlights incorporate advanced technologies like sensors and actuators, enhancing their intelligence and efficiency A crucial advancement in the evolution of smart streetlights involves substituting traditional fluorescent lamps with light-emitting diodes (LEDs) to minimize power consumption. Prior research has focused on optimizing LED streetlights by integrating complementary systems or technologies. For instance, Bhairi et al. [2] employedan LED driver to tailor street lighting to specific requirements, thereby enhancing efficiency and functionalityIn addition to enhancing energy efficiency through LED integration, advancements in smart streetlight technology include features tailored tohuman vision, allowing for automated or manual control of lighting. Baeket al. [3] demonstrated the use of sensors, such as motion sensors, to enable automatic or manual activation of lights from a centralized controlcenter. These studies effectively improved the functionality of smart streetlights while reducing power consumption. However, despite the strides made in reducing power consumption through LED drivers and integrated devices, it's important to note that the components within smart streetlights require periodic monitoring to ensure optimal performance, which can contribute to increased maintenance costs. Implementing periodic maintenance for smart streetlights can be both costly and challenging due to the difficulty in obtaining real-time operational data. To address this issue, integrating Internet of Things (IoT) technology into smart streetlights facilitates efficient data collection for remote monitoring. IoT enables the connectivity of devices to the internet, facilitating the transmission and reception of data for real-time monitoring. In studies such as [4] and [5], smart streetlight systems with embedded cameras were proposed to remotely monitor surroundings and deter theft issues. Yang et al. [4] utilized a long-rangelow-power wide-area network (LoRaWAN module to connect smart streetlights to a central control server, while [5] developed a management system linked to a cloud service named Docker. These approaches leveraged IoT to monitor if smart streetlights provided sufficient illumination, thereby reducing maintenance costs. However, these studies primarily focused on monitoring the surroundings of smart streetlights and did not offer real-time monitoring of integrated devices, such as supercapacitor parameters, lamp status, and environmental conditions. Additionally, they did not address the potentially high-cost implementation of wireless communication modules for the monitoring systemsThis article delves into the deployment of an Internet of Things (IoT)-based smart streetlight monitoring system with low latency. The system employs a real-time NoSQL database to facilitate instantaneous monitoring of smart streetlights, minimizing delays. Additionally, given that smart streetlights are commonly positioned at intersections, the incorporation of supplementary sensors for monitoring temperature and humidity levels aids in mitigating the adverse effects of environmental factorson individuals [6]. Extreme temperatures, whether excessively hot or cold, poserisks of heatstroke or hypothermia [7], while humidity and temperature variations significantly impact the comfort and physiological state of drivers[8]. Consequently, this article aims to offer insights into the implementation of a comprehensive monitoring system that addresses both operational efficiency and humansafetyconsiderations.

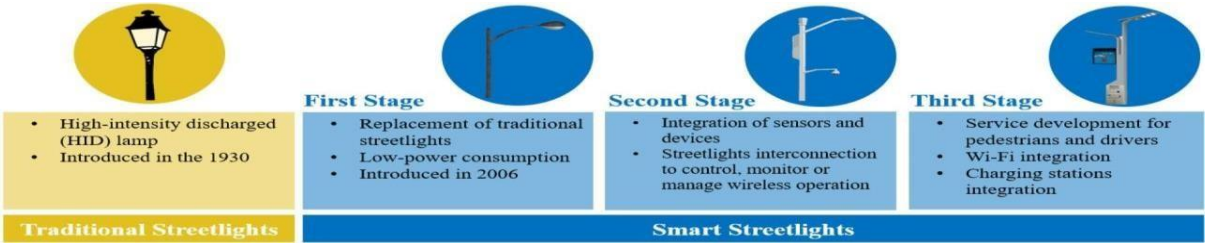

Fig. 1. Smart streetlight development over the years

This article aims to provide real-time monitoring of environmental parameters such as temperature and humidity, which can assistpedestrians and drivers in staying informed about their surroundings, thereby helping to prevent potential road accidents and human illnesses. Additionally, it emphasizes the importance of monitoring the performanceof supercapacitors used in smart streetlights to prevent overcharge and deep discharge, which can significantly degrade their lifespan [9]. To achieve this, the article proposes real-time monitoring of supercapacitor parameters such as voltage and current to support the efficient operationof smart streetlights. The collected environmental and supercapacitor parameters will be transmitted to a real-time database, enabling their retrieval for immediate monitoring

By utilizing a real-time database for data storage, the article enables real-time monitoring by automatically synchronizing collected data with a web-based monitoring system. Furthermore, the article plans to implement a data filtering algorithm to prevent overloading and excessive consumptionof storage space. This algorithm will allow the server to store a wider range of data by disregarding redundant information. Overall, the proposed monitoring system aims to reduce maintenance costs while offering a low-latency and real-time monitoring solution for smart streetlight applications. The key contributions of this article include the integration ofenvironmental and supercapacitor parameter monitoring, real-time data transmission, and the implementation of a data filtering algorithm to optimize storage efficiency

The article presents the implementation of a real-time smart streetlight monitoring system, focusing on two main components

REAL TIME NOSQL DATABASE: A real-time NoSQL database is employed as the primary data storage solution for all collected data. This database operates by storing data in JSON file format, eliminating the need for SQL queries. This setup enables the rapid storage and retrieval of data with minimal delay in PHP execution.

Data Filtering Algorithm: To optimize data storage efficiency, a data filtering algorithm is utilized. Before transmitting collected data to the real-time database for storage, each data set undergoes a filtering process. This algorithm compares newly collected data with previously stored data to identify redundancies. If the newly collected data is redundant, it is not stored in the database. This approach ensures that only relevant data is retained, thereby preventing overloading and unnecessary consumption of storage space

Section II: Discusses related work in the field.

