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Design and Development of a Multi-Channel Wireless Data Logger for Energy Measurement

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Abstract: Electricity consumption rises year after year, particularly during the COVID-19 pandemic where more individuals are expected to work from home. It will have an impact on the electricity bill. Consumers must reduce their electrical usage to reduce their electric costs in the home sector. The main predicament is that they do not know what equipment or activities consume more power than other outlets, or which outlet is less efficient even though the electrical equipment at that outlet does not require high power. Thus, the measurement tool for home power monitoring of electrical outlets was conceived and prototype utilizing ESP32 Wi-Fi module for wireless communication. The monitoring result can be seen via LCD which provides voltage, current and real power readings. The adoption of this prototype makes it easy for the residential electricity sector to determine which outlet uses the most power compared to the others.

Keywords: Wireless, Data Logger, Energy Measurement, ESP32

1. Introduction

An important property of the electricity grid is that production must be carefully matched to consumption to keep voltage and frequency stable and avoid damaging expensive infrastructure. On the other hand, customer activities, needs, and desires as well as weather, shape the patterns of electricity use, which vary seasonally and hourly. These patterns typically result in high concentrations of electricity use in "peak periods". The larger the peak demand, the greater the number of electrical resources that are needed to meet it. Hence, it is of fundamental importance to have a measuring tool for home power monitoring for electrical outlets to find out which outlet uses the most power than the others [1]. To measure energy consumption at the electrical outlet, a multi-channel electrical power measurement data logger is used. A good system can certainly serve several customer needs, starting from the cost, active power used, and the amount of kWh that has been used. The socket is a place to install the appliance considering that the point of the socket in the household will not change and the socket itself is the outermost layer before electricity will be used by the load [2].

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Therefore, the design and development of a multi-channel wireless data logger for energy measurement that is capable of accurately measuring energy and related parameters like voltage, current and power in real time. The data logger is equipped with a Wi-Fi-based wireless communication module that is capable of neatly communicating the sampled data to a computer without any wired interface. The proposed design aims to obtain electrical power measurements at an electrical outlet wirelessly to estimate the power usage as well as detect the highest reading and alert the responsible user to reduce the energy utilization.

Multi-channel Wireless Data Logger for Energy Measurement monitored energy usage on socket-outlet by using ASC712, ZMPT101B, ESP32, and Blynk as IoT platforms, and the parameters measured are logged for future reference. The electricity usage of the socket outlet is also only being monitored remotely. This project is a combination and variation of reforms resulting from previous projects reviewed. Therefore, the aims of this paper are to develop a prototype of a multi-channel wireless data logger for energy measurement, to analyze the values of voltage, current and power obtained by a wireless and traditional multi-channel data logger and to design a system that allows alert notifications to be sent using a wireless connection.

2. Materials and Methods

2.1 Hardware Component

This section provides an overview of the key hardware components used in the Multi-channel Wireless Data Logger for Energy Measurement project.

i. ACS712 Current Sensor

ii. ZMPT101B Voltage Sensor

iii. Liquid Crystal Display (LCD)

iv. ESP32 Wi-Fi Module

2.2 Hardware Development

2.2.1 Circuit Design

Figure 1 shows the complete circuit connection of the system of Multi-channel Wireless Data Logger for Energy Measurement design using Proteus 8 Professional software.

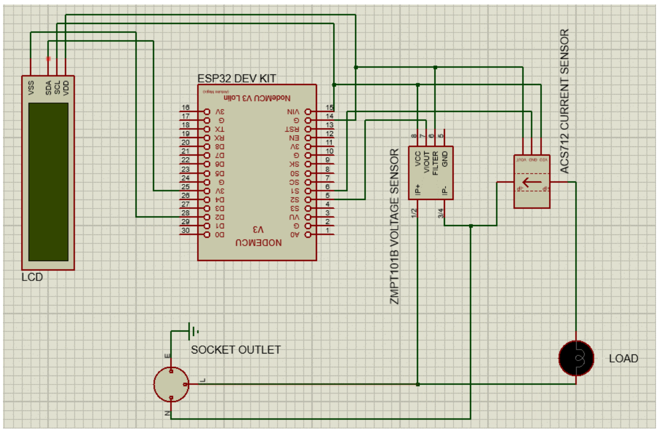

Figure 1: Architecture design of Multi-channel Wireless Data Logger for Energy Measurement using Proteus 8 Professional

