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Smart Watt-IoT Solution for Electricity Usage Monitoring

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Abstract

The Internet of Things (IoT) has changed traditional power monitoring systems into smart, connected platforms that offer real-time data and automation. This paper introduces an IoT-based Smart Energy Monitoring and Consumption System that tracks electricity use by individual appliances in a home. The system uses a non-invasive current transformer (WCS1800-1147) and a voltage sensing circuit based on the LM358, connected to an ESP32 microcontroller for collecting and processing data. A 16x2 LCD screen with an I2C interface shows the data locally, while Wi-Fi allows the system to connect to the cloud for remote monitoring and analysis. The system's accuracy is checked using the Meco Power Guard PG09 portable power meter as a reference. A major part of the system is a context-aware chatbot that uses real-time energy usage and environmental data to give helpful suggestions, encouraging more energy-efficient habits. The solution uses affordable hardware, cloud-based analysis, and conversational AI to help manage energy use proactively, lower electricity bills, and support sustainable energy use in homes.

Keywords: *IoT, Smart Energy Monitoring, ESP32, Current Transformer, Voltage Sensing, Cloud Dashboard, Chatbot, Sustainable Energy.*

1. Introduction

In the context of advancing smart living and promoting sustainable energy habits, efficient household energy management has become increasingly essential. The system outlined here utilizes sensor technology to monitor the power consumption of individual appliances, offering detailed, real-time insights into usage trends across the home. A notable feature of this approach is the inclusion of a context-aware chatbot assistant. This AI-driven component enhances user engagement by sending timely notifications and practical recommendations. For example, by integrating local weather data, the assistant can suggest postponing laundry on rainy days—since drying clothes outside would be ineffective—or recommend reducing air conditioner use when outdoor temperatures are already low. The synergy between sensor-based analytics and conversational AI creates a proactive energy management platform. Users gain increased awareness of their habits and are better positioned to make informed choices, contributing to greater overall energy efficiency. Additionally, the system's modular design supports scalability and adaptation, making it suitable for a wide range of residential environments and a promising solution for future smart homes and sustainable urban communities.

2. Related Work

Abdul Jaleel MM [1] points out the increasing importance of incorporating sensor networks, microcontrollers, and cloud platforms in allowing for the tracking and optimization of energy in real-time. It also places a strong emphasis on using the right sensors, establishing a solid data flow architecture, and developing an intuitive user interface in order to develop a scalable and easily usable product. Noteworthy observations include that product architecture should be modular to support a multitude of devices and that the transmission of data must be secure for privacy purposes. It was made clear from this paper to inform our own system that seamless communication from sensor to cloud, actionable feedback for the user, and, where appropriate, a flexible architecture to accommodate a variety of energy environments are essential. R S