Section III: Provides a detailed explanation of the proposed system.

Section IV: Contains implementation details and presents results.

Section V: Draws conclusions based on the findings presented in the article

II. RELATED WORK:

Smart streetlights represent a significant initial investment in development, but their implementation can lead to substantial long-term cost savings for cities. For example, the Edinburgh City Council initiated a project in 2018 to introduce smart streetlights, with expectations of halving its yearly energy consumption of

£3.2 million and potentially saving up to £54 million in power costs over a 20-year period [10]. Over time, the focus of smart streetlight development has expanded beyond mere power cost reduction to encompass broader citizen sustainability initiatives

This section reviews existing work related to smart streetlights, encompassing both their development and the systems used to monitor them. Specifically, it examines research and projects aimed at enhancing smart streetlight functionality, as well as the databases and monitoring systems utilized in these efforts

The development of smart streetlights has evolved significantly, with advancements occurring in stages as depicted in Figure 1 [11]. Traditionally, streetlights relied on high-intensity discharge (HID) and fluorescent lamps for illumination, but these were associated with drawbacks such as frequent malfunctions and high power consumption.

STREET LIGHTS:

In Stage 1 of smart streetlight development, exemplified bystudies referenced in [12]-[14], efforts were made to transition away from traditional HID and fluorescent streetlights toward more energy-efficient LED alternatives. Shere and Suryawanshi [12] proposed a smart LED driver that enables user controlthrough a mobile application. Jha and Kumar [13] enhanced dimmable LED drivers for streetlights by incorporating triode foralternating current (TRIAC) control. Hsia et al. [14] focused on improving the power quality of LEDs by developing a constant current mode LED driver, ensuring consistent brightness even with fluctuations in power supply. Their work included the development of high-power single-chip drivers for LED dimming, achieving high efficiency levels.These studies primarily concentrated on integrating LED drivers and algorithms to maximize the benefits of LED technology and reduce the power consumption associated with street lighting.

TABLE I
PROPOSED SYSTEM AND RELATED WORKS SUMMARY

Related Works	Streetlight Development Stage	Wireless Module Used	Data Storage/Server Used	Field of Focus
Proposed	Stage 2 - 3	Wi-Fi	Real-time Online Database	Wireless lighting control, autonomous lighting control, wireless monitoring, data management, reduce storage consumption
[12]	Stage 1	--	—	LED dim control, energy efficiency, chip improvement
[13]		--	—	Improve power quality
[14]		Wi-Fi or Zigbee	—	LED dim control, chip improvement
[15]	Stage 2	--	—	Autonomous lighting control, energy efficiency
[16]		--	—	LED dim control, energy efficiency
[17]		LoRa		Wireless light control, autonomous lighting control
[18]	Stage 3	Zigbee	Web server	Wireless lighting control, autonomous lighting control, sensor monitoring
[19]		--	Undefined server	Energy efficiency, Applied machine learning
[21]		Zigbee	Cloud server	Wireless lighting control, pedestrian emergency use
[22]		--	—	LED dim control, visual comfort, energy efficiency
[25]		LoRa	Local server	Wireless lighting control
[28]		Zigbee	Web server	Wireless lighting control, autonomous lighting control, wireless management
[29]		Zigbee	Web server	LED dim control, Wireless lighting control, autonomous lighting control, wireless management
[30]		NB-IoT, Wi-Fi, 4G	Undefined database/server	LED dim control, Wireless lighting control, autonomous lighting control, wireless monitoring
[31]		Wi-Fi	Undefined database/server	LED dim control, Wireless lighting control, autonomous lighting control, wireless management

In the second stage of smart streetlight development, researchers began integrating sensors and connecting smart streetlights to software applications for monitoring, management, and control purposes. This stage became feasible due to the rapid convergence of various technologies, including LED lights, sensors, and compact controllers [15].

For example, Sukhathai and Tayjasanant [16] introduced a smart streetlight system capable of wirelessly controlling and monitoring illuminance levels and the state of LED lights (e.g., on and off). Similarly, Kaleem et al. [17] devised a centralized monitoring system for streetlights, enabling remote monitoring of individual light statuses, power consumption, and associated costs

In the current third stage of smart streetlight development, researchers areemphasizing the enhancement of sustainability aspects. Beyond mere monitoring, the data collected from sensors and integrated devices within smart streetlights are now utilized for machine learning applications, classifications, and analysis. Studies such as [18] and [19] leverage this datato advance the sustainability of smart streetlights.

Gagliardi et al. [18] presented the outcomes of the "Smart Cities Adaptive Lighting System" (SCALS) project, which aims to develop a comprehensiveadaptive urban lighting architecture. This project positions smart streetlights as integral components of a broader technological infrastructure that enables remote monitoring, video processing for vehicles, motion detection and classification, data exchange, and traffic evaluation.

Mohandas et al. [19] employed artificial neural networks and fuzzy logic to create a decision-making module for smart streetlights. This module effectively manages demand-based usage and reduces excessive streetlight usage by utilizing analytical data collected from various sensors such as lighting sensors, motion sensors, and passive infrared (PIR) sensors.

