International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 09 Issue: 05 | May - 2025 SJIF Rating: 8.586 ISSN: 2582-3930

Real-Time Power Usage Analyzing Device: A Non-Intrusive Approach to Energy Monitoring

Shimjith P C
21BTRCS071
Dept of CSE
Jain University, Bangalore, Karnataka
shimjithpc@gmail.com

Richa Elsa Satheesh
21BTRCS056
Dept of CSE
Jain University, Bangalore, Karnataka
richaelsa7015@gmail.com

Ron Jais
21BTRCS061
Dept of CSE
Jain University, Bangalore, Karnataka
ronojaiso69@gmail.com

Sarga Santhosh
21BTRCS068
Dept of CSE
Jain University, Bangalore, Karnataka
sargaaa077@gmail.com

Prof. Moin Hassan
Professor
Dept of CSE
Jain University, Bangalore, Karnataka

Abstract

Many gadgets with different power ratings are frequently used in middle-class Indian homes, but consumers can only obtain information about power use from their monthly electricity bill. There is insufficient information in this bill about incidents of inappropriate usage or power consumption by equipment. By creating a cost-effective, non-intrusive gadget that gathers electrical energy usage data from conventional energy meters, saves it, and displays it in an easy-to-use interface for monitoring and analysis, this study fills this knowledge gap. The technology is generally applicable across many meter types, achieving over 95% accuracy in impression detection for LED-output meters and being compatible with both pulse-output and LED-based energy meters. This study offers a workable solution for better energy management in residential settings by presenting the design, development, and testing of this real-time power usage analysing device.

Keywords: **Energy monitoring, non-intrusive load monitoring, smart meter, real-time power analysis, IoT, energy efficiency**

1. Introduction

For efficient energy management and conservation, awareness of electricity consumption is essential. Several electrical gadgets with varying power ratings run concurrently in typical Indian homes. However, monthly bills only give users aggregated data; they don't offer a thorough understanding of the usage patterns of specific devices or optimization prospects.

1.1 Problem Statement

Electricity invoices as of right now just show total consumption without:

- Breakdown of power utilisation by equipment
- Patterns of consumption dependent on time
- Information about power consumption in real time
- Warning signs of excessive use

1.2 Existing Technologies

There are currently two primary ways that energy meters deliver data:

Data Port Technology: RS-485 and RS-232 communication ports on modern meters used by industrial users provide a wide range of features. Although the technology for these meters is well-established, industrial users are the main goal.

Per kWh impression Technology: The majority of home consumer meters employ this technique, in which each kWh used is represented by a certain number of impressions. Our research is focused on the still-developing technology for gathering data from these meters.

2. Methodology

Five essential components make up the modular gadget design:

1. Impression Detection: Recording energy usage data from conventional meters
2. Processor: handles data and counts impressions
3. Data Transfer: Interacts with the cloud server
4. Time-stamped consumption data is stored in data storage.
5. Output and Analysis: Uses intuitive interfaces to display information.

2.1 System Architecture

The suggested real-time power usage analysis device's general system design is depicted in Figure 1.

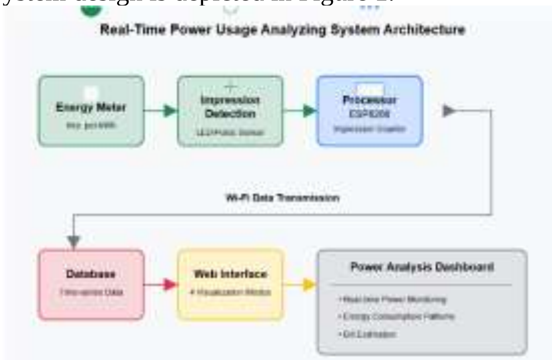

Figure 1 Real-Time Power Usage Analysing System Architecture

The technology doesn't require any changes to the current electrical infrastructure because it takes a non-intrusive approach. The gadget can be connected to conventional energy meters without interfering with their functionality or necessitating expert installation.

2.2 Impression Detection

Depending on the type of energy meter, two impression detecting techniques are used:

1. Optically isolated solid-state pulse output: For meters that use their auxiliary supply to generate DC electric pulses. A voltage regulator is incorporated into the sensing system to transform pulse voltage into levels appropriate for the microcontroller.

LED-based impression detection: For meters that use LED pulses to show consumption. These optical signals are recorded using a detector based on an LDR (Light Dependent Resistor).