Gaikwad [2] Recent advancements in IoT-based smart metering systems have demonstrated the possibilities of linking microcontrollers, sensors, and cloud services to facilitate energy monitoring and energy management. The study developed a three-phase smart meter using the ESP32 microcontroller that provided real-time data, web updates for load shedding functionalities, multiple current and voltage sensors sent via relays, along with a BLYNK-based IoT interface to provide an analysis tool for both end-consumer and utility provider. The smart meter technically provided architecture for secure cloud communication, fault detection, issue detection, and remote functionality using mobile applications. The case study informed us about modular hardware design, calibrating sensors precisely, and superior interfaces to the systems we develop to provide scalable smart energy solutions. Further, the study identified that ESP32 enables low-power and high-performance processing primarily by providing real-time alerts as well as consumption reporting and connecting with devices across a narrow area, this exemplified potential capabilities for industrial and commercial applications. All these considerations informed the development of our system's design based on user data acquisition, which is persistent and meaningful interaction with a user that introduces evolutionary and radical innovations using our sensor technology through logical data analysis. The goal is to make sure the user data we collect can idealize energy consumption to be used for expansion. M Sentamilselvi [3] proposes a privacy-preserving energy management system that combines the power of smart meters enabled by the IoT with machine learning to perform electricity theft detection and automate the billing process. Specifically, to address privacy challenges, the authors conceptually introduce ETDFE (Efficient Theft Detection by Functional Encryption), which encrypts fine-grained consumption data before it is sent for billing so that the system operator can perform billing and load management without knowing actual individual consumption data. They used Convolutional Neural Networks (CNNs) in a secure multi-party computation setup for detecting theft and getting the identity of the fraudulent users, while hardware components such as Node MCU, current sensors, relays, and LCD class A eye health hardware real-time management and automation light lights where to be mount virtual environment favorite connections for monitoring, assessment and disconnection of power for unpaid bills. Additionally, their Smart Energy Theft System (SETS) also has similar performance with their use of models like MLP, RNN, LSTM, and GRU, enabling theft detection accuracy of 99.96% in real settings. This work demonstrates the promise of the combination of encryption and intelligent analytics in the development of energy management systems that are secure, efficient, and scalable. Aytun Onay [4] discusses how IoT technologies can improve energy efficiency through appliance-level monitoring made possible by energy disaggregation. Energy disaggregation takes total energy consumption and separates it according to appliance use, providing transparency that can inform user behavior or help advocate for sustainability. The review outlines different types of algorithms, such as Hidden Markov Models (HMM), Sparse Coding, Graph Signal Processing (GSP), and deep learning models such as LSTM, CNN, and Wave Net algorithms that will improve appliance-level identification performance from aggregated data. Public datasets such as REDD, UK-DALE, and ampds are highlighted as essential datasets for training and validating models. The practical implications encompassed: energy-saving recommendations, occupancy detection, fault detection, and personalized automation. The authors also highlight challenges such as the non-existence of consistent datasets, the need for more privacy throughout iterations of deep learning and edge deployments, and scaling edge computing. Federated learning has been proposed as a model for privacy-preserving model training without exposing raw user data. The outcomes will inform our system through reinforcing the importance of fine-grained monitoring, intelligent analytics, and privacy in developing scalable user-centric energy management solutions. Nitin Shivaraman [5] proposes a decentralized metering architecture designed for mobile IoT devices, like e-scooters, allowing energy

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to be monitored wherever it is consumed, regardless of heterogeneity in a power grid. Their architecture relies on trusted aggregators and utilizes a blockchain-like log to guarantee recording of data that is secure, tamper-proof, and does not rely upon a consensus mechanism. Functional components include real-time monitoring and offline storage, as well as handover protocols, which were tested in real deployments. The paper outlines future improvements planned to shorten consensus methods and implement anomaly detectors, focused on enhancing fraud protection and operational independence. This work supports our system, as its importance when discussing secure, low-latency energy logging in volatile space was very apparent and demonstrates the practical potential of distributed architectures. Guang-Li Huang [6] provides a scalable and inexpensive IoT-based framework to obtain real-time energy monitoring for a smart city infrastructure to address the large energy footprint reported in nearly all urban buildings, which is estimated at approximately 40% of global energy consumption. Their system can provide detailed tracking by buildings, by floors, and across individual devices using SQL-based templates to calculate Key Performance Indicators (KPIs), including annual energy used and CO_2 emissions. Security and multi-tenancy were guaranteed through Key rock for identity management, Pep Proxy for access control, and encrypted MQTT communication. In their field installations, the authors report affordability and implementation at under €10,000 for a 50-flat implementation. Future work suggests utilizing a more robust system that combines advanced machine learning approaches, such as double deep Q-learning, for energy optimization. This paper advances our research by reinforcing the important role of secure, scalable IoT infrastructures in urban energy analytics while also demonstrating the possibilities that KPI-based feedback loops.

