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A Data-centric Smart Street Light Monitoring and Visualization Platform for Campus Management

Somrudee Deepaisarn[1,*], Paphana Yiwsiw[1], Chanon Tantiwattanapaibul[1], Suphachok Buaruk[1] and Virach Sornlertlamvanich[2,3,*]

[1]Sirindhorn International Institute of Technology, Thammasat University, 12120, Thailand
[2]Faculty of Engineering, Thammasat University, 12120, Thailand
[3]Asia AI Institute, Faculty of Data Science, Musashino University, 135-8181, Japan

Abstract

Smart lighting systems have become increasingly popular in several public sectors as a result of the trend toward urbanization and intelligent technologies. This study designed and implemented a web application platform for exploring and monitoring data acquired from lighting devices at a university in Thailand, Thammasat University (Rangsit Campus). The platform offers a convenient interface for administrative and operative staff to monitor, control, and collect data from sensors installed on campus in real time, creating geographically specific big data. Platform development focuses on both back-end and front-end applications to allow a seamless process for recording and displaying data from interconnected devices. Responsible persons can interact with the devices and acquire data effortlessly, minimizing workforce and human errors. In this work, the collected data were analyzed through the exploratory data analysis process. The behaviors of missing data caused by system outages were also investigated.

Index Terms: Smart City, Big Data Platform, Exploratory Data Analysis, Light, Internet of Things (IoT)

I. INTRODUCTION

At present, there is a growing trend for people to relocate to densely populated areas around the world. By 2050, it is estimated that over 60 percent of the population will move to such areas [1]. The smart city concepts have emerged as solutions to promote quality of life in all aspects as well as to develop socio-economy. Sensors and other inter-connected devices so-called Internet of Things (IoT), play essential roles in creating such a conceptual environment [2-3]. There are six aspects of the smart city, according to Giffinger *et al*. [4], which are smart environment, mobility, people, living, economy, and governance. In this research, the smart environment is considered. Smart street lighting system is implemented in a geographically specific location. We studied previous cases of smart street lighting projects at various locations globally. For example, the Amsterdam Smart City (ASC) implemented smart street light that can be adjusted based on the ambient environment that takes into account the parameters related to weather and pedestrian. Optimizing energy usage and reducing carbon footprints are their main goals [5]. Also, Barcelona's Smart Street Lighting System utilized LED devices to save energy and costs [6]. Moreover, improvement in quality of life, reducing crime rates, and enhancing public safety are potential advantages of efficient smart street lighting systems [7].

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***Corresponding Authors** E-mail: somrudee@siit.tu.ac.th, virach@gmail.com

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Fig 1. Satellite map of Thammasat University, Rangsit Campus, Thailand; latitude/longitude location: 14°04'27" N 100°36'08" E. (Image from: Google Map)

With the conceptual system of our intelligent system for street lighting, the ability to manage and visualize data plays a crucial role in ensuring its success. The system establishment requires maintenance and monitoring of the devices installed and controlled within the area. For example, the Barcelona project implemented the Application Programming Interface (API), enabling communication between external platforms, such as the traffic data platform, and the proposed system to allow prompt data transfers [8]. Additionally, other environmental or meteorological data can be acquired through sensors to gain knowledge about the city and create an intelligent system [9]. A similar smart street lighting system was also employed in Singapore, which is located geographically near Thailand. LED street lighting devices were installed and managed by the Land Transport Authority of Singapore. The project aims at energy and maintenance optimization [20]. Notably, they introduced a remote control and monitoring system (RCMS) which depends on weather-related parameters [21].

Strong public and private sector collaboration is required to build sustainable smart cities [10]. Accordingly, we deployed the smart street lighting and environment system as part of the smart city project at Thammasat University, Rangsit Campus, Thailand. The campus is situated in Pathum Thani, which is in the Bangkok Metropolitan Region, as shown in the map in Fig. 1. A total of 167 smart lights were set up on campus. The pole-to-pole separation of the smart lighting devices was set to 20 meters to comply with the standard regulations regarding street lighting in Thailand and to satisfy the security requirements. Smart street light devices can adjust the dimming light-emitting diode (LED) up to a consumption power of 120 W. Efficient dimming can be determined to compensate for the natural illumination levels during the evening, night, and early morning. Our on-campus system assists both vehicles and pedestrians. For the functionalities to work properly, reliable management and maintenance are necessary. Therefore, we built a platform for the administrator to monitor and control the devices. The data recorded from each device can be visualized and kept in a suitable