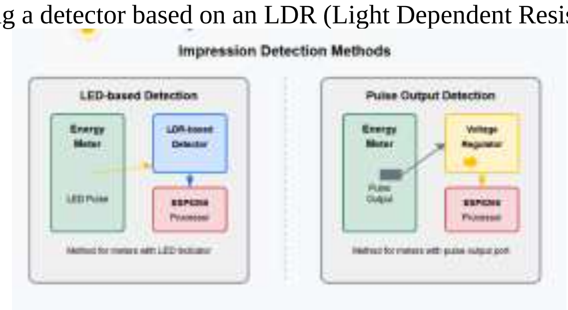

Figure 2 Impression Detection Methods

2.3 Data Processing Unit

The central processor is an ESP8266-12E microcontroller, which does a number of tasks:

- calculating impressions across predetermined durations
- Converting energy consumption values from impression counts
- Controlling wireless access
- Data transmission to cloud storage

As seen in Figure 3, the microcontroller's algorithm employs a strong methodology to guarantee data integrity.

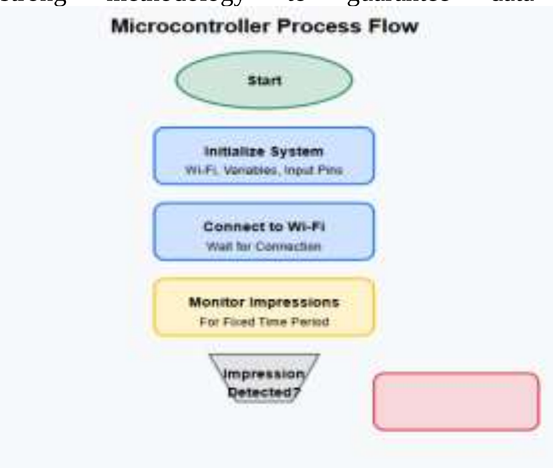

Figure 3 Microcontroller Process Flow

2.4 Data Transmission and Storage

Data transfer makes use of the ESP8266's integrated Wi-Fi capabilities to deliver processed data to a cloud server via HTTP requests. The data structure consists of:

- Number of impressions
- ID of the Device
- Time stamp

There are three main columns in the database schema:

- ID: Primary key with the ability to automatically increase
- Time: Data arrival timestamp from the server
- Units: Data on the raw impression count

2.5 User Interface and Data Visualization

Via a web interface, the system offers several visualisation options:

1. Energy View: Displays energy usage (measured in units) at hourly intervals.
2. Power View: Shows the average power usage per hour (in watts).
3. overall Energy View: Shows the overall amount of energy used each day.
4. View of Energy Parts: Displays usage in between data uploads

3. Implementation

3.1 Hardware Components

The following make up the hardware implementation:

- The microcontroller ESP8266-12E
- Impression detecting circuit (based on an LDR or voltage regulator)
- Module for power supply
- Module for Wi-Fi connectivity (ESP8266 included)

The type of energy meter determines the impression detection circuit. Light pulses are captured by an LDR with the proper conditioning circuitry for LED-based meters. A voltage regulator circuit prepares the signal for microcontroller input in meters that produce solid-state pulses.

3.2 Software Implementation

There are three primary parts to the software architecture:

1. Firmware for microcontrollers: C/C++ code for the Arduino platform that is in charge of:
   - Finding and counting impressions
   - Management of Wi-Fi connectivity
   - Transmission of data to the server
2. Processing on the server: PHP programs manage:
   - Receiving and validating data
   - Database functions
   - Simple data processing
3. Web interface: JavaScript, HTML, and CSS offer:
   - Several views of the data visualisation

- Options for user configuration
- Adaptive design for various gadgets

A sample of code for data transmission and impression counting:

```
void loop() {
  mango="GET /energyf.php?energy=";  int p=2000;  // fixed period 1

  while(p!=0) {
    p=p-1;
    i=1000;  // fixed period 2

    while(i!=0) {
      i=i-1;
      yield();

      if(digitalRead(in1)==HIGH) {
        yield();
        delay(10);

        if(digitalRead(in1)==HIGH) {
          int var=PulseDuration;

          while(var!=0) {
            var=var-1;
            yield();
          }

          x1=x1+1;  // Increment impression count
        }
      }
    }
  }

  mango=mango + x1;  // Append data to web ID

  // HTTP request to server
  WiFiClient client;
  if (client.connect(host, 80)) {
    client.print(mango + " HTTP/1.1\r\n" +
      "Host: " + host + "\r\n" +
      "Connection: close\r\n" +
      "\r\n");

    // Reset counter on successful transmission
    x1=0;
  }

  delay(5000);
}
```

4. Results and Discussion

4.1 System Performance

Energy usage data is successfully gathered, sent, and visualised by the system using the performance indicators listed below:

- When calibrated correctly, LED-based meters have an accuracy of >95%.
- Reliability of data transmission: Data integrity is guaranteed via robust error management.
- Reactivity of visualisation: Near real-time web interface updates

4.2 User Interface

There are four main visualisation options available in the online interface:

1. View of Energy and Power : Displays energy usage per hour in kWh. shows the average power usage in watts.

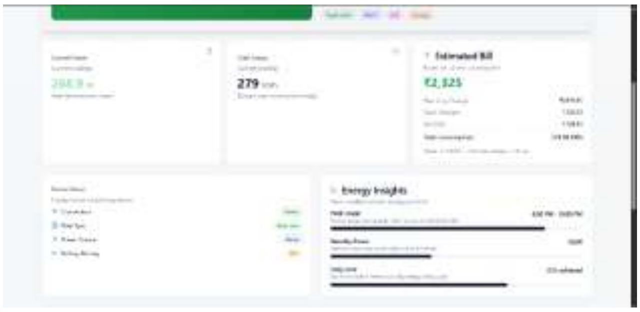

Figure 4 View of Energy and Power

2. overall Energy View: Displays the overall amount of energy used each day.

Figure 5 Power consumption

3. High power usage detection: A notification is given when high power usage is detected. Energy-saving objectives are indicated in weekly reports.

Figure 6 High power usage detection

4.3 Dashboard Integration

The dashboard of the system offers extensive data, such as:

- Real-time power consumption as of right now
- Monthly, weekly, and daily energy trends
- Billing estimates based on current consumption
- Energy-saving suggestions
- Detection of anomalies and notifications

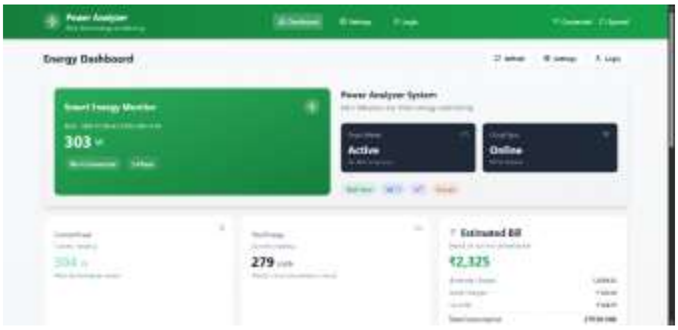

Figure 7 Dashboard

4.4 Comparative Analysis

Our solution is contrasted with current power monitoring systems in Table 1:

Feature	Our System	Commercial Smart Meters	Smart Plugs
Non-intrusive	Yes	No	No
Installation complexity	Low	High	Medium
Cost	Low	High	Medium
Real-time monitoring	Yes	Yes	Yes
Equipment-specific data	Indirect	No	Direct
Retrofitting existing meters	Yes	No	N/A
Energy consumption visualization	Multiple views	Limited	App-dependent

Table 1

5. Applications and Future Scope

5.1 Current Applications

- Residential energy monitoring: Giving households the ability to monitor usage trends
- Energy conservation: Recognising devices with high consumption and usage trends.
- Verifying electric company invoicing by supplying information
- Awareness of consumption: Bringing attention to frequently disregarded energy use.

5.2 Future Work

The system can be improved by:

1. Semi-automated installation: Building an auto-generation website
    - Tables in databases
    - Data storage input webpage
    - Visualisation output webpage
    - Microcontroller code that is already configured

2. Integrating machine learning: Putting algorithms in place for
    - Identification of usage patterns particular to a device
    - Finding anomalies
    - Predictive upkeep
    - Forecasting consumption

3. Mobile application: creating a related app for:
    - Push alerts
    - Monitoring when on the go
    - Additional interactive graphics

4. Additional integration of sensors: Including features for:
    - Measuring power quality
    - monitoring of voltage
    - Analysis of power factors

6. Conclusion

Residential energy monitoring can be done effectively and non-intrusively with the help of the real-time power use analysing gadget. The solution offers home consumers useful usage insights that were previously unattainable by utilising the infrastructure of energy meters that is already in place and integrating it with Internet of Things technology.

When compared to commercial alternatives, the implementation provides a cost-effective solution and achieves over 95% accuracy for LED-based meters. Installation is made simple and compatible with many meter types thanks to the modular architecture.

The system enables customers to make knowledgeable decisions about their energy usage by offering comprehensive visualisation of consumption data, which may result in increased energy efficiency and financial savings. The research shows the possibilities of retrofitting existing infrastructure with IoT capabilities and lays the groundwork for future advancements in domestic energy management systems.

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