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Optimized Smart Energy Management System for Campus Buildings: A Conceptual Model

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Abstract. Given the upcoming post-pandemic times, there are more universities considering adopting the hybridization model. As such, not all the facilities and building utilities will be fully utilized as only half of the student population will be expected, thus wasting the campus's energy consumption. Therefore, an intelligent management system can be implemented into smart campuses to reduce the overall electrical bills to adapt to the hybrid education model. The research will be then conducted on existing prior work which will be over-viewed in this paper in the area of intelligent buildings and energy optimization. It was found that many of the energy optimization models utilized an IoT application highly specific to the designed IoT system only. This inspired us with the aid of Particle Swarm Optimization (PSO) and LTMS AI model to design a fully automatic system capable of reducing the consumed power in campus with monitoring the past readings that can be accessed through a web app dashboard.

INTRODUCTION

Energy Management is a major advancement that researchers are trying to establish. A fully automated smart campus is a step forward towards the future energy saving and simplicity. As building energy management systems (BMSs) must cater to a range of user behavior, building energy use is not always optimized. Now, as data on building energy use has increased, a wide variety of information is available to optimize BMSs so that they deliver energy services exactly when they are needed.

This research aims to divide the work in three parts to fully achieve an automatic controlled smart university campus that is meant to save energy based on its recorded data and the behavior of the user. Additionally, the novelty of this research is focusing on designing an AI model that is optimized with PSO algorithm, applying it on a fully automated prototype of university campus, and be able to see the data readings through the web app dashboard. The three sub sections will be, 1) the brain of the system, which is suitable algorithm, 2) web app connected to cloud database for the user to surveillance the system and the storing of the data, 3) university campus prototype with a miniature of the main appliances that are part of the daily basis in the university.

Simulation Tools and Web App for Campus

There are many reviews on smart buildings being monitored through cloud with the rapid improvement in recent years on sensor technologies, embedded systems, and both mobile technology and applications, it has now become easier to implement better smart home systems to ensure a high quality of life [1]. As such, the team proposed to develop a low-cost, flexible, multi-functional smart home system prototype controlled by a mobile application. This system must be able to meet the core requirements of providing a convenient, efficient, and easy way to monitor home security and improve comfort.

A novel and extensive architecture was successfully developed for a low-cost, flexible home control and monitoring system on the Android OS platform to allow Android-based users control access. One significant advantage of this control system is being able to work in non-Wi-Fi conditions due to utilizing mobile cellular network connections.

However, considering that MATLAB or C-based code is being used to connect with the ThingSpeak platform, there are several disadvantages to consider. Due to the proprietary nature of MATLAB, this may limit the number of users able to access the system as they are required to pay license fees. Unlike MATLAB, Python provides open-source programming and user-friendly syntax, allowing programmers to read, understand, and debug the code more easily. It also provides a wide range of tool-sets relevant to data analytics, whereas MATLAB is more commonly used to solve engineering problems [2].

An evaluation study on the currently available energy consumption monitoring systems was conducted by [3]. Their research results revealed that most of the existing solutions involve high costs and large amounts of investments into communication medium infrastructure. Thus, they developed a low cost IoT energy monitory system using communication mediums which consist of Wi-Fi and MQQT (Message Queuing Telemetry Transport) protocol. The developed system was able to produce detailed measurements of the active power, current, voltage, and accumulative power consumption in a smart house setting. The results obtained were from analyzing the energy profile of an electric kettle.

This research successfully implemented a working low-cost IoT system suitable for energy tracking and monitoring applications. However, this IoT application could be further improved. A labeling system in the JSON structured data could be implemented to identify the type of appliance. This would allow users to identify the primary energy consumption devices, giving them better insights into the energy usage profile system.

An evaluation study conducted by Esquiagola and the team showed that atmospheric pollution causes premature death to millions of people worldwide [4]. Furthermore, given an indoor situation, the air pollution concentration can be greater than the outside concentrations up till ten times owing to malfunctioning heating, ventilation, and air conditioning (HVAC) system. Thus, the team proposed to develop an IoT solution to monitor indoor environments for air quality in hospitals, offices, schools, homes. The proposed work is a continued development of a prior work that used another methodology and introduced the first stage of the platform [5]. This research successfully implemented an IoT platform capable of monitoring indoor airborne pollution. Various advanced sensors were utilized to acquire accurate results of relevant factors responsible for affecting indoor atmospheric pollution, and these data were sent to a dashboard for visualization.

