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Small Scale IoT-Based Energy Monitoring System

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ABSTRACT

The research aims to address the increasing energy consumption in Malaysia, particularly in academic institutions like UiTM Shah Alam. The excessive energy consumption at universities, exemplified by high electric bills due to the continuous operation of electrical components, poses a significant problem. Existing IoT energy monitoring systems lack scalability and real-time accuracy, hindering effective tracking and cost monitoring. The project focuses on designing and developing a system using NodeMCU Lolin and electrostatic sensors to monitor the energy usage of electrical appliances. The objectives include detecting current flow and evaluating power consumption, with the potential to affect the university's energy monitoring and reduce expenses. The project's scope involves hardware and range limitations, with specific target groups. The research methodology involves an experimental design and data analysis to develop and implement the IoT-based energy monitoring system, including sensor deployment and data integration development. This compact and simple integration system providing real-time insights into energy consumption patterns, contributing to energy conservation and sustainability was successfully developed. The system successfully analysed the power consumption of selected appliances, empowering users to have informed decisions and potentially reduce energy expenditures.

Keywords: Internet of Things (IoT); energy consumption; Energy Monitoring System; NodeMCU Lolin; electrostatic sensors

INTRODUCTION

Today, the Internet of Things (IoT) is becoming a common technology framework in digital world. It is also used for connected devices, or "things", that can share data over a low bandwidth network, that refer to the growing networks (Razip et al. 2018; Gray, 2018; Jayakumar et al. 2019). IoT technology empowers electronics and communication enhancements, where sensors and smart devices connected through the network for real time monitoring system. This technology also utilizes embedded environment that support decision making process that essential in many sectors such as in education, automotive, logistics, healthcare, agriculture, and smart cities (Rashid et al. 2019; Rostam et al. 2020; Zamzari et al. 2022; Hamzah et al. 2024; Phadke & Korde, 2024).

Over the years, the amount of energy consumed in Malaysia has increased over the past years. In 2018, the amount of energy consumed in Malaysia summed approximately 145 billion kilowatts per hour compared with the energy consumed in 2017 which was 140.7 billion kilowatts per hour (Hittinger & Jaramillo, 2019). It shows that the energy used is increasing steadily due to waste energy from the consumer. In fact, in UiTM Shah Alam, the total amount the management needs to pay to Tenaga Nasional Malaysia Berhad (TNB) was high. It showed that the energy used at UiTM Shah Alam was high.

The energy consumption at UiTM Shah Alam has reached critical levels, primarily due to several factors contributing to excessive usage. A major contributing factor is the behavior of students residing in campus accommodations, who tend to use energy inefficiently. For instance, many students fail to switch off electrical appliances and devices when leaving their rooms for classes or other activities. This habit leads to significant energy wastage, which, in turn, causes a sharp increase in the campus's electricity bills.

One of the most energy-intensive appliances in student accommodations is the air conditioner. Air conditioners consume a substantial amount of electricity, ranging from 1,000 to 3,000 watts per hour, depending on their horsepower (HP) capacity. When left running unnecessarily, such as throughout the night or while the room is unoccupied, air conditioners contribute heavily to energy waste. This problem becomes more pronounced in scenarios where students are unaware of the impact of such practices on energy consumption and its associated costs (Abduurrahim et al. 2021; Salam, 2020).

Additionally, the lack of automated or IoT-based systems to monitor and manage energy usage exacerbates the issue. Without proper mechanisms to detect unoccupied rooms or appliances left on unnecessarily, the burden falls on individuals to manually manage energy usage, which is often neglected. Implementing solutions that encourage responsible energy behavior and leverage smart technologies could help mitigate these challenges. For instance, IoT-enabled systems could automate the process of turning off unused appliances or provide real-time energy usage feedback to foster awareness among students.

Understanding these behaviors and their impact is critical to addressing the energy consumption challenges at UiTM Shah Alam. Addressing this issue through innovative energy management solutions can significantly reduce wastage, enhance sustainability, and lower utility costs for the campus.

