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# Real-Time Data Analytics for Monitoring Electricity Consumption Using IoT Technology

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## ABSTRACT

**Rising electricity bills as a result of climate variability and new home electrical and electronic appliances are becoming a major source of concern for most end users. Consumers are typically unaware of their household electricity consumption patterns and the costs associated with them, making proper planning and budgeting difficult. Monitoring and controlling energy consumption on appliances can reduce energy costs for end-users. The Internet of Things (IoT) has the potential to provide remote monitoring and control of devices via automated monitoring and control. In this study, we propose an IoT-enabled system for monitoring and controlling energy consumption in homes to save money and make electricity more affordable to low-income people. Autonomous sensor nodes attached to power outlets collect and route power consumption data to the GSM-enabled gateway. Data aggregation is performed by the gateway for data received from all end-nodes within its coverage area. The gateway sends the data to the cloud, where real-time data analytics is performed. We also developed an algorithm that enables users to not only understand their usage patterns but also remotely control their appliances at any time. Mobile phones are used to remotely turn on and off household appliances via a machine-to-machine interface, as well as to provide real-time visualization of household energy consumption patterns.**

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## INTRODUCTION

The rate at which electrical bills are rising causes the majority of consumers, particularly those with low income, to struggle to make these payments. The changing climatic conditions and the adoption of new household devices are two of the primary causes of rising bills. The Internet of Things is a new technology that empowers users with intelligence. The Internet of Things has enormous potential for use in a wide range of scenarios, including healthcare, agriculture, and industry, among others. Numerous studies have been conducted in the energy sector. In recent years, research has been conducted on the aspects of monitoring electricity consumption using the Internet of Things. Because of the miniaturization of IoT sensors and actuators, IoT systems can now be embedded in a variety of components that interact with the energy ecosystem, such as home electronic appliances, household power meters, power utility service wires, and so on (Alulema et al., 2018). The discussed IoT system allows for remote monitoring of electricity consumption in homes. An extensible and modular framework is implemented using an IoT system based on XBee technology, and a data communication protocol is proposed to enable data sharing between all four systems components (Marinakis et al., 2018). The IoT system described in this paper monitors electrical power consumption via a web-based application. It is critical to keep a close eye on the electric power consumption of household electronic appliances. An IoT-based application that controls the use of home appliances in monitoring electricity power consumption has been learned (Luechaphonthara et al., 2019). Based on the Internet of Things, the research presented in (Yuniarto et al, 2019) proposes an intelligent energy meter that controls and computes energy usage. The approach introduced simplifies, manages, and controls energy consumption analysis, allowing for home automation implementation. Wireless communication technologies that ensure efficient energy consumption monitoring in a smart grid are realized. An automated Internet of Things system is proposed for electricity monitoring and remote load control (Mozumder et al., 2018). An IoT framework is built that considers the integration of a digital power meter, a global system for mobile communication (GSM), and a general packet radio services (GPRS) system. Using an existing electrical energy meter in conjunction with IoT-based technology improves customer energy consumption behavior and experiences. An essential Internet of Things intelligent device that monitors and controls electricity generation, designed and implemented. The smart device keeps track of the time the electricity is on and monitors the amount of energy and fuel consumed during the generation process.

In (Hartman et al., 2018), IoT-based energy monitoring and controls are introduced, and a cost-effective energy monitoring and control system is implemented using IoT devices. Air conditioners, smart lights, and other electrical appliances can be controlled remotely. This system is enabled by three key components: a cloud-based database for IoT data storage, a hardware component with a microcontroller for processing IoT requests, and a front-end Application Programming Interface (API) through which the end-user interacts with the system.

Whereas the authors (Evariste et al., 2016) propose residential energy management based on an analysis of historical and real-time energy consumption. The authors use the metering device identification number to uniquely identify the energy users. The technique presented in this research enables users to retrieve energy consumption data in real-time, for hourly, daily, weekly, and monthly intervals. Furthermore, monthly energy consumption is compared to inform homeowners of months with high energy consumption, assisting homeowners in making appropriate decisions and improving their energy consumption behaviors. The authors of (Marinakis et al, 2018) present an IoT system for managing energy utilization for industrial entities. A communication framework is introduced that supports demand response. To deploy industrial energy customer demand response systems, an IoT-based energy management platform can be designed and developed using a common information model and open communication protocols that benefit from combined energy supply networks.