Additionally, efforts are directed towards improving smart streetlights to benefit pedestrians and drivers. For example, EnGoPlanet, a New York-based company, developed smart streetlights that offer Wi-Fi connectivity and serve as charging stations for pedestrians [20]. Anitha et al. [21] integrated emergency buttons into streetlight poles to trigger alarms and alert the nearest police station when pressed for emergency assistance. Davidovic et al. [22] conducted research on the preferred LED illumination colors for smart streetlights, focusingon enhancing visual comfort for drivers

Smart Streetlight Monitoring System:

Smart streetlights are equipped with sensors and actuators to enable automatic control of lighting. These sensors gather data thatcan be utilized for monitoring smart streetlights, thereby reducing the need for manual maintenance. Ravikumar [23] integrated Bluetooth technology into smart streetlights for wireless control and monitoring. While effective for wireless control and monitoring, Bluetooth's limited range makes it less reliable for data transmission over long distances, resulting in potential delays in data gathering.

In contrast, long-range wireless communication modules like LoRaoffer advantages in terms of distance coverage, with transmission capabilities up to 5 km [24]. Bingol et al. [25] utilized LoRa technology to control smart streetlights, facilitating bidirectional communication between control management systems and streetlights.

However, other communication technologies such as ZigBee and Wi-Fi provide better transmission rates than LoRa [26]. ZigBee, for instance, offers data transmission coverage of up to 100 m and supports data rates of up to 250 kb/s [27]. It can be integrated intosmart streetlights to establish long-range remote monitoring systems. For example, Daely et al. [28] employed ZigBee-based wireless communication to transmit real-time data on streetlight parameters to a web interface.

Similarly, Khatavkar et al. [29] utilized ZigBee for wireless control ofLED drivers in smart streetlights. ZigBee is a popular wireless communication module used in various smart devices, including smart streetlights.

In another approach, Wi-Fi communication is utilized between narrowband IoT (NB-IoT) embedded in smart streetlights and terminal applications for monitoring [30]. Dheena et al. [31] developed an IoT-based smart streetlight management systembased on Wi-Fi, albeit limited to controlling lamp states (e.g., on/off).

In this article, a Wi-Fi module is proposed as the preferred wirelesscommunication technology for smart streetlights and real-time databases. This setup enables real-time monitoring of smart streetlights, ensuring efficient management and control

Data Storage and Data Filtering:

One of the critical decisions in developing a monitoring system is selecting the appropriate data storage solution. Local and cloud-hosted databases are commonly utilized for monitoring systems ofsmart devices.

A local database operates within local servers and is responsive in storing and managing data applications [32]. However, data stored in local databases can only be accessed within local area networks [33]. On the other hand, a cloud-hosted database is a database service developed and accessed in a cloud platform [34]. User- friendly cloud services are driving the development of IoT applications [35]. Gujar [36] and Jha et al. [37] utilized cloud storagefor controlling and monitoring smart streetlights. Similarly, Juwita etal. [38] and Wiratno and Hastuti [39] utilized real-time databases fortheir proposed monitoring systems. Juwita et al. [38] focused on monitoring parking spaces in a smart parking system, while Wiratnoand Hastuti [39] concentrated on real-time bus transit tracking. Bothstudies provided real-time monitoring by leveraging automatic datasynchronization across different platforms, such as mobile, web, anddesktop applications.

Data filtering is an essential strategy for refining data sets by removing redundant or irrelevant data [40]. Data filters are commonlyemployed to reduce storage consumption in machine learning systems and IoT applications. Singh et al. [41] and Ret al. [42] utilized data filters to reduce storage consumption of big data collected for machine learning applications. Singh et al. [41] proposed integrating fuzzy logic into a bloom filter algorithm to reduce cloud storage consumption without compromising accuracy, while Riaz et al. [42] filtered only useful data from collected redundant data based on parameters such as velocity, variety, and volume. However, unlike existing studies where data filters are primarily applied in machine learning systems, this article proposes the use ofdata filters for smart streetlight applications. While previous studies gather data periodically, this article achieves real-time data acquisition and monitoring without requiring extensive data storageby employing the proposed data filtering algorithm. Further details on this algorithm will be elaborated in the following section

III. System Overview

Fig. 2 illustrates the overall system diagram of the proposed real-time monitoring system for smart streetlight applications. An auxiliary controller is developed to simulate the time scheduling of smart streetlights. As depicted in the figure, the auxiliary controller comprises amicrocontroller, various modules, and sensors. These components collaborate to gather data from sensors and modules, transmitting it to the real-time database.Fig. 3 showcases the data gathering diagram of our proposed real-time monitoring system for smart streetlight applications. The process involvesfour key steps:

1. DataAcquisition:Sensorsgatherdataconcerningenvironmental parameters (e.g., temperature and humidity) as well as supercapacitor parameters (e.g., voltage and current) to enable real-time monitoring of smart streetlight parameters. The collected data is transmitted to the ESP8266 Wi-Fi module for further processing.
2. Data Processing: Upon data acquisition, the ESP8266 Wi-Fi module locally processes the collected data using our proposed data filtering algorithm. This algorithm refines the data to include only relevant information, filtering out redundant or irrelevant data points