Figure 2 features the details of circuit design using Fritzing software showing the illustration of the components connected. The microcontroller board used is the ESP32 Dev Module. VCC and GND pins of both ACS712 Current Sensor and ZMPT101B Voltage Sensor are connected to the 5V and GND pin from the ESP32 expansion board. The output analog pin of the ZMPT101B Voltage Sensor is connected to the GPIO35 of ESP32 while the analog pin of the ACS712 Current Sensor is connected to the GPIO34 of ESP32. Connect the VCC, GND, SDA and SCL of the LCD display to ESP32 5V, GND GPIO21 and GPIO22 of ESP32 respectively.

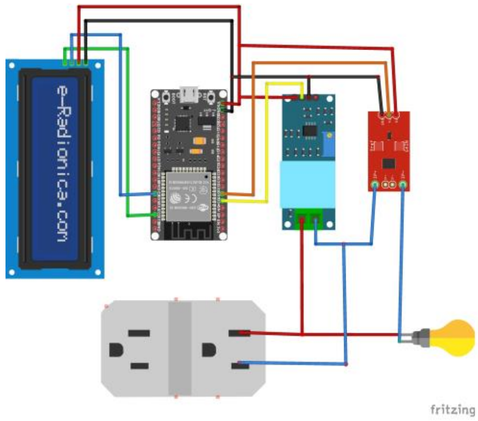

Figure 2: Circuit design using Fritzing

2.2.2 Product Design

The product design was drawn using SOLIDWORK. Figure 3 shows the front view and the side view of the end product outline. The details such as the sizing of the product are shown in Figure 3.

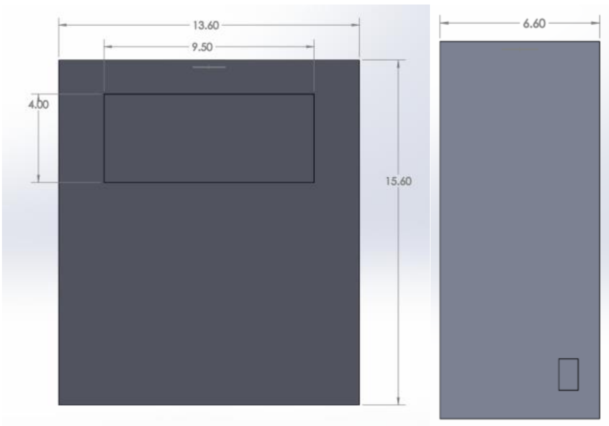

Figure 3: Front and side view of product using SOLIDWORK

2.2.3 End product of Prototype

Figure 4 shows the end look of the prototype of Multi-channel Wireless Data Logger for Energy Measurement.

Figure 4: The end product of prototype

2.3 Experimental Setup

Figure 5 illustrates the current reading by Fluke 375 Clamp Meter for each load such as laptop charger, 10W LED lamp, fan, and electric iron. Meanwhile, Figure 6 shows the reading of voltage taken by clamp meter for the electric iron, fan, 10W LED lamp and laptop charger.

Figure 5: Current reading was taken using Fluke 375 Clamp Meter for each load

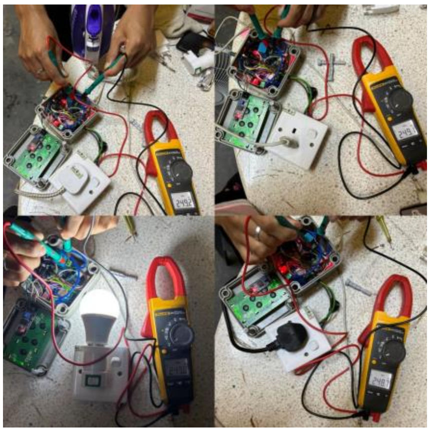

Figure 6: Voltage reading taken using Fluke 375 Clamp Meter for each load

In the Multi-channel Wireless Data Logger for Energy Measurement, the measurement of power in watts (W) and energy in watt-hours (Wh) is determined through calculations based on the formulas integrated into the coding of the system. The coding incorporates relevant mathematical equations to process the real-time data acquired from sensors such as current and voltage sensors. By utilizing these formulas, the system translates the sensor readings into meaningful values of power and energy, which are then displayed and logged for further analysis.