3. Proposed System

Smart Watt is an IoT-based smart energy monitoring and consumption solution designed to provide real-time tracking and intelligent support for household electricity usage. Unlike the traditional system that provides the consumption data, the proposed system measures each application-level voltage and current using a non-invasive current transformer (WCS1800-1147) and a voltage sensing circuit like the LM358 amplifier. The readings are then processed by the ESP32 microcontroller. The 16x2 LCD with an I2C interface displays real-time consumption reading without an internet connection. At the same time, the data is transmitted via Wi-Fi to cloud platforms where the data can be stored, visualized, and analyzed. The main feature of the proposed system is the integration of an analyzing chatbot that engages the user by analyzing real-time consumption data and weather information to give appropriate suggestions. The system uses the Meco Power Guard PG09 portable power meter for reliability and accuracy. This system merges real-time sensing, cloud-enabled analysis, and AI-driven interaction, transforming energy monitoring from a passive process into an active management tool that promotes sustainable usage and cost reduction. The dashboard displays current and historical data, aiding in setting alarms, managing devices continuously, and tracking energy usage trends for each appliance. Making wise decisions to conserve power. The system is precise since individual devices have distinct dimensions, making it straightforward to incorporate additional sensors without significant alterations. The CT detectors and their input channels must be properly configured to maintain accuracy. The secure storage of all data in the vault simplifies analysis and provides insights into reducing energy consumption. In general, this intelligent device provides comprehensive and practical electrical usage statistics that assist individuals, businesses, and factories in optimizing their power consumption, minimizing wastage, and enhancing overall energy efficiency.

4. Methodology

The proposed system has two parts: the hardware, which measures and collects the data from each appliance, and the software, which processes, analyses, and provides efficient data.

4.1. Hardware components

The proposed system utilizes a combination of microcontroller, sensors, and analog conditioning

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circuits to enable accurate energy monitoring. The core hardware includes:

- **ESP32:** Serves as the main controller, handling data acquisition, processing, and communication via Wi-Fi, MQTT, HTTP, and Blynk.
- **WCS1800:** Split-core current sensors for measuring current from three separate loads.
- **LM358 or ZMPT101B:** Voltage sensing modules for capturing mains voltage, with isolation for safety.
- **ADS1115 (4-channel, 16-bit ADC):** External analog-to-digital converter for high-resolution sampling of voltage and current signals.
- **16x12 LCD:** Displays real-time power and energy data locally.

Supporting Components: Burden resistors, bias resistors, RC filters, decoupling capacitors, voltage regulators, fuses, and terminal blocks ensure signal integrity, safety, and stable operation. Calibration is performed using a reference meter (e.g., Meco Power Guard) to derive scale factors and phase correction constants, which are stored in non-volatile memory (SPIFFS or Little FS).

4.2. Software Implementation

The software stack is designed for efficient sampling, signal conditioning, and real-time analytics.

5. System Architecture

The planned IoT-based energy monitoring system would be able to measure and assess actual energy usage in real time across a variety of electrical loads. It combines cloud-based visualization, high-resolution data acquisition, analog signal conditioning, and current and voltage sensing. The architecture is modular, adaptable, and designed for inexpensive installation in home and small business settings.

5.1. The Layer of Sensors

The system makes use of a voltage sensor (LM358 or ZMPT101B) to record the shared mains voltage v(t) and three split-core current transformers (CTs) to measure the individual load currents i_1(t), i_2(t), and i_3(t). These sensors output analog signals that are directly related to the measured electrical parameters.

5.2. Analogue Conditioning

To maintain and center the signal around mid-rail voltage (approximately 1.65 V), each CT output goes through a burden resistor, biasing network, and RC filter. The voltage sensor experiences similar conditioning to guarantee that it is compatible with the ADC input range. In this step, the data is made ready for precise digitization while maintaining signal integrity.

5.3. Data Acquisition

The ADS1115, a 16-bit analog-to-digital converter with four channels, receives conditioned analog signals. Using the I²C protocol, the ADS1115 interacts with the ESP32 microcontroller. To obtain voltage and current waveforms with enough resolution for power calculations, sampling is done at regular intervals. The ESP32 manages channel reads, implements calibration constants, and does signal processing.

5.4. Processing and Computation

The ESP32 performs real-time computations such as: RMS voltage and current, Real-time and instantaneous power, the power factor and apparent power, and Energy integration throughout time. The total consumption figures are derived by aggregating these measures, which are calculated for each load. To guarantee the accuracy of measurements, calibration constants for scale and phase correction are used.

5.5. Interaction and Communication

Per-load power and cumulative energy consumption are shown locally on a 16x2 I²C LCD screen that displays the processed data. At the same time, the ESP32 uses MQTT, HTTP, or Blynk protocols to send data to cloud services like Things Board, Firebase, or Influx DB. The remote monitoring and analytics are made possible by the delivery of JSON payloads every 5 to 15 seconds. When thresholds are exceeded, signals are sent through Telegram or push notifications.