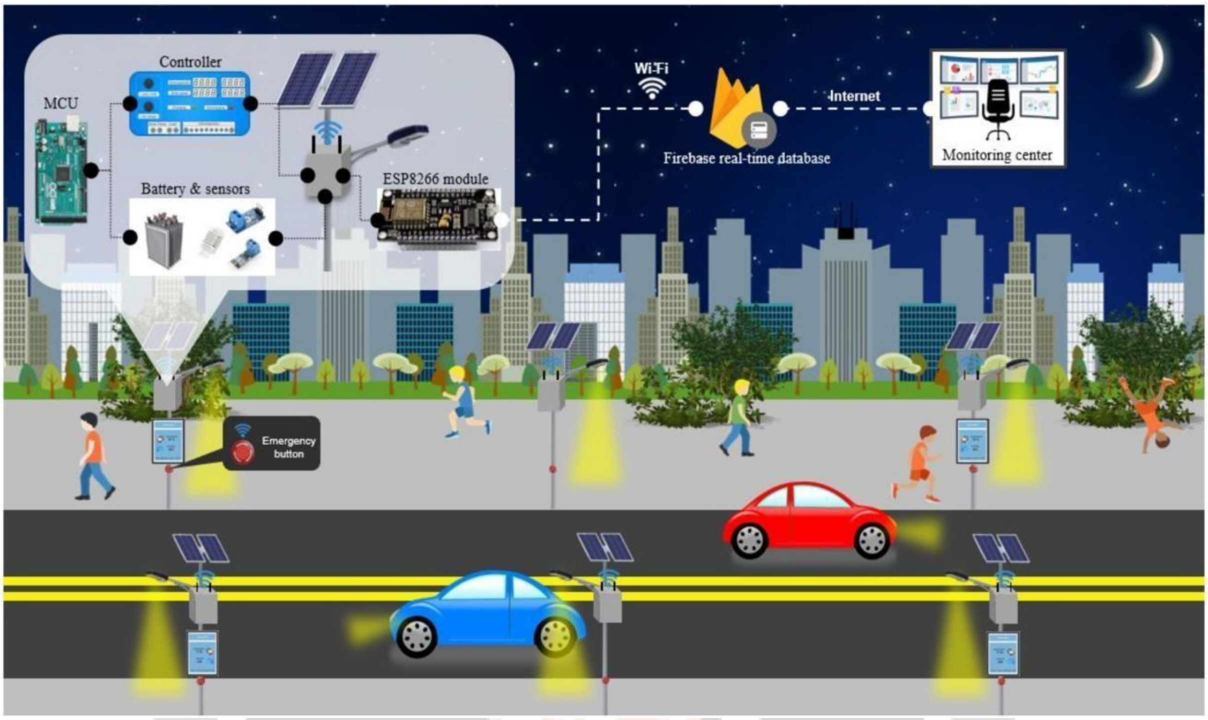

Fig. 2. Overall system diagram of the proposed smart streetlights.

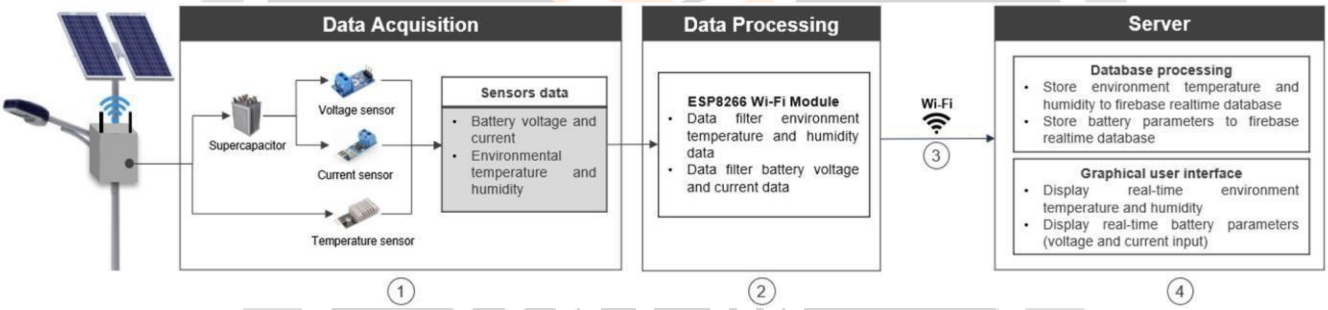

fig. 3. Data gathering diagram of the proposed smart streetlight monitoring system.

3. Wireless Data Transmission: The ESP8266 Wi-Fi module isresponsible for transmitting the processed data wirelessly. Initially, it configures itself to connect to a Wi-Fi network using an ESP8266 library. This configuration involves setting parameters such as SSID, password, and IP address. Once connected to the Wi-Fi network, the ESP8266 module sends the necessary data, filtered by the data filtering algorithm, to the real-time database.

4. Data Storage: The acquired data from the auxiliary controller, including supercapacitor parameters (voltage and current) and environmental parameters (temperature and humidity), are stored in the Firebase Realtime database. This database facilitates automatic retrieval and visualization of data via a graphical user interface (GUI), leveraging the platform's automatic data synchronization capabilities. In this article, aweb-based monitoring system serves as the GUI for remote monitoring of smart streetlights.The proposed real-time monitoring system depicted in Fig. 2 aims to reduce the cost of periodic manual maintenance by implementing automatic data synchronization with the Firebase Realtime database. Thisenables real-time monitoring of smart streetlight devices, enhancing operational efficiency and reducing maintenance overheads.

B. Data Filtering AlgorithmAside from the aforementioned contributions, this articlehas, also developed and introduced a data filtering algorithm which aims to reduce the data storage consumption in the cloud. Data filters, as previously mentioned, are used to reducestorage consumption of data collected for machine learning systems and IoT applications. Previously mentioned relatedAside from the contributions mentioned earlier, this article has also developed and introduced a data filtering algorithm aimed at reducing data storage consumption in the cloud. Data filters, as previously mentioned, are commonly utilized y decrease storage consumption on c

Algorithm 1 Data Filtering

Input: Sensor value
Variables: newSensorValue (new acquired sensor value), oldSensorValue (previously acquired sensor value)
loop:
if sensor value == 0 then
Save data to database
while sensor value == 0 do
Alert monitoring center "sensor not acquiring data"
end while
if oldSensorValue != newSensorValue then
Send data to database
else
Ignore data and wait for new sensor value