The structure utilizes the gateway to execute requests, collect and pre-process data, and store it into a local database before eventually sending it to the cloud. Python scripts will then implement certain programs to execute all required actions, and the MariaDB stores the data locally. A Python script was also used to utilize the HTTP API to transfer data to the Ubidots platform from the gateway. The platform offers the framework for capturing, processing, and visualizing the data in real-time.

The proposed system uses a wide range of sensors, making it possible to obtain a fine-grain analysis of indoor environmental conditions. Implementing multiple particulate matter sensors over a range of sensitivities provides the user with a clearer insight into detected air pollutants. Additionally, the VOC (Volatile organic compounds) sensor has versatile functionalities as it can be used to detect both the presence of organic air pollutant compounds and the presence of humans, a primary source of VOC. However, this also poses a problem where the system cannot differentiate between a person and an airborne organic compound pollutant. Therefore, either simple data analytics should be used, or users should be provided with options to manually set comparison thresholds to differentiate effectively between the air pollutant and human presence. This article shows that it is crucial to develop a helpful, interactive, and informative dashboard to help the user.

As for the research study made by Jaribion, it was identified that one neglected strategy to promote productivity in the workplace is found in the organization's physical infrastructure design and the technology empowering it [6]. As such, the team proposed to develop a comprehensive framework to create an IoT-enabled workplace, capable of sensing indoor environmental factors directly tied to occupants' satisfaction in office buildings to promote productivity. The paper demonstrates how to build an IoT-enabled workplace and shows the benefit to energy management and both remote systems monitoring and control. A survey was then conducted and results from 50 unique users showed that 61% approval from the users for implementation of an IoT-enabled workplace in which an intelligent system controlled the environmental factors. This filled the literature gap on the additional study needed on identifying the contribution significance of implementing real-time decision making based on sensory data, applied to offices and workplaces.

This research produced important contributions to developing an intelligent controlling system capable of considering the feedback and preferences of occupants by utilizing a fuzzy logic optimizing approach. A clear visualization was also provided for the users for efficient monitoring and control, together with vast energy saving benefits from the automation control process.

A research study conducted by Avancini and his team, showed a considerable increase in global energy consumption, with both residential and commercial buildings contributing to half of the total world energy consumption [7]. As such, to deal with the new challenges in energy networks, it is necessary to develop new efficient and smart sensing systems with the integration of advancing smart meters. Thus, they envision the proposed energy management system capable of providing noteworthy economic benefits to both suppliers and consumers, leading to a greener energy usage overall. The authors of the research paper developed a Smart Energy Meter with two-way communication capabilities, a defining feature which distinguishes smart meters from conventional meters.

Additionally, since there is no single standard communication protocol for IoT sensors, the energy management system was designed to be able to communicate with commonly used protocols such as MODBUS, CoAP, SNMP, and MQTT. The system was developed in C# language and uses RESTful APIs for optimization of client-server communication. This research produced important contributions with regards to energy monitoring systems with a new IoT-based smart energy meter and a new energy management system for receiving data from smart sensors. Although a concrete conceptual theoretical approach was provided, actual testing would be needed to demonstrate and further validate the theory. For example, by bringing in some examples where problems were encountered while transitioning to theory stage.

An evaluation study conducted by Ramani showed that there are major drawbacks with the existing electricity billing system due the manual work required, as well as limitations in automated switching between parallel energy systems [8]. Thus, they proposed a system with the purpose to minimize electrical billing error and reduction of both paperwork and human dependency in the system. An IoT system would be developed to monitor and control both solar energy and energy meter. The developed automated system was capable of monitoring power usage and providing continuous energy from parallel energy sources in their prototype. The benefit of this IoT system was a

low-cost approach to monitor and parallel control of switching between two energy sources. Data collected from the sensors would undergo cloud-based processing and delivered to the mobile phone application. However, as not much coding modification was made on the Android application, this proposed automated switching control is not truly automated. The switching control and device control mentioned by the authors required user input from the Android application by the consumer. Unlike the forementioned work, the proposed IoT web application in this paper enables the connected optimization model to directly manage and make required adjustments the connected prototype system. This will reduce the need for user input and allow users to enjoy optimizations automated solely by the IoT application.