Marinakis et al. (2018) investigates an improved IoT-based intelligent energy management system in buildings. The research paper (Marinakis et al.,

2018) studies an enhanced IoT-based framework for smart energy management in buildings. The proposed framework improves on existing techniques by combining multiple data types such as smart energy management systems, energy production, energy costs, and homeowner power usage behavior to generate planned energy consumption details with clear customized information for energy end-users. In addition, an IoT-based energy management approach for smart cities is being implemented (Liu et al., 2019). In the context of smart cities, the implemented technology uses intelligent edge computing to control and manage energy. A software model system is presented for integrating edge computing-based IoT energy management in the smart city ecosystems. It is suggested that a deep reinforcement learning approach be used to ensure efficient energy scheduling.

The Internet of Things may be used to present an architectural design that includes an energy management assistant. The architectural assistant described in this paper improves the transparency of energy consumption rates and knowledge about energy loss, as well as predictive processing, analysis, and visualization to predict probable energy-related risks in industrial facilities and future energy levels.

The authors of (Luan et al., 2016) created an IoT-based energy monitoring system. This work includes a remote energy monitoring system built on a browser-server architecture. A wide range of technologies are used to ensure the smooth operation of the IoT system.

## METHODS AND MATERIAL

This section explains the architecture of the system as well as the working of the proposed algorithm.

### Architecture of the system

The proposed household electrical energy management system as depicted in (Figure 1) and consists of autonomous energy sensors attached to power outlets throughout each house, a GSM/GPRS gateway, cloud data analytics, and end-user devices. Digital instrumentation, communication networks, and front-end and back-end software applications are used in the design. The role of remote energy monitoring via IoT improves industrial and enterprise energy management, encourages energy-saving behaviors, and reduces greenhouse emissions. In the switchgear industry, an energy monitoring and control system is asserted (Muddaliar et al., 2020). A single board IoT computing device may be used to implement cost-effective IoT-based real-time energy management (Raspberry Pi). The system comprises industrial energy metering devices, a single board computer, a cloud web service, control, and monitoring applications. Daily energy usage monitoring is emphasized as the first step toward energy-saving practices.

Even though IoT-based research work in IoT-based energy electricity and electrical energy monitoring has been completed, it still requires improvement and contribution to the body of knowledge; in this work, we emphasize real-time data analytics on electricity consumption monitoring via IoT systems.

To manage electricity consumption, an advanced Monitoring scheme algorithm proposed in this paper is compared to a non-intrusive scheme algorithm (Sheng Wu et al., 2020). In comparison to the non-intrusive monitoring algorithm, the proposed algorithm is more effective and efficient in providing monitoring.

Energy sensors measure energy consumption through the outlets that power the appliances and send the data to the GPRS gateway. The data is then routed to the cloud via the MQTT protocol by the gateway. The following machine learning scheme is used to analyze energy data. Based on the results of the data analysis, the cloud-based mobile application allows users to remotely control energy consumption by turning on/off appliances. Users are also provided with a detailed report on their household's energy consumption regularly.