In existing smart streetlight monitoring systems, data istypically collected periodically from sensors embedded in the streetlights. However, this periodic data collection approach limits the system's ability to provide real-time monitoring. In contrast, the proposed data filtering algorithm in this article aims to address this limitation by ignoring unnecessary and redundant collected data. By filtering out irrelevant data, the algorithm ensures that only the most relevant information is stored in the cloud database. This approach not only helps prevent overloading and unnecessary data storage but also allows for more efficient utilization of storage space

The data filtering algorithm is implemented to enable continuous monitoring of smart streetlights without consuming excessive data storage. As outlined in Algorithm 1, data collected from integrated sensors serve as input. The algorithm distinguishes between new data (stored in the newSensorsValue variable) and previously acquired data (stored in the oldSensorValue variable).Upon collecting data, the algorithm initially checks if the value is equal to0. If so, it sends this value to the database to alert the monitoring center of a sensor malfunction. Otherwise, it compares the newSensorsValue and oldSensorValue to avoid redundant data storage. For example, if the previously recorded temperature is 35°C and the latest data also registers 35°C, only one instance of 35°C is stored, while subsequent instances are ignored. Once the temperature changes, the new data is stored, awaiting further changes.The effectiveness of the data filtering algorithm significantly impacts data retrieval in IoT web applications. By reducing data storage consumption, the algorithm facilitates faster data retrieval for visualization. Consequently, the proposed system can retrieve data with minimal delay, enhancing its responsiveness.In summary, redundant data is not saved to the database, allowing for more relevant data storage while preventing overloading and unnecessary use of data storage resources.

Real-Time Database:

In this implementation, a real-time database serves as the storage for theacquired sensor data, with the Firebase Realtime Database being the chosen platform. Developed by Google, Firebase Realtime

The process begins with the Arduino Mega collecting data fromthe sensors and transmitting it to the ESP8266 Wi-Fi module through a serial connection. The ESP8266 module then executesa data filtering algorithm to refine the collected data. Upon receiving the filtered data, the ESP8266 Wi-Fi module initiates an HTTP request to transmit the data to the Firebase Realtime Database via the Internet.

Once stored in the Firebase Realtime Database, the data can beautomatically retrieved and visualized through a graphical userinterface (GUI). This visualization is made possible by leveragingthe platform's automatic data synchronization capabilities, allowing for real-time monitoring of the smart streetlight system.

System Requirements

This section outlines the system requirements for the proposed low-delay IoT-based smart streetlight monitoring system:

1 Arduino Mega2560 Microcontroller: The developedauxiliary controller is operated by a microcontroller, with the Arduino Mega embedded as the microcontroller. Arduino Mega2560 is a microcontroller board based on the ATmega2560 [44]. It acquires all the data collected by the sensors integrated into the smart streetlight application.

2. Sensors/Modules: The developed auxiliary controller comprises various types of sensors and modules, including DHT22 for temperature measurements, a real-time clock (RTC) module for tracking sunset and sunrise times, and voltage and current sensors for monitoring the supercapacitor. DHT22 is chosen as the temperature sensor for its accessibility, availability, and low cost. It measures environmental temperature and humidity, which are displayed in both the GUI of the monitoring center and the LCD display for public information. Supercapacitor parameters such as voltage and current input are collected by MLE00960 and ACS712T-20A, respectively, and displayed in the digital segment display embedded in smart streetlights and the GUI of the monitoring center. The ESP8266 Wi-Fi module is utilized for wireless data transmission from each smart streetlight to the real-time database.

3. Web-Based Monitoring System: To visualize the stored data, a web-based monitoring system is deployed in this article. The system retrieves all acquired data saved in the Firebase Realtime database, reducing the maintenance cost of smart streetlight monitoring. The web-based monitoring system integrates Firebase's API to leverage the platform's automatic data synchronization, enabling real-timemonitoring of acquired data.Overall, these system components enable efficient monitoring and management of smart streetlights, facilitating real-time data retrievaland visualization for enhanced operational control

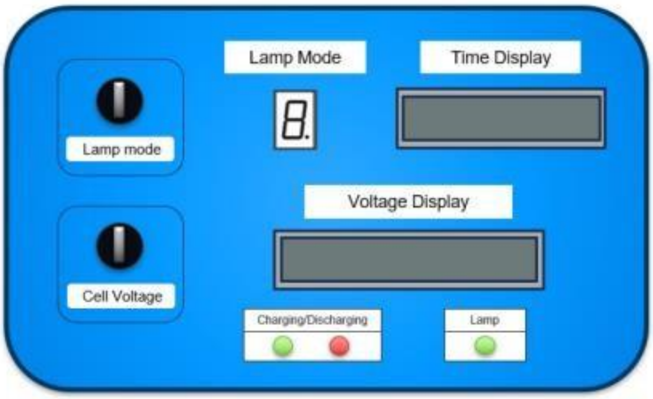

Fig. 4. Auxiliary testbed prototype design.

TABLE II
CONTROLLER PREDEFINED SETTINGS PER MODE

Mode	State	Duration
1	ON	During sunset
	OFF	During sunrise
2	ON	**24** hours
	OFF	**0** hour
3	ON	**a** hours after sunset
	OFF	**(24 – a)** hours
4	ON	**b** hours after sunset and **c** hours before sunrise
	OFF	**(24 – (b + c))** hours

IV **IMPLEMENTATION AND RESULTS:**

An auxiliary controller design, as illustrated in Fig. 4, has been developed as a testbed in this article to control smart streetlights and acquire data from sensors. In addition to the sensors and modules mentioned in the previous section, the auxiliary controller includes various components such as LED digital display, LED lights, and a rotary switch.