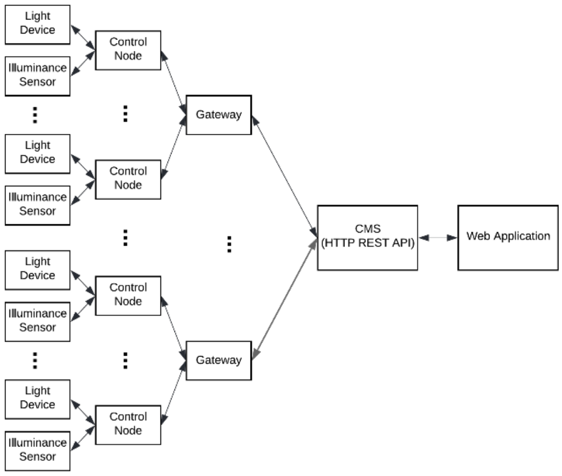

Fig 2. Measure of service disruption time.

database for analysis, introducing a data-centric scheme under the umbrella of the smart city. Exploratory data analysis was performed to bring about a deeper understanding of data characteristics. These include correlation value regression analysis and the study of the problematic issue caused by missing values in the dataset. Through inferences from the data, reasonable data analysis techniques can be applied to achieve some practically valuable conclusions in the future.

In summary, the proposed system comes with improved monitoring and data collection. Through visualization and exploratory data analysis, further implementation can be facilitated more accurately; for example, the automated light-adjusting system to optimize illuminance and energy consumption in the area. This system, coupled with an intelligent campus concept, advances the sustainable development of Thammasat University by driving toward optimal campus management solutions.

II. Infrastructure and System Requirements

Smart street lighting and environmental station consisting of sensors for measuring temperature (°C), relative humidity (%), wind velocity (m/s), wind direction (azimuth degrees) illuminance (lx), rain level (arbitrary), Ultra Violet A (W/m^2), Ultra Violet B (W/m^2) and air pressure (Pa) (MinebeaMitsumi, Inc., Japan) were installed at Thammasat University, Rangsit Campus, Thailand. A total of 167 dimmable LED lighting devices, each equipped with localized illuminance sensors and communication nodes, were installed on the campus area and connected to the external control system through three gateways. Six control zones were defined following the main road in the university to ease the management and control of these devices.

In the presented system, the dimmable smart lights are integrated with an external management platform, the CMS

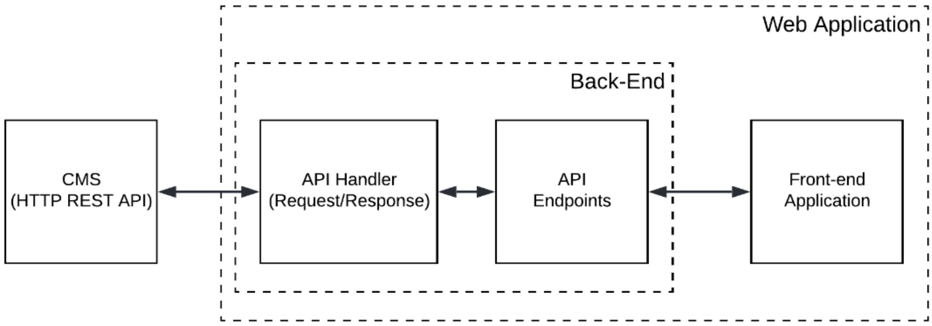

Fig 3. Diagram illustrating the connection of CMS API, back-end part, and front-end part of the web application.

Neptune - SC-v6.0.3 (Paradox Engineering, Switzerland), which is operated by the lighting product manufacturer. Representational State Transfer (REST) was used to call API on Hypertext Transfer Protocol (HTTP). The connection between devices and the CMS API is illustrated in Fig. 2. The system's back-end sends HTTP requests and receives responses using the REST API that CMS provided. Additionally, it should be able to collect and visualize data, as well as monitor device status. The system's front-end is compatible with various operating systems because of the web application design. It promotes accessibility and uberization, as demonstrated in Fig. 2.