5.6. Oversight and Governance

The device has a calibration interface that may be accessed through a web dashboard or serial connection, as well as over-the-air (OTA) firmware updates. This guarantees maintainability and flexibility for future improvements, such as weather-

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integrated control logic or load forecasting using machine learning Shown in Figure 1.

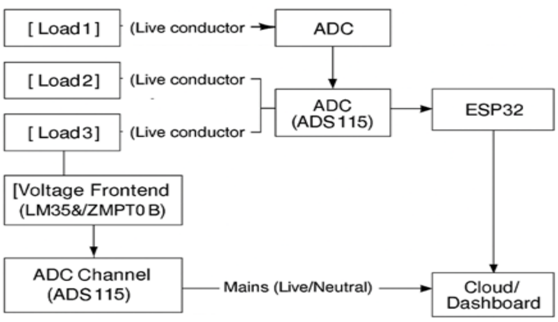

Figure 1 Flow Diagram

6. Results And Discussions

The IoT-enabled energy monitoring system was implemented and evaluated using common household appliances. The results demonstrate that the system can effectively capture, process, and present energy usage information in real time Shown in Figure 2.

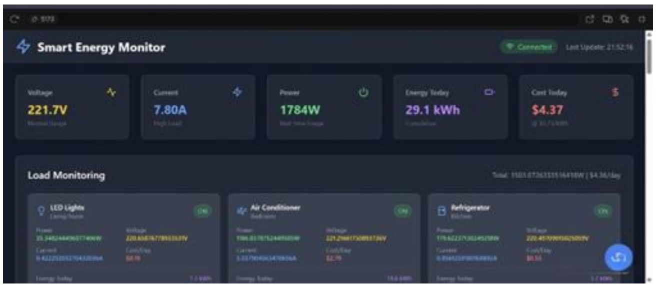

Figure 2 Main Dashboard

As illustrated in the figure, the main dashboard provides continuous updates on essential parameters such as voltage, current, active power, and daily energy consumption. This ensures that users can monitor their household electricity usage immediately Shown in Figure 3.

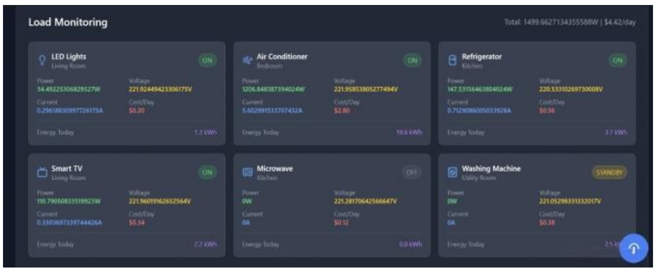

Figure 3 Appliance-Specific Monitoring

The system also supports appliance-specific monitoring. In the figure, individual devices, including the television, microwave, and washing machine, are displayed with details such as operational state (ON, OFF, or Standby), power drawn, and estimated daily cost. This allows users to easily identify devices that contribute to unnecessary consumption Shown in Figure 4.

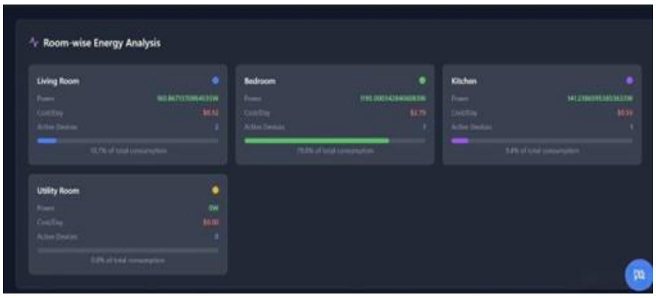

Figure 4 Room-Based Analysis

To provide a broader perspective, the platform incorporates. As shown in the figure, energy usage is grouped by location (living room, bedroom, and kitchen), along with active device counts and cost estimates. This classification makes it easier to pinpoint high-demand areas within a household Shown in Figure 5.