In our implementation, some components from the initial auxiliary controller prototype design have been replaced with other components. For example, a button is used to replace the switch mode selection, and a potentiometer is used to replace the cell voltage selection, as illustrated in Fig. 5. The on/off schedule of the smart streetlight is controlled by the selected modes using ourdeveloped auxiliary prototype. The user-selected mode determines the smart streetlight's controls. The user can Furthermore, the auxiliary controlle also acquires supercapacitorchoose from four different modes, each with its corresponding predefined parameters such as voltage and current. These parameters are measured tosettings, as listed in Table II.

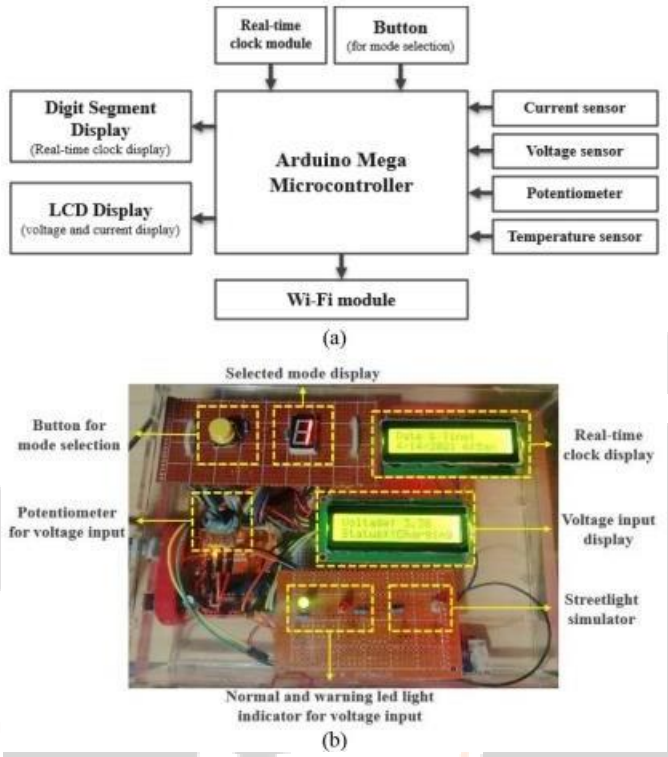

Fig. 5.(a) Block diagram of the proposed smart streetlight con- troller.
(b) Actual auxiliary control prototype testbed.

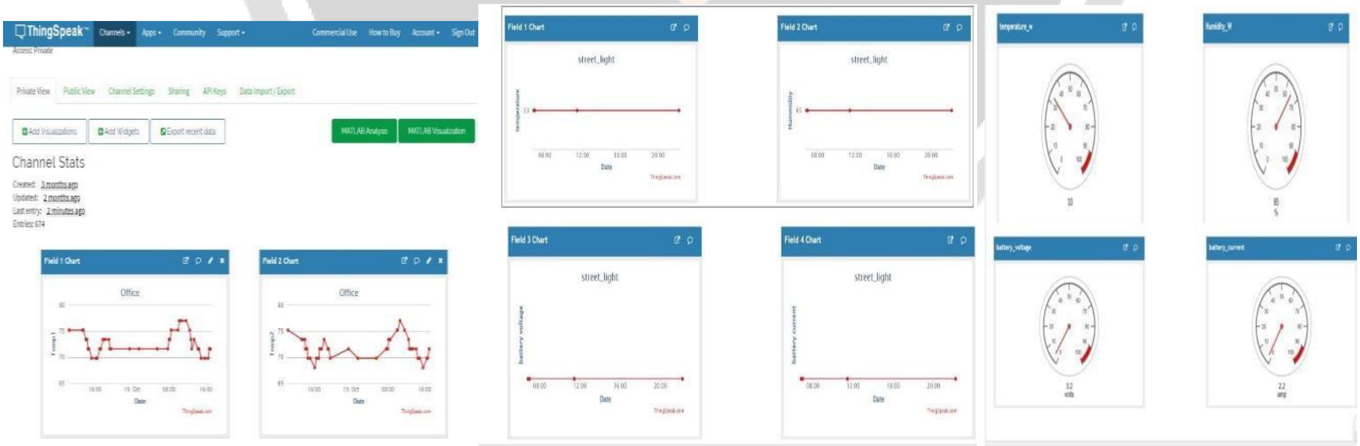

Fig. 6. testing for (a) CHART 1, (b) CHART2, (c) CHART3,

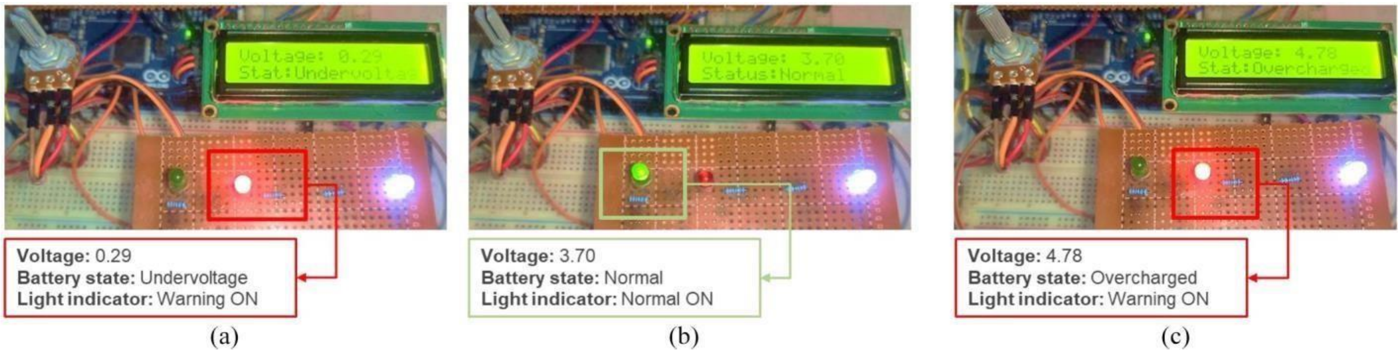

Fig. 7. Prototype testing for (a) undervoltage warning, (b) normal voltage, and (c) overcharged warning light indicator.

monitoring, a prototype of the designed auxiliary controller testbed was developed.