An IoT-based power monitoring and control system was proposed by [9]. Based on their literature review on existing electricity energy meter reading systems, current limitations included: Consumers were aware power consumption amount only after one or two months after the bill issue, lack of control on power consumption of end-users when they fail to pay their electricity bills on time, and the energy meters could be tempered easily. As such, authors successfully designed an efficient real-time wireless network for monitoring power usage of electrical appliances. This allowed consumers to view their power consumption usage on web, revenue loss reduction to supplier company due to theft detection system, and easy remote disconnection of service to consumers. The benefit of the developed system allowed users to obtain power values and ease of remote-control access to connected gadgets. The current was measured by means of a series resistor, although this would require series connection of the wireless sensor point to the active power line. Thus, this proves to be no easy installation technique as it involves cutting the wires of the appliance supply line or breaking walls to reach those encapsulated wiring sections.

The traditional system, known as the relational database system, is now more commonly known as SQL systems. The data is organized in a relational model, uses a fixed schema, and stores the data in the traditional format of rows and columns in a table. The system consists of several keys; however, the primary key allows the system to identify the unique row in the table. Several relational databases are available, such as Oracle, MySQL, and SQL Server [10]. However, there are significant drawbacks in light of an ever-increasing number of IoT applications and ever-changing data requirements. These drawbacks comprise the complexity of scaling up as it requires more than just the addition of new hardware and high associated costs [11]. Despite these setbacks, it is still a reliable and efficient standard model. To address the prior problems mentioned came the emergence of NoSQL databases. Features of this improved database format include a non-relational model, schema-free and a flexible schema design able to process several types of data. Scalability and high data availability make NoSQL databases a favorable choice for storing IoT data and Big Data. It contains both traditional relational SQL database characteristics while integrating new solutions unique to the NoSQL databases. As such, they prove to be an excellent and adept database management system given the handling progressively increasing volumes of IoT data [12].

With the emergence of NoSQL databases to address the limitations of SQL databases comes a large selection of many NoSQL databases. Each of these databases possesses slightly different implementation characteristics, query language, strategies to distribute data. Therefore, it is necessary to identify the appropriate NoSQL database for the given requirements in the IoT application. Based on an evaluation study by Amghar on the four popularly used NoSQL databases, comparisons were made based on their needs for data management [13]. These databases are namely MongoDB, Cassandra, Couchbase, Redis, and Neo4j.

AI Algorithm

Smart buildings, as mentioned, need the aid of Artificial intelligence to operate autonomously and integrate the proliferation of data from IoT devices and occupant behaviours to apply learning, optimize performance, and improve environmental efficiency. There are multiple existing models regarding smart building, such as Artificial intelligence models integrated into smart buildings, how the Artificial intelligence model is associated with swarm intelligence to handle data, and how swarm intelligence supports smart building in energy efficiency. Swarm intelligence (SI) is a subfield of Artificial intelligence, and it is one of the computational intelligence strategies used to take care of complex issues. Some well-known SI calculations included Particle Swarm Optimization (PSO), Artificial Bee Colony (ABC), and Ant Colony Optimization (ACO) [14]. PSO cannot work alone with sensors it needs a controller that can communicate with them. In [15] research, PSO is proposed to manage the energy consumption and efficiency in a smart building by managing the temperature. The PSO is utilized with a control horizon switching method to achieve optimal control, including the Time On Use (TOU) tariff, to calculate the energy costs. The results of simulations show that the proposed algorithm can reduce energy costs and peak power. They chose to apply MPC with PSO to model and simulate the cooling system.

In another approach [16] writer proposed Radial Basis Function (RBF) network with PSO to predict the energy consumption. Although the Basic Function (BF) neural network has proven to be viable in predicting energy consumption, the learning speed is too slow because it is a global approximation network. The shortcomings caused by this make it less suitable for practical uses. Hence a much relevant, typical local approximation neural network, RBF, is used together with PSO, a simple yet effective algorithm in neural network training. The PSO shall first optimize RBF network parameters (connection weights, hidden node centers and width), then the optimized RBF neural network is applied to forecast the energy consumption value according to historical energy data [16].

Prototype

An intelligent building integration can be characterized by existing components, add-on components, and the function [17]. The combination of the first two components creates the desired process.

- The existing component: Independent devices or technology which provides the primary functions such as HVAC economizer unit and filament lamps etc.
- The add-on component: Sensor devices which serve to obtain the necessary data for smart implementation within the vicinity. The devices range from cameras, PIR sensors, temperature, and humidity sensors etc.
- The function: The outputs from combining the two components create the illusion that the technology is intelligent and responsive to its occupant. Therefore, the function is usually the first thing to consider when implementing or designing a smart technology.

Each application is designed and assembled independently in a self-contained manner. The lack of shared resources builds up the cost for each smart technology introduced. This is because the two systems are often brought from two different vendors. The solution to improve the current design is to revamp the design with an internet connection, making it an IoT device.