III. Back-end System Development

The back-end system development is fully explained in our previous conference paper entitled "Smart Street Light Monitoring and Visualization Platform for Campus Management" [22], which was presented at the 17th International Joint Symposium on Artificial Intelligence and Natural Language Processing (iSAI-NLP), Chiang Mai, Thailand. In this paper, the additional maintenance and logging system is proposed as follows. See the back-end system process in Fig. 3.

A. Maintenance and Logging System

Due to the current infrastructure on campus, electricity power failure may unpredictably happen from time to time. This causes risks of data lost in our database as communication must be made between interconnected devices through gateways. Therefore, the back-end system can be improved by integrating the device disconnection detection API where one or more devices are disconnected from the electrical grid and acknowledging responsible persons via notification displayed on the user interface for maintenance. The detection system will send an HTTP request to CMS API to listen for device disconnection events in 10-minute intervals and record those events into the database. The ability to monitor and get notified when devices fail to communicate to the network is important to maintain the smart lighting system and enhance the reliability of the data stored in the database. The process of the detection system is illustrated in Fig. 4.

IV. Front-end User Application Development

A web application was designed in a way that enhances the accessibility cellular communication on HTTP protocol with optimized the user experience [14-15]. Bootstrap CSS library was applied to allow responsive web design so that full view can be displayed on various screen sizes [16].

The data visualization dashboard was written with JavaScript using the Chart.js library [17]. The values are sent from each sensor every 10 minutes. The measurements include temperature (°C), relative humidity (%), wind velocity (m/s), wind direction (azimuth degrees), illuminance (lx), rain level (arbitrary), Ultra Violet A (W/m^2) and Ultra Violet B (W/m^2). Fig. 5 illustrates the dashboard, which displays numerical values from the latest readings.

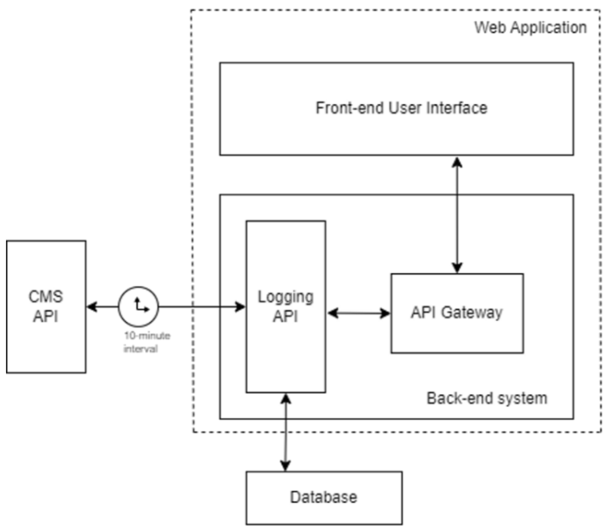

Fig 4. The maintenance system process. Logging API will send an HTTP request to CMS API on 10-minute interval basis. An HTTP response is sent back, containing the disconnection event if any. Later, those events are recorded in database.

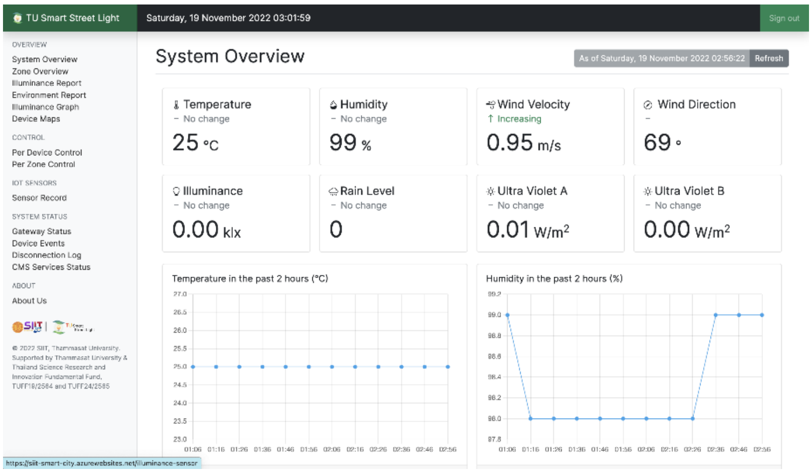

Fig 5. The web application user interface showing the environmental values measured from the installed station.