In addition, a crucial concern in energy consumption monitoring is the absence of a comprehensive system providing accurate estimations for analyzing electrical appliance consumption. Current monitoring solutions often fail to offer detailed insights into individual appliance energy usage, leaving users unaware of which devices consume the most energy and contribute significantly to overall consumption. Consequently, consumers find it challenging to develop effective energy-saving strategies, which results in wasteful practices and higher utility bills.

To tackle this problem, a novel energy consumption monitoring system is required, capable of accurately estimating the energy consumption of individual electrical appliances and providing users with detailed insights. By delivering comprehensive and informative analysis, such a system would empower users to make informed decisions, optimize their energy usage, and play an active role in energy conservation efforts, ultimately reducing their environmental impact.

THEORETICAL ANALYSIS

The literature review delves into a variety of IoT-based energy monitoring systems, providing valuable insights and methodologies for effective energy management. These systems leverage platforms such as Arduino, ESP8266, and STM32, which are integrated with sensors and communication modules to monitor real-time energy consumption, automate utility billing, and enable remote control of electrical appliances (Muhammed et al. 2022; Raju et al. 2022; Andrei et al. 2021). A range of communication technologies, including GSM, LoRa, and cloud-based databases, are employed for the seamless transmission and storage of energy data (Adriani et al. 2022; Boobalan et al. 2021; Varadarajan et al. 2022). These systems go beyond basic energy monitoring by incorporating advanced features such as fire safety measures, environmental monitoring, and enhanced control options through voice commands or mobile applications.

Furthermore, many of these projects demonstrate innovative approaches to optimizing energy use, reducing waste, and promoting sustainable practices. The integration of IoT devices with mobile apps or web interfaces allows users to gain better insights into their energy usage patterns and make informed decisions. Collectively, these findings provide a robust understanding of current advancements and challenges in the field. This serves as a crucial foundation for designing a Small Scale IoT-Based Energy Monitoring System aimed at addressing energy waste issues at UiTM Shah Alam while promoting efficient energy management practices.

MATERIALS AND METHODS/METHODOLOGY/ EXPERIMENTAL PROCEDURE

The proposed Small-Scale IoT Energy Monitoring System is designed to monitor and manage the energy usage of electrical appliances efficiently. Leveraging the NodeMCU Lolin V3 ESP8266 microcontroller and an electrostatic sensor, the system is capable of tracking the current flow, analyzing power consumption patterns, and estimating overall energy usage. This innovative approach is particularly significant for UiTM Shah Alam, as it provides a practical solution to monitor energy usage more effectively and reduce excessive consumption. By doing so, the system has the potential to significantly lower utility costs while fostering more sustainable energy practices across the campus.

The implementation of this project follows a systematic research methodology. It begins with designing the system architecture, which outlines the integration of hardware and software components. The deployment phase includes installing sensors to collect accurate current flow data, which is then transmitted to the NodeMCU for processing. The collected data is integrated into a monitoring system, allowing users to analyze energy consumption in real-time. This analytical capability enables the identification of inefficient energy usage patterns and informs corrective actions to reduce waste.

Despite its potential benefits, the project does face certain limitations. The system's performance is constrained by the hardware's capabilities, which may limit scalability or accuracy in some applications. Additionally, it is tailored to specific types of devices and appliances, which may restrict its generalizability to other contexts without further modifications.

Nevertheless, this Small-Scale IoT Energy Monitoring System lays the groundwork for effective energy management in institutional settings. While its current scope is focused on university energy usage, the system has the potential to be scaled and adapted for residential or commercial purposes. With ongoing refinements, this project could become an essential tool for promoting energy efficiency and cost savings in various environments.

HARDWARE IMPLEMENTATION

This project applied NodeMCU ESP8266 as a microcontroller that plays an important role in monitoring energy consumption. The microcontroller contains a built electric sensor, which used a resistor and transistor. This feature helps the hardware easily connected to the Blynk Application.