The sensing modules, which include all the add-on components, can be controlled by a single or multiple units are the controller units. The Controller unit represents a decision-making service for every control action. The decision-making process usually takes constraints and sensor measurements as input and then relies on an optimization engine to determine the optimal control action. However, the optimization engine has to be programmed thoroughly according to the maker's ideal design. Furthermore, to create an intelligent and adaptive system, the module requires an intensive amount of data stored in a server for reviewing purposes. In summary, the general Smart Building architecture is illustrated in Figure: 1 above.

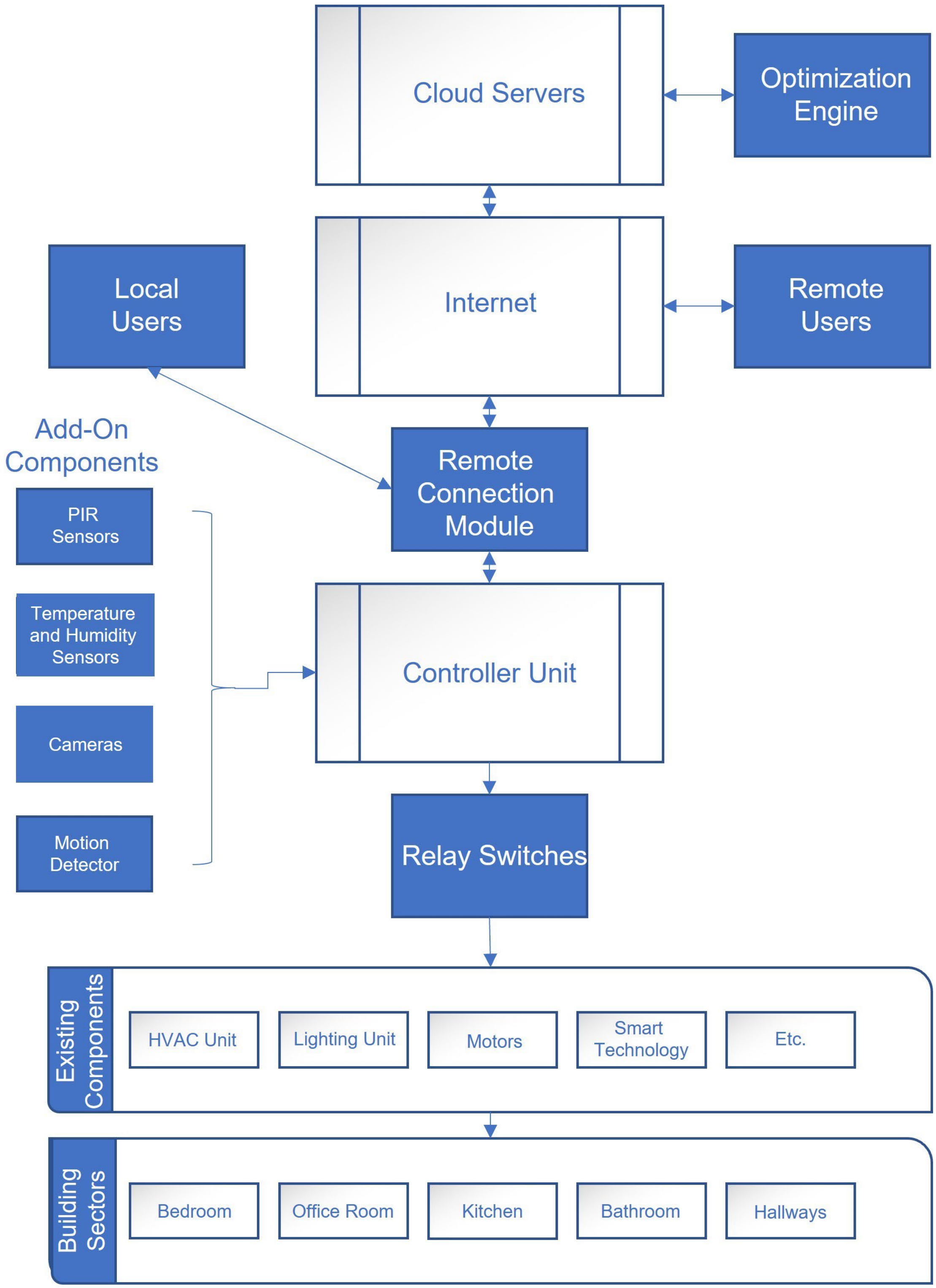

FIGURE 1. Architecture of a Smart Building

One of the literature works towards Smart Building prototype can be found this author's research [18]. The author brought up the research question towards building a Smart Building based on IoT and Fog-Cloud technology. In such work, the authors proposed the solution to provide an intelligent, green, and connected building and a building that gives users real-time control over all the appliances presented with ease. The author claims that one of the Smart Building's purposes is to control and supply high energy appliances intelligently. However, the system must be designed to be affordable without compromising with its QoS. Moreover, for a Smart Building, an increase in sensors increases the rate of data generation. Therefore, a Smart Building solution should react in real-time by running all processes in cloud and Fog before triggering the appropriate actions and services with or without human intervention. The author's research proved effective as their data could be monitored for enhanced analytics over long-term data storage. In addition to that, the building's in-built intelligence also saves electricity as it can detect human presence and stops unnecessary wastage of power. Thus, it confirms to represent as a green building. The author's system design uses Arduino Uno, Sensors, Bluetooth Module, Wi-Fi module, fog gateway server. However, the results for each sensor implemented are not shown within the research. Furthermore, the overall electrical energy used is mentioned but not for each of the segments. Therefore, it is unclear for the user further to optimize their energy usage within parts of the building. The results could be further detailed if the author calculated the energy used for each output, such as lighting, HVAC unit, and motor utilized before and after implementing the smart technology.

Institut Teknologi Sumatera (ITERA) has started developing smart campuses to decrease the wastage of electricity energy [19]. However, the author observed that the lights or air conditioning are kept on even when nobody is in the room. In their study, the implementation of smart-room technology based on the Internet of Things is proposed to increase energy efficiency. Furthermore, the author provides a model to manage sensors to create a smart room used in daily life. The main component of this smart switch is the Solid-State Relay (SSR), where the ESP8266 controls the element as a micro-controller and a Wi-Fi module is used to connect to the local server using the MQTT protocol. Sonar sensor was used to detect visitors then from which the lights and fans were turned on or off. The testing design was simple it did not involve a lot of sensors and appliances that is being used daily in university.