TABLE III
SUPERCAPACITOR STATUS BASED ON VOLTAGE

Voltage	Light Indicator	Status
0V – 3.1V	Warning Led ON	Undervoltage
3.2V – 4.2V	Normal Led ON	Normal
4.3V – 5V	Warning Led BLINK	Overcharged

In this article, the proposed streetlight is implemented and simulated on the premises of the Kumoh National Institute of Technology (KIT) located at Gumi-si, South Korea. As illustrated in Fig. 8, the proposed system (consisting of smart LED streetlight, auxiliary components, and supercapacitor device) are installed in our university's laboratory. On the other hand, the solar panel system that supports the power supply for the proposed streetlight is installed at the rooftop of the building. The monitoring system presented in [30] collects the lamp state, environmental, and supercapacitor parameters, the same as the data collected in this article. However, since the proposed monitoring system in [30] does not apply any data filtering algorithm, it only acquires data every 20 min, as opposed to proposed real-time monitoring solution.

Fig. 8. Actual implementation and simulation of smart streetlight application

TABLE IV
COMPONENTS PARAMETERS FOR SIMULATION

	Solar Panel Parameters
Nominal voltage	38.5V
Nominal current	5.71A
Power consumption	220W
	Supercapacitor Parameters
Nominal voltage	4.2V
Nominal current	4A
Power consumption	15W
	Streetlight Parameters
Nominal current	0.7A
Power consumption	20W
IP Code	IP67
	ESP8266 Parameters
Upload Speed	115200
CPU Frequency	80 MHz
Flash Size	4M (3M SPIFFS)

The effectiveness of our data filtering algorithm was evaluated by acquiring and storing data in a local database for 15 minutes. Table V provides a summary ofthe comparison between conventional data saving without data filtering and our proposed data filtering algorithm

TABLE V
DATA STORAGE SIZE COMPARISON

Tables in database	W/o data filtering [30]	Proposed data filtering algorithm
Lamp state	53.2 KB	6.08 KB
Environmental parameters	45.8 KB	8.24 KB
Supercapacitor parameters	67.4 KB	8.13 KB

The effectiveness of our data filtering algorithm was evaluated by acquiring and storing data in a local database for 15 minutes. Table V provides a summary of the comparison between conventional data saving without data filtering and our proposed data filtering algorithmFirstly, we noted that the storage space consumed by lamp state data is 53.2 kB without data filtering, whereas it reduces to 6.08 kB with our data filtering algorithm. This represents a significant reduction of 88.57% in storage usage for lamp state data.

Secondly, the emergency parameters accumulate 45.8 kB of storage space without data filtering, but only 8.24 kB with our algorithm.

This results in a reduction of storage size usage for emergency parameters by 82%.

Lastly, without the data filtering algorithm, the acquired supercapacitor parameters occupy 67.4 kB of storage space, which decreasesto 8.13 kB with data filtering. Consequently, there's an 87.93% reduction in storage usage for supercapacitor parameters.

In summary, our data filtering algorithm effectively reduces storage size consumption by up to 88.57%. This reduction allows for more diverse data to be stored in the data storage system. All stored data can be retrieved for real-time monitoring using a Web-based monitoring system, as illustrated in Figure 9

To demonstrate the low-delay data retrieval capability of our proposed real-time monitoring system, we conducted a simulation comparing a local-based monitoring system with an online-based real-time monitoring system utilizing a database, such as the Firebase Realtime Database. The system proposed in [28] was used as the basis for our simulation, and it was re-simulated in this article to facilitate a comparison between the local-based monitoring system and the online- based real-time monitoring system