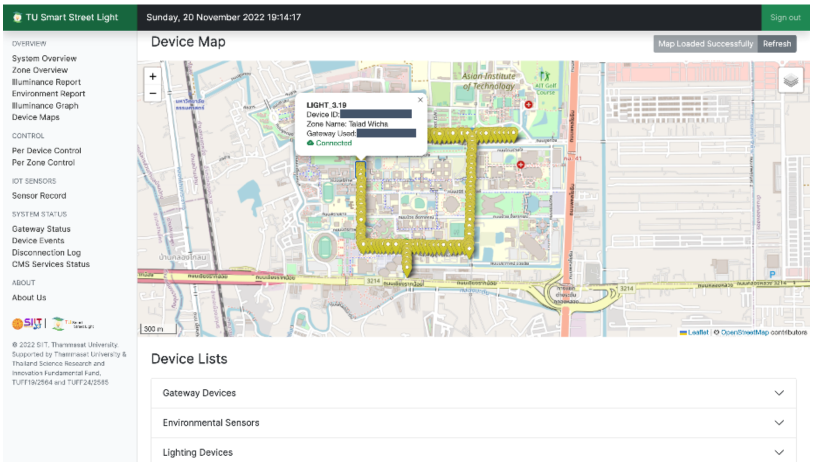

Fig 6. Map showing the locations of the 167 LED smart lighting devices.

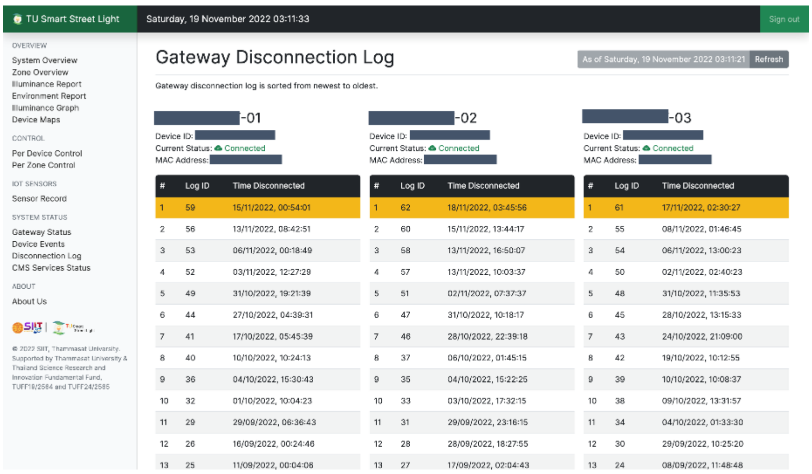

Fig 7. The user interface of historical gateway connection devices. The table is shown disconnection log for each gateway device along with its useful information such as device name and current connection status. Yellow highlighted rows show the most recent disconnection event.

The line graphs show the past two-hour entries. As mentioned in Section III, the API endpoint was used to acquire all these sensor values. The data were stored in the database, and produce monthly reports of all environmental sensors in the comma-separated values (csv) format. Monthly datasets are available for download at https://siit-smart-city.azurewebsites.net/csv-download, where the dataset is simultaneously updated every 10 minutes. This provides time-series data for analyzing environmental data on campus.

The Leaflet.js library of JavaScript was utilized to display an interactive map of 167 lighting devices and three gateways [18], enabling access to precise locations and status information of each device (see Fig. 6). Finally, the platform that is a merging of Sections III and IV are deployed on Microsoft Azure App Service where Node.js applications are well supported [19]. The public URL is generated, allowing the user to access and monitor the smart street lights and environmental sensors. Data stored can be kept for reference and capable of use in further analysis.