One of the research projects presented a system for Smart Home Automation technique with Raspberry Pi using IoT and it is done by integrating cameras and motion sensors into a web application. They used a Raspberry Pi module with Computer Vision techniques to be able to control home appliances that is connected through a monitor-based internet. Raspberry Pi operates and controls motion sensors and video cameras for sensing and surveillance. On top of that they used the device for security and to capture intruders [20].

The summary of previous research works has been indexed in Table: I.

TABLE I. Survey of energy optimized smart systems

Ref.	Components	Autonomous	Individual Energy Consumption Monitoring	Storage Platform	Cost Effective
[1]	Arduino, PIR sensor, temperature and humidity sensor, particulate matter sensor, gas sensors, LUX sensor, Wi-Fi module	Yes	No calculation	ThingSpeak web service	Used low-cost devices
[3]	Raspberry Pi, Router, Energy meter, CT (current transformer) sensor, energy measurement chip and ESP8266	No	Able to calculate	InfluxDB	Used low-cost devices
[4]	Raspberry pi, border router, IAQ sensor node, wireless module. Sensors: Temperature, Humidity, Pressure, Particulate Material, TVOC and eCO2.	No	No calculation	MariaDB	Used low-cost devices
[6]	Sensors: Particulate matter (PM), Air quality, Temperature and Humidity.	Yes	Yes	Local storage	Used low-cost devices
[7]	IoT Enabled Smart Energy Meter	No	Yes	Horus NMS	Used high-cost devices

[8]	Arduino, ESP8266, Voltage divider, battery, solar panel, optocoupler, inverter, relay, LCD, Energy meter, LDR sensor	Yes	It is calculated for the whole system instead individually	Not mentioned	Not mentioned
[9]	GSM Module, LCD, ZigBee Module, PIC micro-controller, Energy Meter	No	It is calculated for the whole system instead individually	Not mentioned	Used low-cost devices
[18]	Arduino, Relay, Wi-Fi module, Bluetooth module, Cisco router, RFID reader, Laser, LDR, temperature and humidity sensor, PIR sensor, ultrasonic sensor, gas sensors, air pollution sensor, Flame Sensor	Yes	It is calculated for the whole system instead individually	Via fog cloud	Used low-cost devices
[21]	Arduino, relay, Ethernet shield, wireless module, gas sensor, temperature sensor, PIR sensor, ultrasonic sensor	No	No calculation	Through web app	Used mid-cost devices
[22]	Raspberry Pi, analog temperature sensor, analog soil moisture sensor, rain sensor, LDR, temperature and humidity sensor, analog to digital converter, Wi-Fi module, LCD display, router	No	No calculation	Sparkfun DB	Used low-cost devices
[19]	ESP8266, LDR, sonar sensor, light intensity sensor, relay, servo motor	Yes	No calculation	Not mentioned	Used mid-cost devices
[20]	Raspberry Pi, GSM Module, Sensors	User controlled	No calculation	MYSQLDB	Used high-cost devices