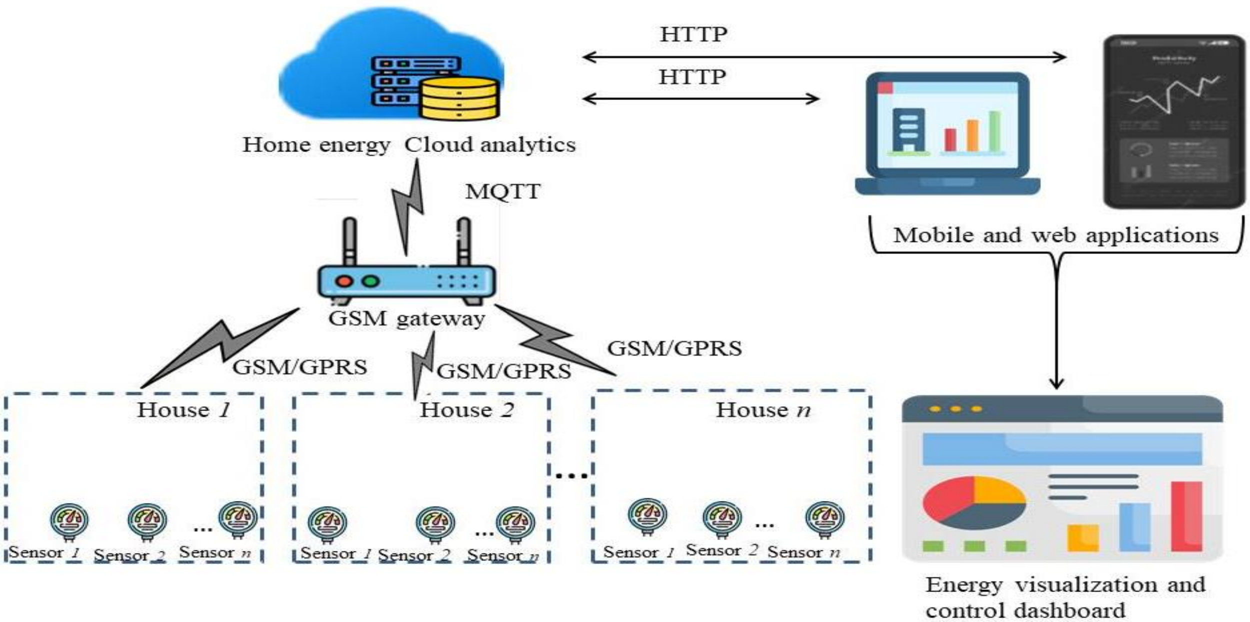


**Figure 1:** The overall structure of the real-time home electrical energy monitoring and control system.

## Design of proposed Monitoring scheme algorithm

The Monitoring scheme algorithm will be used in the proposed electricity consumption model. It is more efficient to use a Monitoring Scheme algorithm that reduces electricity consumer consumption. This scheme is used by considering the power consumed by various appliances, in which case we have classified them into three (3) types. That is $P_{tn}$ where Ptn is the total power consumed by all home appliances at any given time slot and Equation (4) gives the total power consumed by all appliances in the home per 24 hours (0).

## Crucial appliances

As we have seen in our algorithm scheme, this will consider the power consumed by various appliances. These appliances are divided into three (3) types. The first type is Real-time appliances. These can be interrupted or delayed during their operation, they also have the flexibility during their operational time. Using binary variables 0, and 1, where Equation one (1) depicts the set of appliances that consume electricity. If the appliance is turned on, the total home power consumed will be calculated using Equation (1).

$$X_{i,n} = \begin{cases} if\ i^{th} \text{devices is on in time } t_n \\ \quad \forall = 1 \dots R_T,\ n = 1 \dots N \\ 0,\ if\ i^{th} \text{devices is off in time } t_n \end{cases} \qquad (1)$$

The second type is Uninterruptible Appliances (UA). These appliances cannot be interrupted in their operation, although they do even have the elasticity of their power consumption.

Using binary variables 0, and 1, Equation (2) depicts the set of appliances that consume electricity. If the appliance is turned on, the total home power consumed will be calculated using Equation (4).

$$Y_{j,n} = \begin{cases} if\ j^{th} \text{devices is on in time } t_n \\ \quad \forall = 1 \dots U_A,\ n = 1 \dots N \\ 0,\ if\ j^{th} \text{devices is off in time } t_n \end{cases} \qquad (2)$$

The third type (3) is Programmable Appliances (PA). These appliances can be scheduled and controlled through the Smart plug.