A. User Interface for Maintenance System

As mentioned previously, the detection system is implemented to be responsible for handling device disconnection events. The user interface is provided for maintenance staff to notify them in case of a disconnection event occurring in the system. The data shown on this interface is obtained from the database via logging API. In the case of the most critical devices, such as gateway devices, the historical disconnection log is also shown in the table form to inform the maintenance staff about previous events and perform their duty accordingly. The user interface of this system is shown in Fig. 7.

V. Data Inference

The dataset is gathered from the environmental sensors, where values are kept in an external database, which can be called by API. The environmental information ranges from February through November 2022. Artificial intelligence applications can be applied, especially for the prediction of future environmental values. These datasets collect information on a variety of environmental variables, including temperature, humidity, wind speed, and index of Ultra Violet A and B. These variables can be used to build a predictive model that considers the relationship between the environmental conditions. However, the illuminance value is the only parameter in this work that we want to analyze and to pre-investigate the dataset. This dataset is pre-processed using Pandas, the most powerful Python package for data analysis, time series analysis, and statistics. The main task of exploratory data analysis processes from the environmental database system is introduced in this section. In this section, we carried out the data preparation, correlation assessment between parameters, exploratory data analysis of the dataset, and assessment of missing data.

A. Data Preparation

The raw data of illuminance value are gathered as time series data using a date and time as an index. These raw indexes are acquired in the format of "yyyy-mm-dd hh:mm:ss", where the first set of data refers to the year month and date, and the latter set of data refers to the timestamp indexes of hour, minute, and second within the day. We collect the response from the interconnected smart devices every 10-minute timestamp. However, communication delays often occur while sending loads of data messages. Therefore, the data are rounded to 10 minutes between adjacent records to correct the data prior to performing further statistical analysis to make sense of the acquired dataset. As a result, there are six timestamps in an hour, which means 144 timestamps per day.

B. Correlation Matrix

To explore the relationships between the different environmental parameters collected from the sensors, we conducted a correlation matrix analysis. This analysis allowed us to determine the correlations between each pair of variables and their directions, as well as identify any significant relationships. Seven variables are studied, including illuminance, temperature, wind velocity, air pressure, humidity, Ultra Violet A index, and Ultra Violet B index. The correlation coefficients ranged from -1 to 1, where strong positive and strong negative correlations take correlation values close to 1 and -1, respectively. The

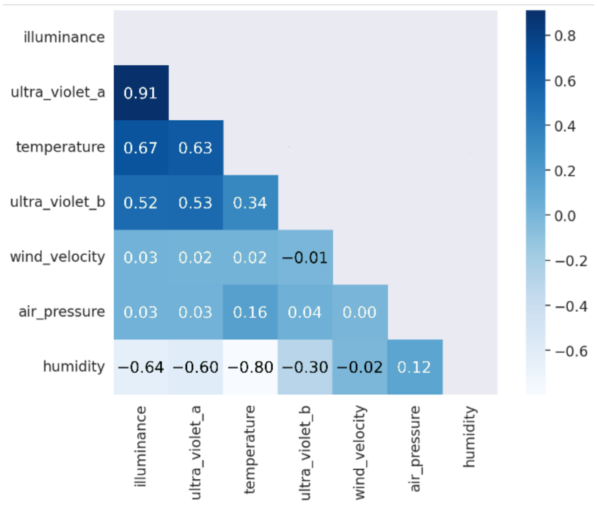

Fig 8. Correlation matrix for assessing correlation between different parameters, *i.e.* illuminance, Ultra Violet A, temperature, Ultra Violet B, wind velocity, air pressure, and relative humidity, respectively.

correlation is close to 0 when little or no correlation is observed.

Our correlation analysis revealed several significant correlations between the environmental variables, as shown in the correlation matrix in Fig. 8. The strongest positive correlation was found between illuminance and the Ultra Violet A index (r = 0.91), indicating that the light information is strongly related. Additionally, we found a strong positive correlation between illuminance and temperature (r = 0.67), suggesting that higher levels of illuminance were associated with higher levels of temperature. Illuminance, Ultra Violet A, and temperature are directly proportional. Relative humidity and temperature also have a high negative correlation (-0.80), meaning that they are inversely proportional. This agrees with the fact that the components of radiation at midday consist of 95% of Ultra Violet A and 5% of Ultra Violet B [23]. Then, we consider the regression of Ultra Violet A, as can be seen in Fig 9.