SYSTEM MODEL

This study is focusing on the controlling of the energy that is being consumed in the university buildings. Using the Particle swarm optimization algorithm alongside the AI model to optimize how the usage is adjusted to the user preference and to the grid. The data is generated through iterations to give high accurate automated system that ensures that it meets the requirements. Figure: 2 shows the model overview starting from input sensors to auto controlled smart campus prototype. Using Firebase with its wide functionality to host the web app dashboard that is designed to show the sensor parameters versus time with the ability to control the system manually. Currently the system which can be seen in Figure: 3 is part of the mini replica of university main rooms as in library and classrooms. The improved AI model and PSO algorithm will be implemented in the automated system to improve its accuracy in terms of reducing power consumption. Currently the small circuit which can be seen in Figure: 3 where the improved model will be tested is part of the mini replica of university main rooms as in library and classrooms.

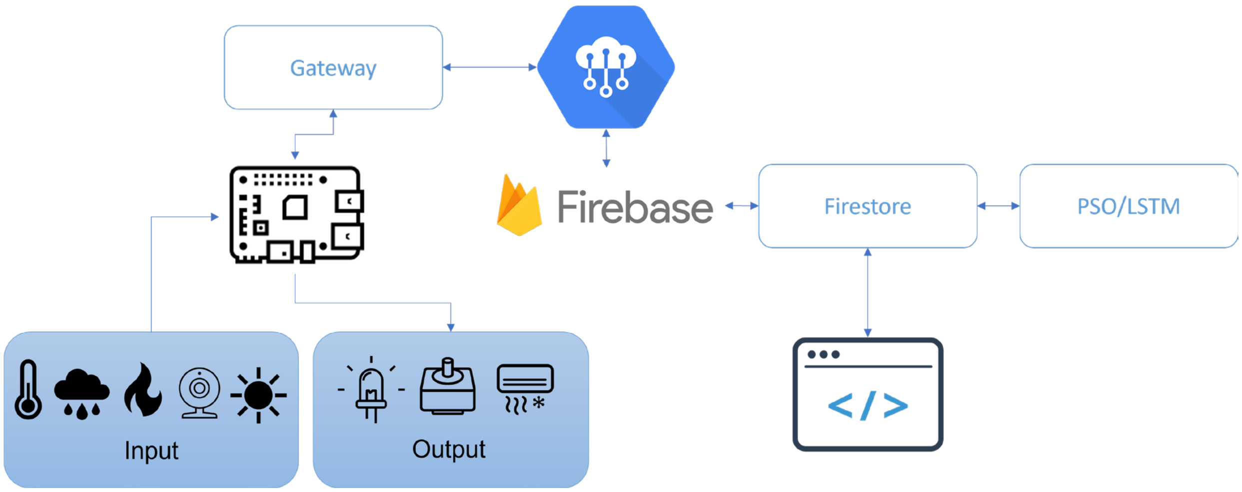

FIGURE 2. An overview of our model.