Figure 5 Time-Based Load Patterns

For long-term consumption awareness, the system visualizes time-based load patterns through bar graphs, as presented in the figure. These graphs highlight energy usage variations throughout the day and help identify peak load hours. Such insights can guide users to shift appliance usage to non-peak times, reducing overall electricity expenses. The load distribution interface, shown in the figure, further breaks down energy usage across multiple appliances. This view highlights devices such as air

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conditioners and refrigerators, which typically dominate overall household consumption. By analyzing this distribution, users can prioritize optimization strategies for high-load devices Shown in Figure 6.

Figure 6 Load Distribution Interface

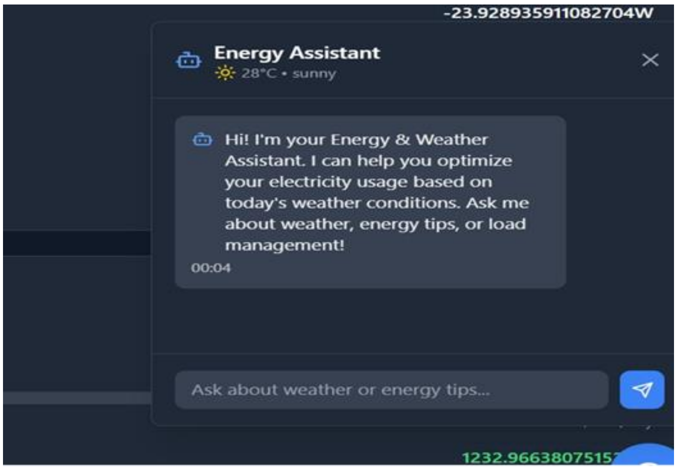

Figure 7 The Intelligent Chatbot Assistant

An important improvement in the system is the intelligent chatbot assistant. As depicted in Figure 7, the chatbot communicates with users in natural language, offering both system updates and energy-saving suggestions. Unlike conventional dashboards, the chatbot provides context-aware advice, such as recommending reduced appliance usage during favorable weather conditions. This interactivity adds a proactive element to energy management. In summary, the results confirm that the developed system not only monitors energy consumption accurately but also transforms raw data into actionable insights. By combining real-time dashboards, historical trend analysis, and an intelligent assistant, the platform encourages both energy conservation and cost savings in residential environments.

Conclusion and Future Work

The proposed IoT-based Smart Energy Monitoring and Consumption System successfully demonstrates a low-cost and scalable solution for appliance-level electricity monitoring. By integrating the ESP32 microcontroller with current and voltage sensors, the system accurately calculates real-time power and energy consumption, which is displayed locally on a 16×2 LCD and transmitted to the cloud for remote analysis. Calibration using the Meco Power Guard PG09 confirmed the reliability of the measurements within an acceptable error margin. A key contribution of this work is the integration of a context-aware chatbot assistant, which enhances user interaction by delivering personalized recommendations based on energy consumption patterns and contextual data such as weather conditions. This transforms the system from a passive monitoring tool into an interactive platform for proactive energy management. The results indicate that the system can promote awareness, reduce electricity costs, and encourage sustainable energy practices, making it a promising approach for future smart homes and urban energy management. While the system achieved its objectives, several enhancements can be explored in future developments:

- **Automated Control of Appliances:** Integration of smart relays and IoT switches to allow the system to automatically turn off devices when not in use.
- **Integration with Renewable Energy Sources:** Extending the system to monitor and optimize the usage of solar panels or hybrid inverters.
- **Machine Learning for Predictive Analytics:** Using AI to forecast electricity bills, predict consumption trends, and provide personalized energy-saving suggestions.
- **Scalability to Commercial/Industrial Domains:** Expanding the system's applicability beyond households to larger residential complexes, offices, and small

industries.

- **Enhanced Chatbot Capabilities:** Improving chatbot intelligence with advanced natural language processing (NLP), multilingual support, and integration into popular messaging platforms such as WhatsApp and Telegram.
- **Gamification and User Engagement:** Incorporating reward-based mechanisms to encourage users to adopt energy-efficient habits.

By implementing these enhancements, the system can evolve into a comprehensive smart energy management ecosystem, contributing significantly to sustainable urban development.

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