2.4 Methods

The whole system of Multi-channel Data Logger for Energy Measurement will start with sensor calibrating and then it will detect the reading such as voltage, V and current, I. The Bluetooth-based system will start operating to transmit data and receive by the LCD. LCD then will display on the screen "Voltage=", "Current=", and "Power=". If the energy consumption exceeds the limit set on each loading of the house, the Blynk system will send pop-up notifications to the device owner. However, if the energy consumption does not exceed the limit set, the system will start to read new value iterations of the voltage and current sensors.

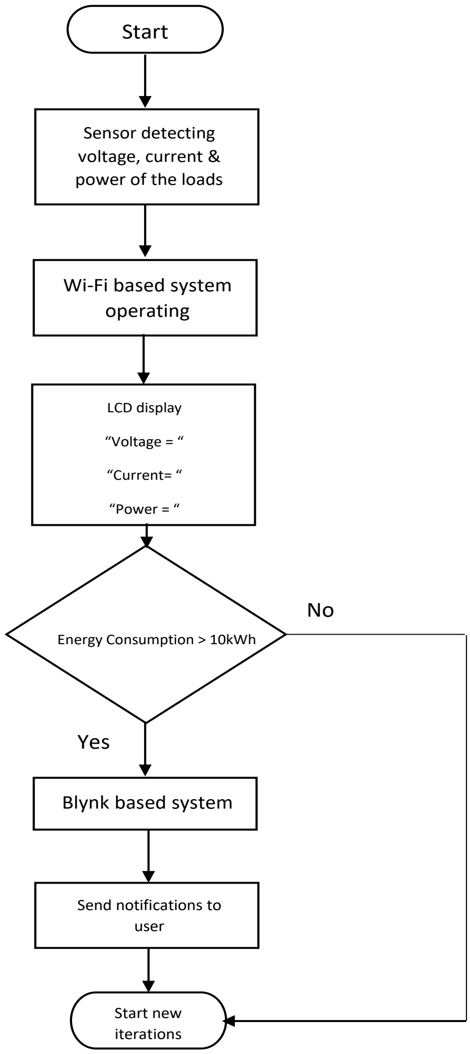

Figure 7: Flowchart of the system

2.5 Arduino IDE

Arduino Ide is used to create or write the code, then uploads it to Arduino hardware which executes the code, interacting with inputs and outputs such as sensors, servo motors, and buzzer. Besides, in Arduino Ide there is a Serial Monitor. Its function is to send messages from your computer to an Arduino board (over USB) and to receive messages from the Arduino. For this part, Serial Monitor is used to show the received or output value of infrared sensor and ultrasonic sensor [3].

2.6 Blynk Application

Blynk is an Internet of Things platform, which makes controlling hardware remotely and visualizing its data very easy. Using Wi-Fi or Hotspot can connect to the Blynk apps. For this project, this app is used to receive signals from Arduino and then give the notification to mobile phones when the bin is full [4].

2.7 Equations

The formulas used are provided from Eq.1 until Eq. 4. These formulas are implemented within the coding of the data logger system, allowing it to continuously compute and update the power and energy values as the sensor data changes over time. This integration of formulas into the coding ensures accurate and real-time measurements of power and energy consumption, providing valuable insights into energy usage patterns. The following equations describes the percentage error, calculated power and energy compute during results and discussion:

$$Error\ \%\ (V) = \frac{Clamp\ Meter\ (V) - Sensor\ AC\ (V)}{Clamp\ Meter\ (V)} \times 100 \qquad Eq.1$$

$$Calculated\ (W) = Sensor\ AC\ (V) \times Sensor\ AC(A) \qquad Eq.2$$

$$Error\ \% = \left|\frac{Calculated\ values - Measured\ values}{Calculated\ values} \times 100\right| \qquad Eq.3$$

$$Calculated\ (Wh) = \frac{Calculated\ (W) \times 1hr}{1000} \qquad Eq.4$$

3. Results and Discussion

3.1 Analysis of parameters measured.

3.1.1 Comparison between sensor and clamp meter measurement

Table 1 shows the observed results of current measurements using a sensor and a clamp meter for various loads. The "Differences (A)" column indicates the variance between the two measurements. From Table 1, we can observe that the sensor AC readings consistently show a higher value compared to the clamp meter readings. The differences range from 0.00A to 0.42A, with the highest difference occurring with the fan load. The clamp meter is only able to give one decimal point of the correct reading. Therefore, these two measurements are not able to be compared accurately.