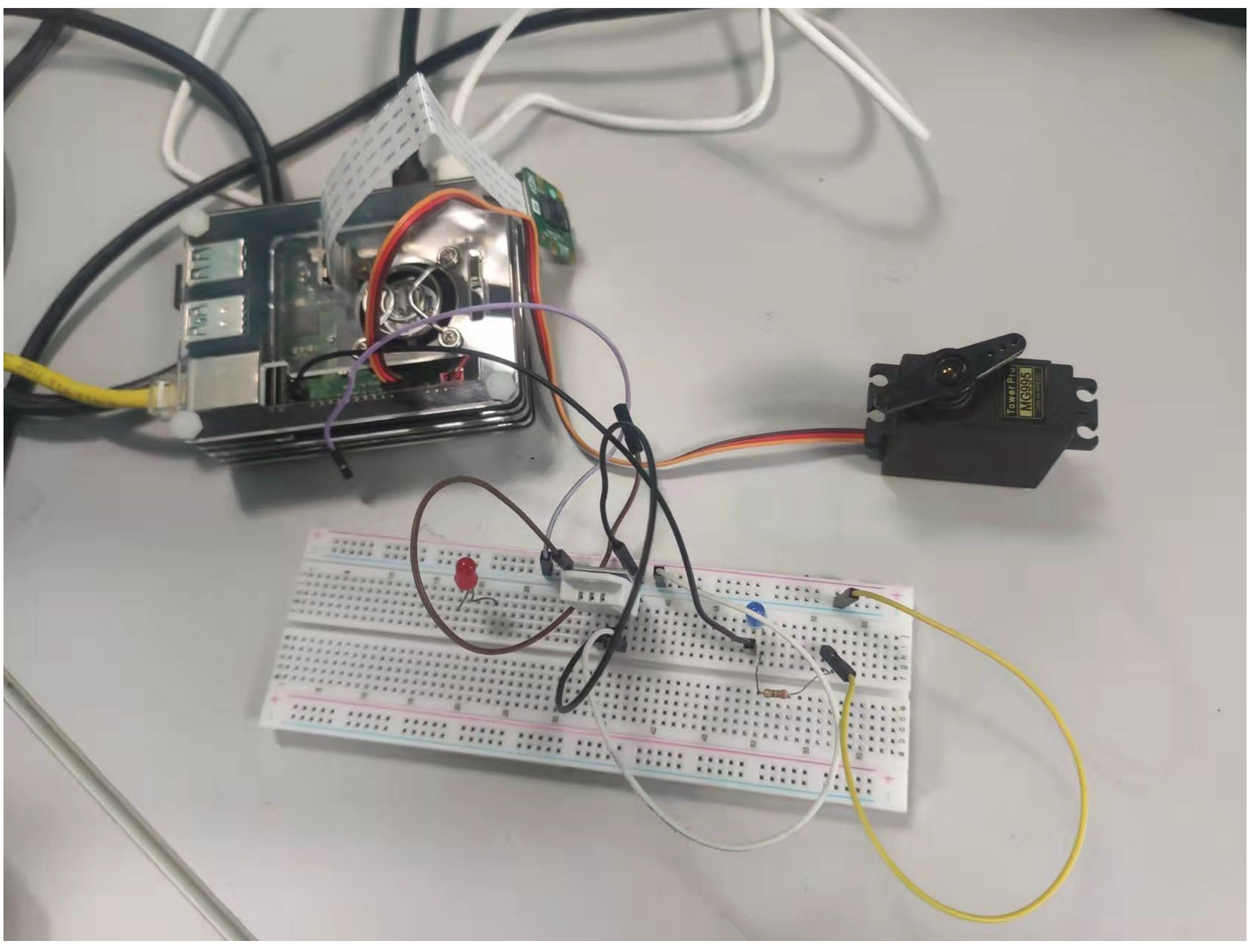

FIGURE 3. A sample of the setup that will be tested with AI model.

The dashboard in Figure: 4 is under more adjustments but it is enough for now to be used for the testing. It shows the temperature vs. time and in other graph vs. power which is all updated in real-time without the interference of the user.