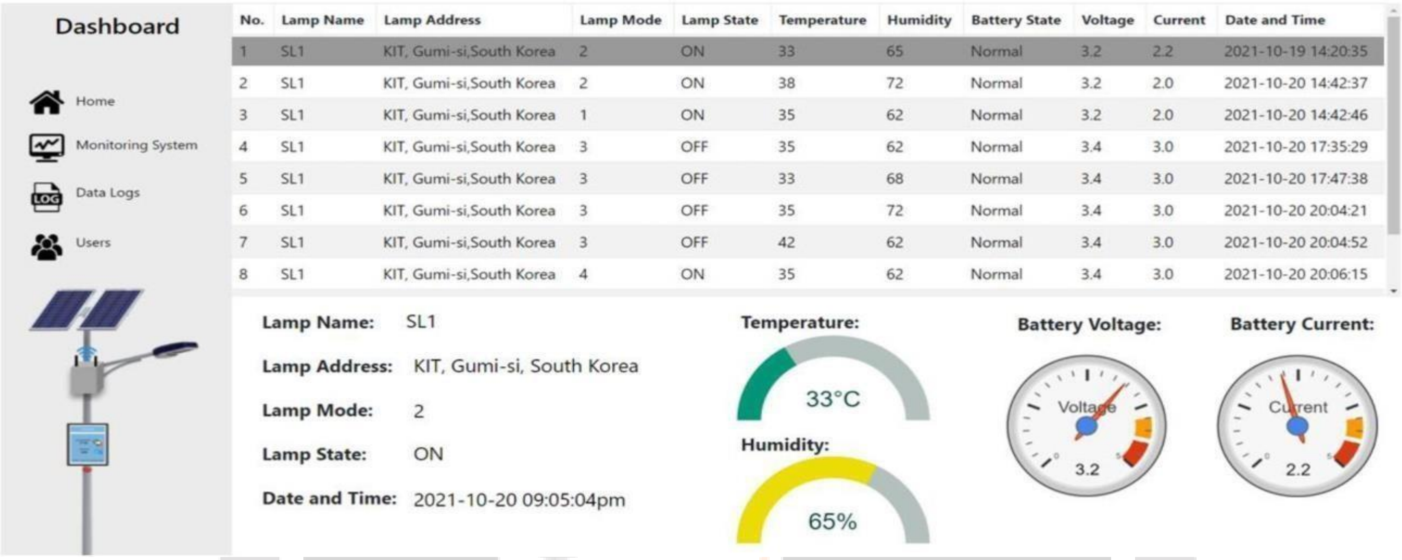

Fig. 9. Proposed Web-based real-time monitoring system of the smart streetlights.

TABLE VI
COMPARISON OF EXECUTION TIME FOR RETRIEVING DATA USING WEB-BASED MONITORING SYSTEM

	Environmental Parameters (EP)		Supercapacitor Parameters (BP)		Lamp State (LS)		EP & BP		EP & LS		BP & LS		Overall	
ms	**Proposed**	**[28]**	**Proposed**	**[28]**	**Proposed**	**[28]**	**Proposed**	**[28]**	**Proposed**	**[28]**	**Proposed**	**[28]**	**Proposed**	**[28]**
Trial 1	0.08	1.67	0.48	3.92	0.56	3.30	0.12	3.24	0.13	1.99	0.26	1.91	0.42	3.03
Trial 2	0.09	1.02	0.07	14.07	0.12	1.03	0.11	1.04	0.07	1.56	0.10	23.19	0.56	25.92
Trial 3	0.17	20.17	0.10	1.14	0.19	1.31	0.09	1.13	0.22	1.45	0.08	1.53	0.32	1.41
Trial 4	0.08	1.09	0.08	1.23	0.27	2.29	0.83	22.12	0.11	1.79	0.10	1.07	0.27	1.51
Trial 5	0.14	2.16	0.08	1.16	0.08	1.38	0.10	1.19	0.09	1.44	0.07	1.53	0.90	1.32
Trial 6	0.09	1.49	0.09	2.10	0.08	1.10	0.10	2.31	0.10	1.06	0.27	1.29	0.29	12.90
Trial 7	0.11	1.63	0.11	1.95	0.12	1.08	0.09	1.51	0.09	1.09	0.10	1.37	0.55	12.26
Trial 8	0.08	1.03	0.10	1.02	0.10	1.52	0.08	1.05	0.08	1.94	0.13	1.58	0.33	15.09
Trial 9	0.09	1.09	0.07	1.09	0.65	2.48	0.15	1.09	0.14	22.77	0.09	1.22	0.27	11.05
Trial 10	0.41	1.21	0.13	1.72	0.09	1.33	0.10	1.09	0.07	1.24	0.18	1.27	0.43	1.95
Average	0.13	3.25	0.13	2.83	0.22	1.68	0.17	3.57	0.11	3.63	0.13	3.59	0.43	17.75

In our simulation, we compared a Web-based monitoring system using Firebase with a Web-based monitoring system utilizing local data storage. Asdepicted in Table VI, the local Web-based monitoring system was capable ofachieving rapid data retrieval.

To further validate the reliability of our proposed monitoring system, we conducted retrievals involving combinations of data. For instance, environmental parameters and supercapacitor parameters were retrieved simultaneously. The results showed that local monitoring achieved an average retrieval time of 3.57 ms, whereas our proposed monitoring system achieved an average retrieval time of 0.17 ms.Similarly, when retrieving bothenvironmental parameters and lamp state data, local monitoring exhibited an average retrieval time of 3.63 ms, considerably slower than our proposedmonitoring system which achieved an average retrieval time of 0.11 ms.

Furthermore, when retrieving supercapacitor parameters and lamp state data,local monitoring had an average retrieval time of 3.59 ms, whereas our proposed monitoring system achieved an average retrieval time of 0.13 ms. These results demonstrate the significantly improved performance ofour proposed real-time monitoring system compared to traditional local-based monitoring systems, particularly in terms of low-delay dataretrieval.

V.CONCLUSION:

Smart streetlights hold promise to replace traditional streetlights. It helps reduce the maintenance cost of traditional streetlights by integrating drivers and devices to make them "smart" and operate on their own, e.g., automatically turning on/off. Previous studies used these technologies integrated in smart streetlights for remote monitoring. However, monitoring systems do not provide real-time monitoring to ensure smart streetlights'operability. streetlight applications using a cloud-hosted real-time database platform was proposed. This article has shown that is able to provide real- it time monitoring of data collected from smartstreetlights by taking advantage of the automatic data synchronization feature of the implemented real-time database, which automatically synchronizes data once new data have been stored. Furthermore, we implemented our proposed data filtering algorithm, which disregards redundant data, to acquire real-time data to avoid consuming large amounts of data storage. By means of simulation, we showed that our proposed monitoring system using the Firebase Realtime database is much faster in data retrieval compared to a local Web-based monitoring system.

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