Table 1: Current reading comparison using various types of loads

No	Loads	Observed Results		Differences (A)
		Sensor AC (A)	Clamp Meter (A)	
1.	No Electrical Load	0.0000	0.0	0.00
2.	10W LED Lamp	0.1302	0.0	0.13
3.	50W Fan	0.6169	0.2	0.42
4.	Electric Iron	1.0962	1.4	0.30
5.	Laptop Charger	0.1730	0.3	0.13

Table 2 presents the voltage measurements obtained using an AC sensor and a clamp meter. The "Error (%)" column represents the percentage difference between the sensor and clamp meter readings. In Table 2, the voltage measurements from the sensor AC consistently indicate lower values compared to the clamp meter readings.

The percentage errors ranged from 0% to 89.78%, with the highest error occurring with the electric iron load. The average error in Table 2 is calculated as 69.67%, which represents the overall percentage difference between the sensor AC and clamp meter voltage measurements across all loads. The formula used to calculate percentage error of voltage is in Eq. 1.

Table 2: Voltage sensor vs multimeter measurement

No	Loads	Voltage Result		Error (%)
		Sensor AC (V)	Clamp Meter (V)	
1.	No Electrical Load	0.00	0.0	0
2.	10W LED Lamp	25.12	245.7	89.78
3.	50W Fan	33.82	245.5	86.22
4.	Electric Iron	32.66	245.0	86.67
5.	Laptop Charger	35.03	244.7	85.68
Average Error				69.67

Both tables suggest that there may be some discrepancies between the readings obtained from the sensor AC and the clamp meter. Further investigation or calibration might be required to understand the cause of these differences and determine the accuracy of the measurements.

3.1.2 Calculated vs. measured values of power and energy.

Table 3 presents the calculated power values and the sensor-measured power values for different loads. The "Error (%)" column indicates the percentage difference between the calculated and measured power. From the table, it is shown that for most loads, the measured power is slightly lower than the calculated power. However, the differences are relatively small, ranging from 0.14% for the fan to 13.08% for the electric iron. The average error across all loads is 2.90%. The formula to determine the calculated power and percentage error has been shown in Eq. 2 and Eq. 3 respectively.

Table 3: Calculated and sensor measured power

No	Loads	Power Result		Error (%)
		Calculated (W)	Measured (W)	
1.	No Electrical Load	0.0000	0.0000	0
2.	10W LED Lamp	3.2706	3.2869	0.50
3.	50W Fan	20.8635	20.8936	0.14
4.	Electric Iron	35.8019	31.1199	13.08
5.	Laptop Charger	6.0602	6.0129	0.78
Average Error				2.90

Figure 8 displays the power reading on Blynk dashboard for 10W LED lamp, electric iron, laptop charger and fan.

Figure 8: Power reading taken using prototype device for each load

Table 4 displays the energy values calculated and measured for each load. The calculated energy values are given in watt-hours (Wh), while the measured energy values are in kilowatt-hours (kWh). The "Error (%)" column represents the percentage difference between the calculated and measured energy. The results indicate that the measured energy values are generally lower than the calculated energy values. The percentage errors range from 4.89% for the 10W LED lamp to 59.16% for the fan. The average error across all loads is 19.53%. The formula used to solve the calculated energy and percentage error were explained in Eq. 4 and Eq. 3 respectively.

Table 4: Energy values calculated and measured

No	Loads	Energy Result		Error (%)
		Calculated (kWh)	Measured (kWh)	
1.	No Electrical Load	0.0000	0.0000	0
2.	10W LED Lamp	0.00327	0.00311	4.89
3.	Fan	0.02086	0.03320	59.16
4.	Electric Iron	0.03580	0.03890	8.66
5.	Laptop Charger	0.00606	0.00455	24.92
Average Error				19.53

The calculated and measured power and energy numbers appear to differ significantly, according to these tables. It is crucial to investigate the measurement equipment accuracy and consider any variables that might be to blame for these discrepancies, like device efficiency, power factor, or measurement mistakes.