C. Exploratory Data Analysis

Table 1 shows the top three variables that correlate to illuminance, listing Ultra Violet A, temperature, and Ultra Violet B. It can be seen that all of the standard deviation values are high compared to the target variables. This was also observed in the analysis of residual between actual and predicted illuminance using time-series model, as presented in [24]. Ultra Violet A, as the most correlated parameter, has the highest correlation to the illuminance profile. The relationship between these two parameters is further illustrated in linear regression as shown in Fig. 9 where the actual and the predicted value were plotted and fitted with a line graph. The illuminance increases significantly when the Ultra Violet A increases, which agrees with the physical properties of visible light and radiation [23]. In contrast to the correlation coefficient, the result from Table 1 also presents the standard deviation value which considers the difference between actual and predicted value of

Table 1. The linear regression model of the three most correlated variables to illuminance.

Variable	Correlation coefficient (r)	Linear fitting of illuminance vs. variable	Standard deviation
Ultra Violet A	0.91	$y = 2712.30x - 1422.82$	9,442.33
Temperature	0.67	$y = 4603.43x - 100236.55$	27,596.01
Ultra Violet B	0.52	$y = 88012.85x + 6691.25$	11,931.14

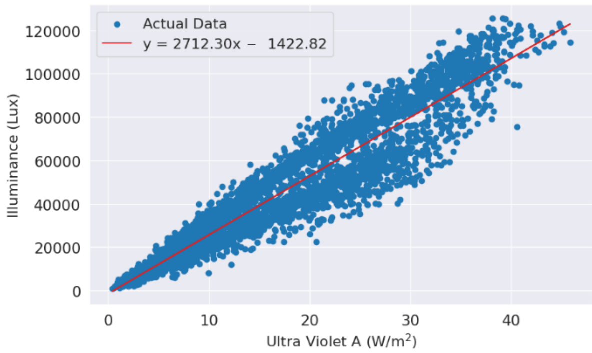

Fig 9. Scatter plot of predicted against actual values, and a linear fitting illustrating the correlation between illuminance and Ultra Violet A.

illuminance. These statistical values help us observe the characteristics of errors distributed in the predicted values which will be useful for further analysis

D. Missing Data

The presence of missing values in the dataset could occur if there is an issue with the data collection tools or if a weather station goes offline, as shown in Fig. 10. Gaps in the data lead to errors in the forecast and a lack of confidence in model accuracy. Missing values can also affect prediction tasks by introducing bias into the forecast, which can occur when certain features of data are more likely to be missing than others. This is the reason why it is important to minimize the impact of missing values as much as possible. Fig. 11 demonstrates the entire illuminance dataset as time series data, where the x- and y-axes represent time of the day and date, respectively. The missing value in the series dataset can be easily observed using this kind of illustration. The specific time window of this illustration precisely ranges from midnight on 2022-02-05 to midnight on 2022-11-01.

VI. Discussion

The present study aims to address the need for data visualization and device monitoring at Thammasat University, Rangsit Campus, Thailand, by developing a web application. The application offers a user-friendly interface that is easy to use for managing the system, enabling the collection of real-time data acquisition from environmental sensors and monitoring devices. The system only measures light-related information, such as illuminance and Ultra Violet A and B index but also monitors other environmental parameters, including temperature and humidity. Our preliminary observations suggest that these environmental parameters are correlated with the lighting parameters, highlighting the need for a system that facilitates their acquisition for further data analytics. To this end, we have designed a system that minimizes human efforts in collecting these data and

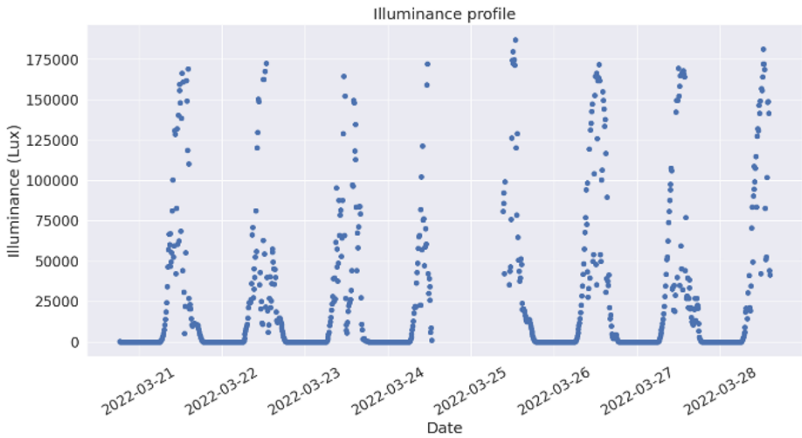

Fig 10. Illuminance profile with some missing values introducing gaps in the time-series data.