MICROCONTROLLER

Figure 1 shows the microcontroller of the project, which is NodeMCU ESP8266. It acts as the microcontroller of the project by enabling wireless connectivity and remote operation of the project. It only has one analogue input pin and eight digital input pins. It operates at 3.3V meaning that applying more voltage source may cause the microcontroller to be broken. This microcontroller also operates with 2.4GHz Wi-Fi (Rawat et al. 2023; Phadke & Korde, 2024).

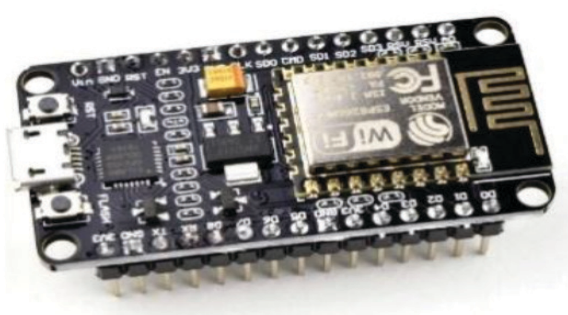

FIGURE 1. Microcontroller used is NodeMCU ESP8266

ELECTROSTATIC SENSOR

Figure 2 demonstrates the electrostatic sensor consists of three transistors (2N2222), three resistors, (1 MΩ, 100 kΩ and 220 Ω), an LED, and an antenna. This electrostatic sensor can sense an AC-energized object due to electromagnetic induction.

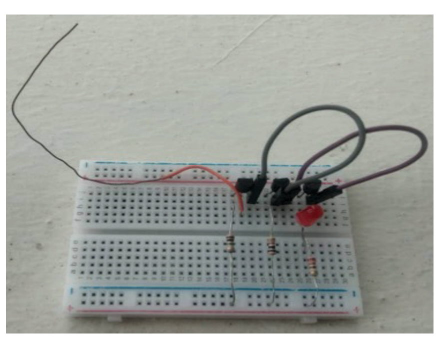

FIGURE 2. The design of Electrostatic Sensor for the proposed system

The limitation of this sensor is it needs to be located nearby to the targeted object (the appliance) as it will easily be distracted if there is another electrical appliance nearby.

SOFTWARE IMPLEMENTATION

ARDUINO IDE

The software part for this project was develop in the Arduino IDE. It is software from Arduino itself that can run and develop codes for a project. The users only need to develop a code, compile it, and upload it to the connected device.

FIGURE 3. Interface of Arduino IDE

Figure 3 indicates the interface for the Arduino IDE software. The code of the program was written in this software. For common projects, there are two different parts of codes, which are void loop and void setup. Void setup is usually for the beginning of the code at it will run only once. For void loop, all the code in this void will do repetition indicating a looping process occurred in the project.

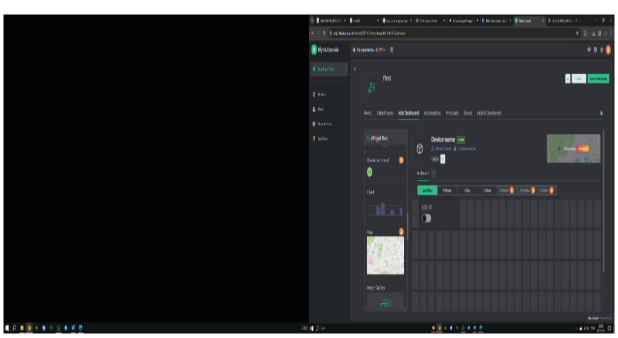

FIGURE 4. Interface of Blynk application

Figure 4 displays the interface for the Blynk Application. This application can produce a lot of output from the widget box such as sliders, graphs, maps, charts, gauges, and labels. The NodeMCU ESP8266 needs to connect to the Blynk apps to control the output. The configuration of the Wi-Fi can be adjusted in the Arduino IDE based on the details of the Wi-Fi of the users (Yusoff et al. 2023; Soleh et al. 2023).