3.2 Data Logger and Monitoring System

Figure 9 illustrates the monitoring systems of the project. The figure shows the mobile dashboard of Blynk that displays the readings of Vrms, Irms, power and energy usage of the socket-outlet. Blynk is a popular mobile app platform for Internet of Things (IoT) projects. It allows users to create customizable dashboards to display real-time data from various sensors and devices [5]. The step to create the energy measurement data on Blynk dashboard are as follows:

1. A New Template. Assign the name, Hardware, and Connection Type is created.
2. From the Web Dashboard, 4 widgets Gauge is created. The data streams such as Vrms, Irms, Power and kWh was put into the Gauge widgets.
3. For the settings of Datastreams, the name, Pin, Data Type, Units, Minimum, Maximum, Decimals and Default Value is constructed.

For data loggers, the Super Chart widgets are used to get the parameters reading according to time. This widget is only available in the Mobile Dashboard of Blynk.

Figure 9: The monitoring system on Blynk dashboard

Figure 10 illustrates the Vrms, Irms, Power and Energy usage of the socket outlet being recorded for a certain period as a function of data logging. Meanwhile, Figure 11 represents the Blynk notifications of the monitoring systems that provide real time energy usage information about energy consumption and alerts the user when the usage exceeds predefined limits.

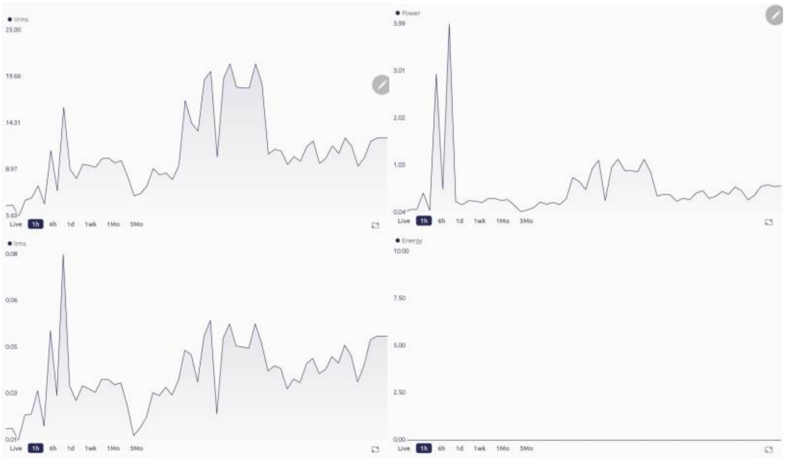

Figure 10: Data logging on Blynk dashboard

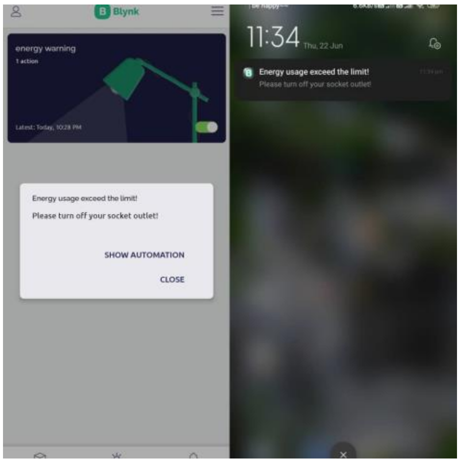

Figure 11: Blynk notifications

4. Conclusion

The construction of the prototype of a Multi-channel Wireless Data Logger for Energy Measurement was completed by using ACS712 Current Sensor and ZMPT101B Voltage Sensor with ESP32 as the microcontroller and LCD as the display medium to display the parameters measured along with Blynk as an online data store through a cloud system. Testing the prototype of the Multi-channel Wireless Data Logger is done by testing the ACS712 Current Sensor and ZMPT101B Voltage Sensor capability to give an accurate reading of the current and voltage. The measurement from the sensor was then compared with the reading of the Fluke 375 Clamp Meter as the reference value. The results show that between the measurements from the clamp meter and the sensor AC, there might be some inconsistencies. To understand the reason for these discrepancies and assess the precision of the results, additional research or calibration may be necessary. The device prototype is not very efficient for everyday use since the sensor’s calibration and the formula of the calculations need to be reevaluate.

Acknowledgement

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