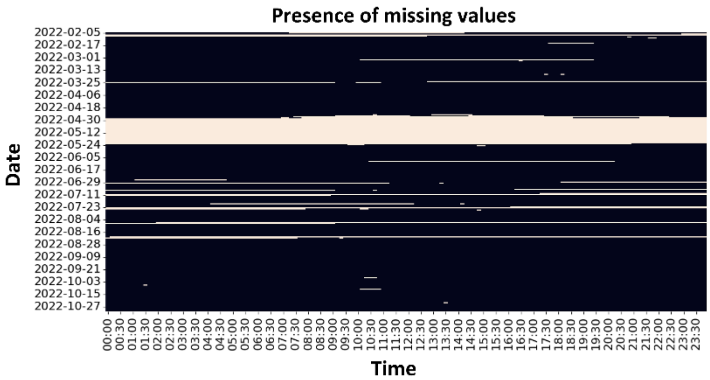

Fig 11. Presence of missing values.

provides an easy-to-use interface for street light management by the operative staff. The proposed system also integrates a maintenance and logging system to monitor disruptions caused by electrical blackouts and grid instability. However, gaps in data remain challenging, requiring proper statistical analysis, including missing data analysis and correlation assessment. These statistical processes help identify and address inconsistencies in the data, allowing for more accurate predictions. The aim of our research is to investigate the potential of an intelligent platform for the purpose of monitoring and visualizing smart street lighting devices in the context of campus management. We found that illuminance, Ultra Violet A, Ultra Violet B, and temperature are directly proportional to solar radiation; hence, they strongly correlated as expected. Relative humidity and temperature also have a high negative correlation, meaning they are inversely proportional. This reflects the physical fact that once the temperature is higher, the air is so much dryer that it can take more moisture before reaching saturation, causing low relative humidity. Vice Versa, when the temperature decreases, the relative humidity increases. These behaviors can be observed, and the prediction of natural light levels can be observed, leading to the prediction of necessary LED lighting levels at a particular timestamp, day, and season. Our primary objective is to reduce energy consumption and promote sustainability. To this end, we intend to develop a prediction model that will facilitate the automatic adjustment of lighting systems on campus, providing a sophisticated solution for the outdoor environment. The anticipated benefits of this endeavor are expected to extend to both the campus people and system administrators.

VII. Conclusion and Future Work

This study has developed a web application to monitor smart lighting devices at Thammasat University, Rangsit Campus, Thailand. The back-end part of the application has a feature called API endpoints that can send data from an external platform to the front-end part. The front-end application uses a responsive design with the Bootstrap CSS framework. Additionally, the application provides a Leaflet.js map to display device locations and uses a Chart.js map to display device locations, and uses Chart.js for environmental sensor data visualization. The web application has been made available through Microsoft Azure App Service and can be accessed using its public

URL. The collected data has been carefully investigated via data inferences, especially for missing data caused by system downtime. Future work could include data applications, such as a prediction model and further contribute to energy conservation and sustainability efforts. The attempts to deal with missing or anomaly values, such as smoothing techniques, statistical techniques, *etc.*, may give some clues toward more precise predictions. Learning about current and future data is not made possible without the existence of efficient collection, database, visualizing system, which altogether built data-centric platform. For advancing the infrastructure and ability for more in-depth analysis is to consider interaction of the system with camera and motion sensors, which provide other types of information related to the distributions of pedestrian and vehicles in the ambient areas. This complex information will put more costs on computational resources and robust algorithms to process, but will give rise to determining much thorough insights with appropriate problem statements and subsequent data analysis.

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