Figure 5 illustrates the flowchart of the Small Scale IOT Based Energy Monitoring System. The program starts when the electrostatic sensor detects if there is any current flow into the device. If there is a current flow, the information will be sent to the database. If there is no current flow, the signal will not be sent to the database. The IoT platform that will be used is the Blynk app. The server clock will record and calculate the duration when the sensor is active. The program will continuously be working because there is an infinite loop in the system.

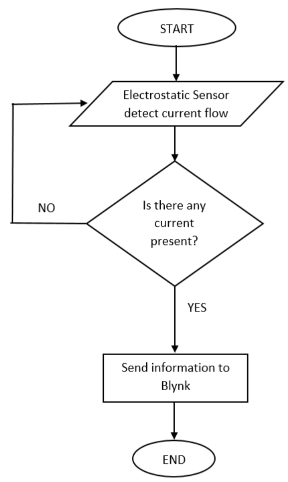

FIGURE 5. Flowchart of the proposed project

Figure 6 displays the block diagram of Small Scale IoT Based Energy Monitoring System. This Small-scale Energy Monitoring System consists of 1 input which is an electrostatic sensor. The electrostatic sensor is used to detect current flow when the device is turned on. This project uses NodeMCU Lolin V3 ESP8266. The NodeMCU is used to control the operation of the system and connect the electrostatic sensor to the database.

For the output, 2 outputs are the development which are database (PC) and LED. This database used to store the data from the NodeMCU and display it on a server, which is Blynk Application. The user can monitor the energy usage of the electrical appliance on their PC or phone through the Blynk application installed on their device. The LED is use to indicate that there is current flow at the devices, as the LED will light up when the sensor detects the current.

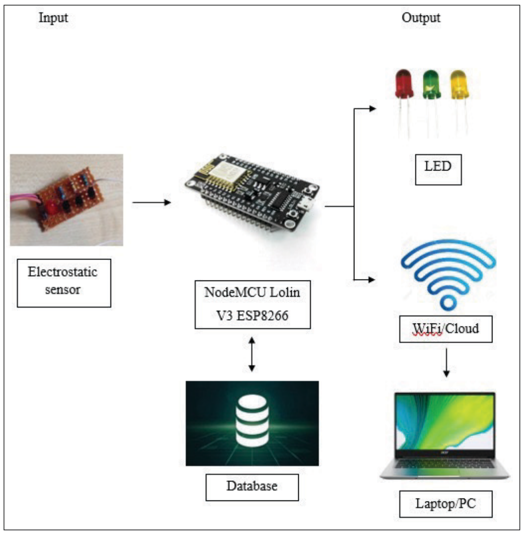

FIGURE 6. Block diagram of the IoT-based energy monitoring system

RESULT AND DISCUSSION

HARDWARE DESIGN AND IMPLEMENTATION

The configuration of the hardware are being set up according to the schematic diagram in Figure 7. Three transistors NPN-type have been used (2N222), three resistors (1 MΩ, 100 kΩ, and 220 Ω), an LED, and an antenna. The hardware used NPN-type transistor because it is generally faster than the PNP-type in terms of responsiveness. The function of the transistors is to amplify the antenna to obtain greater results. The LED is the output to indicate the sensor is detecting the current, as it will turn on.

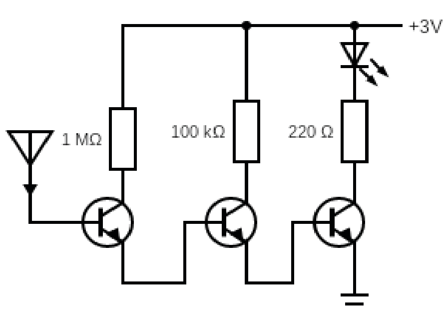

FIGURE 7. Schematic diagram of electrostatic sensor

Figure 8 shows the hardware during the turn-off condition. The LED will turn off if there is no presence of any detection on the antenna.