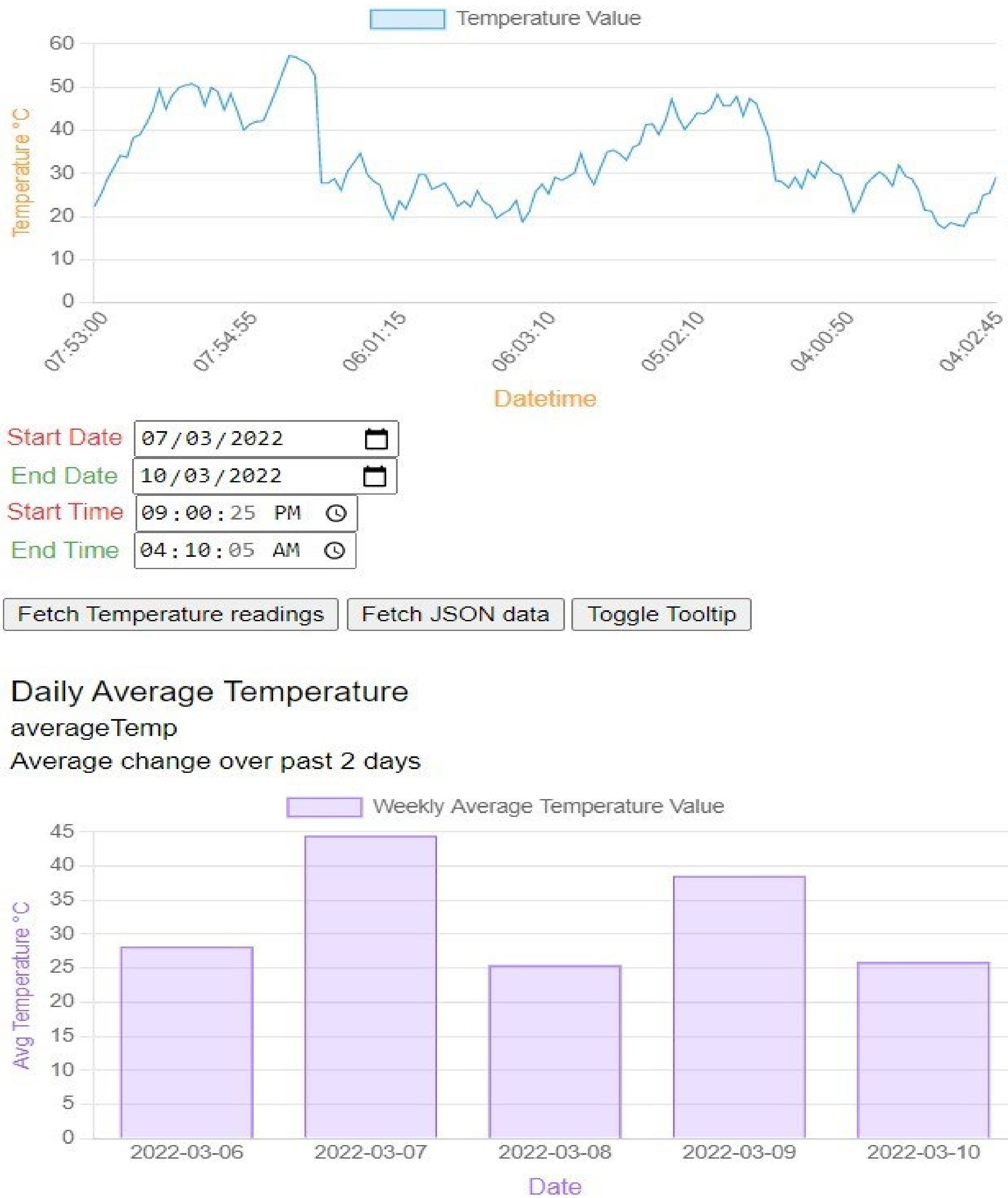

FIGURE 4. A sample of the dashboard.

RESEARCH CHALLENGES AND FUTURE WORK

This paper moreover examined the inquire about challenges that are fundamental in optimizing smart building structures, which help in their arranging, control, and operation. Additionally, different components saddle vitality and increment the utilization of renewable energy assets. The number of the challenges for the smart computerized campus are specified here:

- To tackle the potential of campus energy.
- To boost the campus's renewable vitality utilization.
- To minimize the operational fetched of the smart campus.
- To keep up the relentlessness and unwavering quality of the system.
- To minimize the utilize of utility vitality by giving RE resources.
- To make the framework solid by executing progressed optimization strategies into the system.

In this paper, brief comparative research has been analyzed and recommended supported various optimal approaches for various systems, and that they were investigated with multiple optimization techniques, simulation tools, and differing kinds of energy storage technologies. By reviewing several prior works that were being done on this topic, a PSO with an AI model such as LSTM was proposed for this research to be implemented on raspberry pi. Python programming language is be used due to its wide library and simplicity. Regarding the evaluation study on tools and techniques, the MQTT protocol and Firestore database have been selected. However, further testing will only show if these will remain the best options later on. With the combination of JavaScript and HTML to run the web app where the dashboard shows the user graphs of the power consumption after and before optimization for the smart campus. The next step is to implement this system and test it in a prototype replica of university main rooms that was designed in SOLIDWORKS. A further improvement is being considered in order to cover all the gaps and objectives of this research.

CONCLUSION

The implementation of smart buildings or appliances is the current future and development of this era. This paper reviews the recent research on algorithms used for energy management and systems that were designed to stimulate smart buildings using various sensors. Manually and automatically controlled also, being monitored online through web or mobile apps. Next, a summary with the reviewed research. Then, the current challenges and potential future works are presented with the research gap included. In conclusion, upcoming research will fill the many gaps that were missed by the previous researchers.

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