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IoT-Based Arduino Energy Monitoring and Predictor

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Abstract: Electricity has become an essential part of everyday life. From household appliances to industrial machines, almost every activity depends on electrical energy. However, most people do not clearly understand how much electricity they consume at different times of the day because traditional electricity meters only show the total usage. As a result, it becomes difficult to identify unnecessary power consumption.

This paper presents a simple and cost-effective IoT-based energy monitoring and prediction system using the ESP32 microcontroller. The proposed system measures electrical parameters such as voltage, current, and power using sensors connected to the ESP32 board. The collected data is sent to a cloud platform through Wi-Fi so that users can monitor their electricity usage in real time using a web dashboard or mobile application.

In addition to monitoring, the system also analyzes previously collected data and predicts future electricity consumption using basic data analysis techniques. This helps users understand their energy usage patterns and take better decisions to reduce electricity wastage. The proposed system is affordable, easy to implement, and suitable for homes, small businesses, and educational institutions.

Keywords: *Internet of Things, ESP32, Energy Monitoring, Smart Meter, Energy Prediction, Smart Home.*

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I. INTRODUCTION

In today's world, electricity plays a very important role in daily life. Almost every device we use, such as computers, fans, lights, refrigerators, and mobile chargers, requires electrical power to operate. Because of this increasing dependence on electrical devices, electricity consumption has also increased significantly over the years.

However, many people are not fully aware of how much electricity they actually use. Traditional energy meters installed in homes usually provide only the total energy consumed over a certain period of time. They do not show real-time energy usage or provide information about which devices are consuming more electricity. As a result, it becomes difficult for users to manage their energy usage efficiently.

The Internet of Things (IoT) has opened new possibilities for monitoring and managing electricity consumption. IoT technology allows devices to collect data using sensors and send it to the internet where it can be stored, analyzed, and displayed to users in real time. This makes it possible to track energy consumption remotely and identify patterns in electricity usage.

One of the most widely used microcontrollers for IoT applications is the ESP32. It is affordable, powerful, and comes with built-in Wi-Fi and Bluetooth connectivity, which makes it suitable for smart monitoring systems. By connecting sensors to the ESP32, it becomes possible to measure electrical parameters and transmit the data to cloud platforms.

Recently, researchers have also started combining energy monitoring systems with prediction techniques. By analyzing previously collected data, it is possible to estimate future electricity consumption. This can help users plan their energy usage better and avoid unnecessary wastage.

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This paper proposes a simple IoT-based ESP32 energy monitoring and prediction system that allows users to monitor electricity usage in real time and also predict future energy consumption.

II. LITERATURE REVIEW

In recent years, many researchers have worked on IoT-based energy monitoring systems to improve energy efficiency.

El-Khozondar et al. (2024) developed a smart energy monitoring system using the ESP32 microcontroller. Their system collected electricity consumption data and displayed it through an online dashboard so that users could monitor their power usage in real time.

Another study by Muñoz (2024) focused on developing an IoT-based smart energy meter that measures electrical parameters such as voltage and current using sensors. The collected data was transmitted to a cloud server where users could monitor their energy usage remotely.

Mendoza et al. (2024) proposed an IoT-based energy monitoring system for university buildings. Their system helped track electricity usage in different rooms and assisted administrators in managing energy consumption more efficiently.

More recent research in 2025 explored the use of machine learning techniques with IoT systems to predict electricity demand. These predictive systems analyze historical energy data and help forecast future energy usage, which can be useful for better energy management.

Although many of these systems successfully monitor electricity consumption, some of them focus only on monitoring and do not include prediction features. Therefore, this research aims to combine both energy monitoring and prediction in a single system.

➢ *System Architecture*

The proposed system consists of several components that work together to monitor and analyze electricity consumption.

First, sensors are used to measure electrical parameters such as voltage and current from the connected load. These sensors send signals to the ESP32 microcontroller.

The ESP32 microcontroller processes the sensor data and calculates values such as power and energy consumption. Since the ESP32 has built-in Wi-Fi, it can easily send this information to a cloud platform.

The cloud platform stores the collected data and displays it through graphs or dashboards so that users can view their energy usage in real time.

Finally, the stored data can be analyzed using simple prediction algorithms to estimate future electricity consumption.