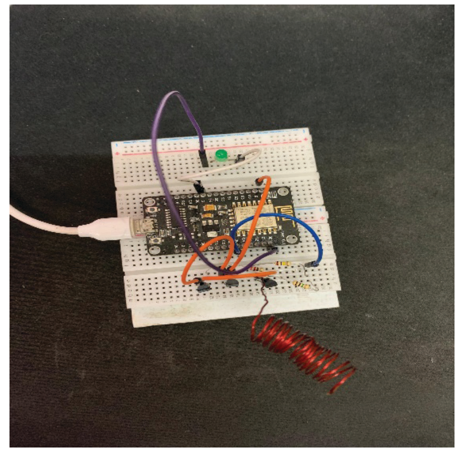

FIGURE 8. Hardware during turn-off condition

Figure 9 illustrates the hardware during the turn-on condition. The LED turned on because the antenna is detecting the emf from the charging port of the power bank. The information detected from the antenna will be send to the Blynk to monitor the energy usage of the appliances.

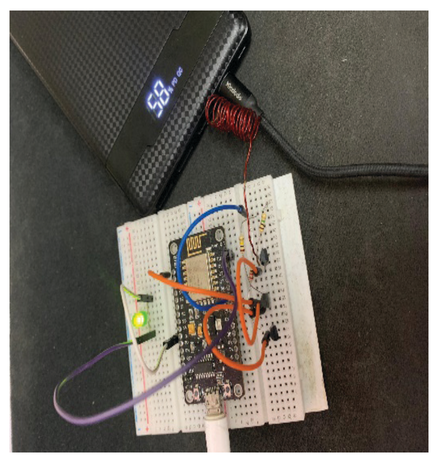

FIGURE 9. Hardware during turn-on condition

SOFTWARE IMPLEMENTATION

The software part of this project have been created using the Arduino IDE software. The program runs on the Arduino platform, providing a solution to display the obtained electromotive force (emf) values. These values are directly presented on the computer screen through the Serial Monitor tool, making it straightforward for users to monitor and understand the power information in real time. This integration simplifies the monitoring process, ensuring a user-friendly experience.

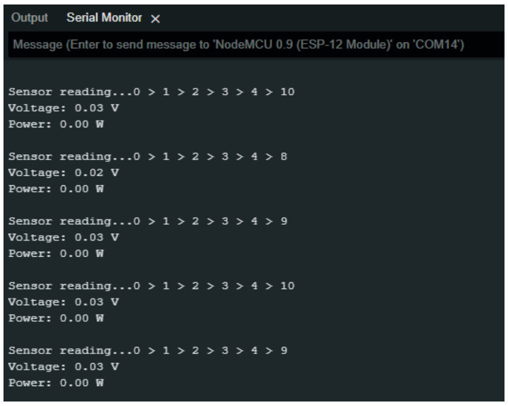

FIGURE 10. Output obtained on Serial Monitor

According to Figure 10, the value obtained on the sensor reading was the emf value obtained from the sensor reading. The voltage and the power can be obtained through the equation:

$$\frac{1024}{3} = \frac{ADC\ Reading}{Analog\ Voltage} \tag{1}$$

$$P = \frac{V^2}{R} \tag{2}$$

Equation (1) shows the equation to calculate the voltage from the ADC Reading obtained from the sensor. The 3.3V being represented as 512 in the Arduino's ADC is a result of this ratiometric conversion, where the ADC output is proportional to the ratio of the input voltage to the reference voltage (Haraoubia, 2019). The value 3.3V has been chosen because it is the system voltage for NodeMCU ESP8266. Equation (2) is the formula to obtain power where the voltage, V, is obtained from the analog voltage and the resistor, R, is obtained from the total of the resistor used in the electrostatic sensor.

FIGURE 11. Latest Data for Monitoring Energy

Several analyses have been conducted through the Blynk software. Users can monitor their energy usage either on their PC or phone. They can monitor it with the latest data, last hour, 6 hours, 1 day or 1 week according to their preferences. The results obtained are shown in Figure 11 until 15, which represent the obtained values, organized into a chart for straightforward visualization of energy usage.

The chart serves as a practical tool, which can simplify the understanding of data trends. Users have the flexibility to choose different time intervals for monitoring energy consumption. Whether one is interested in the most recent data (Figure 11) or wants to observe trends over an hour (Figure 12), 6 hours (Figure 13), a whole day (Figure 14), or even a week (Figure 15), various options are available. This adaptable approach enables users to gain an understanding of energy utilization patterns across different periods. Three different types of values obtained were also being displayed such as emf, voltage, and power. These values were displayed to ease the process of monitoring the energy usage

FIGURE 12. Energy monitored for an hour

FIGURE 13. Energy monitored for 6 hours

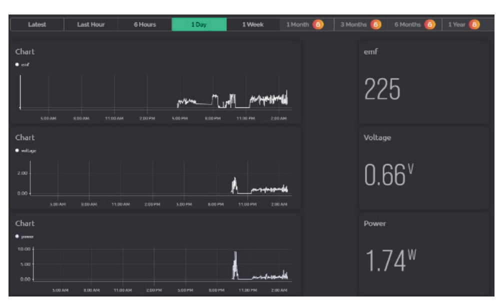

FIGURE 14. Energy monitored for 1 Day

FIGURE 15. Energy monitored for 1 week

By referring to Figure 13, there is a flat reading on the chart. It indicates as the hardware is not in the turn-on condition therefore no reading was obtained during the process. The huge spike on the power chart means that the energy consumption during 9.00p.m. to 10.00p.m. is high and the graph continues to maintain a regular reading indicates as the energy consumption is good.

To enhance the functionality of the IoT-based energy monitoring system, it is crucial to integrate remote monitoring and control capabilities. This feature empowers users to conveniently access real-time energy data and exercise control over connected devices from anywhere, using either a web-based platform or a mobile application. Through the interface, users can not only monitor energy consumption but also remotely manage appliances, such as toggling them on or off as needed.

This functionality not only adds convenience but also facilitates energy optimization efforts, allowing users to make informed decisions to minimize consumption and maximize efficiency. Whether adjusting thermostat settings or scheduling appliance usage, remote monitoring and control offer users greater flexibility and control over their energy usage, ultimately contributing to enhanced sustainability and cost savings.

Other than that, when selecting hardware components for the IoT-based energy monitoring system, it is essential to take full consideration of project requirements and budget constraints. Microcontrollers such as Arduino or Raspberry Pi are great to serve as the brains of the system, providing computational power and interfacing capabilities. Depending on the complexity of the project and desired functionalities, one can opt for a simpler microcontroller like Arduino for basic tasks or Raspberry Pi for more advanced processing and connectivity options.

The selection of the sensors also plays a critical role in collecting energy data accurately. Current sensors, voltage sensors, and temperature sensors are commonly used to monitor different aspects of energy consumption and environmental conditions. The selection of sensors should align with the specific parameters to be monitored in the system.

CONCLUSION

In conclusion, the Small-Scale IoT Energy Monitoring System developed in this project effectively addresses the pressing issue of excessive energy consumption. By incorporating an electrostatic sensor and the NodeMCU ESP8266 microcontroller, the system is capable of accurately monitoring current flow and estimating energy usage. The hardware implementation is complemented by a software component designed using the Arduino IDE and integrated with the Blynk application, enabling real-time monitoring and analysis of electromotive force values. This integration allows users to access and track energy data conveniently through a user-friendly interface, fostering greater awareness of energy consumption patterns.

The project emphasizes the importance of responsible energy use, shedding light on the significant impact of student behavior on overall energy consumption. For instance, leaving electrical appliances running unnecessarily is a key contributor to energy waste, and this system aims to mitigate such inefficiencies by promoting more conscious usage. While the project has certain limitations, such as its small-scale scope and the need for further optimization, it serves as a strong foundation for developing a practical and accessible energy monitoring solution.

Moreover, the system's potential extends beyond classroom applications. With further refinements and scalability, it could be adapted for broader use cases, such as residential or commercial energy management. This initiative represents an important step toward enhancing energy efficiency and sustainability, offering a valuable tool for addressing energy waste while providing opportunities for future enhancements and expansions.

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DECLARATION OF COMPETING INTEREST

None.

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