- *Hardware Components*

✓ ESP32 microcontroller
✓ Voltage sensor (ZMPT101B)
✓ Current sensor (ACS712 / SCT-013)
✓ Wi-Fi network
✓ Power supply

- *Software Components*

✓ Arduino IDE for ESP32 programming
✓ IoT cloud platform such as ThingSpeak or Firebase
✓ Python for data analysis and prediction

III. METHODOLOGY

The working of the proposed system can be explained in a few simple steps.

First, voltage and current sensors measure the electrical parameters from the connected electrical device. These sensor readings are sent to the ESP32 microcontroller.

Next, the ESP32 processes the sensor data and calculates power consumption using the basic electrical formula:

Power = Voltage × Current

The calculated values are then transmitted to a cloud platform using Wi-Fi. Users can view this data through an online dashboard where graphs and charts display electricity usage.

Over time, the system collects historical energy data. This stored data can be analyzed using prediction algorithms to estimate future electricity consumption. These predictions help users understand their usage patterns and take steps to reduce unnecessary power usage.

➢ *Implementation*

```
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
LiquidCrystal_I2C lcd(0x27,16,2);
int voltagePin = A0;
int currentPin = A1;
float voltageCalibration = 0.025;
float currentCalibration = 0.050;
float energy = 0.0;
float costPerUnit = 6.0;
unsigned long lastTime = 0;
void setup()
{
Serial.begin(9600);
lcd.init();
lcd.backlight();
```

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```
// Welcome
lcd.setCursor(0,0);
lcd.print("WELCOME");
lcd.setCursor(0,1);
lcd.print("POWER MONITOR");
delay(2000);
lcd.clear();
// Department
lcd.setCursor(0,0);
lcd.print("Electronics &");
lcd.setCursor(0,1);
lcd.print("Communication");
delay(3000);
lcd.clear();
}
void loop()
{
int vRaw = analogRead(voltagePin);
int cRaw = analogRead(currentPin);
float voltage = vRaw * voltageCalibration;
float current = cRaw * currentCalibration;
float power = voltage * current;
if(millis() - lastTime >= 1000)
{
energy = energy + (power/1000.0)/3600.0;
lastTime = millis();
}
float cost = energy * costPerUnit;
// Serial Monitor
Serial.print("Voltage: ");
Serial.println(voltage);
Serial.print("Current: ");
Serial.println(current);
Serial.print("Power: ");
Serial.println(power);
Serial.print("Energy: ");
Serial.println(energy);
Serial.print("Cost: ");
Serial.println(cost);
// LCD display
lcd.setCursor(0,0);
lcd.print("V:");
lcd.print(voltage,1);
lcd.print(" I:");
lcd.print(current,1);
lcd.setCursor(0,1);
lcd.print("U:");
lcd.print(energy,3);
lcd.print(" Rs:");
lcd.print(cost,1);
delay(1000);
}
```

IV. RESULTS AND DISCUSSION

After implementing the system, it was observed that the ESP32 successfully collected sensor data and transmitted it to the cloud platform. The dashboard displayed voltage, current, and power values in real time.

The prediction model analyzed the historical energy data and provided an estimate of future electricity consumption. Although the prediction is basic, it still provides useful insights into energy usage patterns.

The results show that IoT-based monitoring systems can help users better understand their electricity usage and encourage them to adopt more energy-efficient habits.

➤ *Advantages*

The proposed system offers several advantages:

- Real-time monitoring of electricity consumption
- Remote access through internet connectivity
- Low-cost and easy implementation
- Ability to analyze energy usage patterns
- Helps reduce electricity wastage

V. LIMITATIONS

Despite its advantages, the system has some limitations. Sensor accuracy can affect the precision of measurements. The system also requires a stable internet connection for real-time monitoring. In addition, prediction accuracy depends on the amount of historical data available.

➤ *Future Scope*

Future improvements can include integrating advanced machine learning algorithms to improve prediction accuracy. The system can also be connected to smart home automation systems so that appliances can automatically turn off when unnecessary power usage is detected. Developing a dedicated mobile application for notifications and alerts can also improve the system.

VI. CONCLUSION

This paper presented a simple and affordable IoT-based ESP32 energy monitoring and prediction system. The system measures electrical parameters using sensors and sends the data to a cloud platform for real-time monitoring. By analyzing historical energy data, the system can also estimate future electricity consumption.

The proposed system helps users understand their electricity usage patterns and encourages more efficient energy consumption. With further improvements and integration with smart technologies, such systems can contribute to smarter energy management in homes, institutions, and industries.

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