Using binary variables 0, and 1, Equation (3) below depicts the set of appliances that consume electricity. If the appliance is turned on, the total home power consumed will be calculated using Equation (3).

$$Z_{k,n} = \begin{cases} if\ k^{th} \text{devices is on in time } t_n \\ \quad \forall = 1 \ldots P_A,\ n = 1 \ldots N \\ 0,\ if\ k^{th} \text{devices is off in time } t_n \end{cases} \tag{3}$$

The total power consumption for all appliances concerning time slots is estimated by utilizing Equation (4). The reason to group our appliances are due to the introduction of sensing technology in our algorithm scheme. This works better due to sensors controlling some of the appliances that are integrated with sensing technology, which will lower the total power.

$$P_{tn} = \sum_{i=1}^{RT} (M_i, n)(X_i, n) + \sum_{j=1}^{UA} (N, n)(Y_j, n) + \sum_{k=1}^{PA} (O_k, n)(Z_k, n) + k \tag{4}$$

The total power consumed by Programmable appliances.

The total power consumed by Uninterruptable appliances.

The total power consumed by Real time Appliances.

The total power consumed in every time slot is estimated using this equation for all appliances.

The explanation above explained the variables in Equation (4). The below diagram respectively shows the pseudo-code for monitoring consumption by return total power consumed used.

**Pseudo code forMonitoring Scheme algorithm**

**Step 1: Initialize Variables:**

Read_value_Ps = 0, //Ps is presence sensor
Read_value_Ms = 0, //Ms is the motion sensor
Total power consumption Ptn = 0,
Voltage of the appliance Vc = 0,
Current of appliance is = 0,
Sensing period St = 0,
Temp_value = 0,
Sleep_electricity Se = 0,
Sleep_time = Slt = 0,
The power consumed by Real-time appliance $M = 0$,
The power consumed by uninterruptable appliance $N = 0$,
The power consumed by programmable appliance $O = 0$.

**Step 2: While (Step1 = Current_Step)** //Steps $\neq$ current_step
**Step 3:** Read step.
**Step 4:** Switch (n) // case of steps
**Step 5: Case 1**: current_step = "No one in house"
**Step 6: While**((read_value_Ps && Read_Value_Ms)== 1) // sensing used for presence and motion sensor.
**Step 7:** $\sum_{i=1}^{RT}(\mathbf{M_i}, \mathbf{n})(\mathbf{X_i}, \mathbf{n}) = \mathbf{0}$ //No power will be consumed for real-time appliances.
**Step 8: else**
**Step 9:** $\mathbf{P_{tn}} = \sum_{j=1}^{UA}(\mathbf{N_j}, \mathbf{n})(\mathbf{Y_j}, \mathbf{n}) + \sum_{k=1}^{PA}(\mathbf{O_k}, \mathbf{n})(\mathbf{Z_k}, \mathbf{n})$
**Step 10: Break;**
**Step 11: Case 2**: Current_step = "Someone in house"
**Step 12: While**((read_value_Ps&&Read_Values_Ms)$\rightarrow$ 1)
**Step 13:**

$$P_{tn} = \sum_{i=1}^{RT}(M_i, n)(X_i, n) + \sum_{j=1}^{UA}(N_j, n)(Y_j, n) + \sum_{k=1}^{PA}(O_k, n)(Z_k, n) + k$$

**Step 14:** Send (Ptn, time_slots) //Send the data consumed to IoT board
**Break;**
**Step 15: Case 3:** Current_step=" outside appliance in a house on time_slots during the night".
**Step 16: if** (light sensor detects lighten up = 1)

**Step 17:** **set**(dimlight) **then** $P_{tn} < \sum_{i=1}^{RT}(M_i, n)(X_i, n)$

**Step 18:** **Case 4** Current_step = "voltage, low on line"

//Switch off all Real-time appliances, but uninterruptable appliances should not be turned off the algorithm would not affect the total work done by interruptible appliances by turning them off.

$P_{tn} = 0 + \sum_{j=1}^{UA}(N_j, n)(Y_j, n) + \sum_{k=1}^{PA}(O_k, n)(Z_k, n) + k$

**Step 19:** **Case 5:** Current_step = "Panic mode at the house"

**Step 20:** **if** (there is panic mode)

**Step 21:** Switch off all Real-time appliances

**Step 22:** **Then** $P_{tn} < \sum_{k=1}^{PA}(O_k, n)(Z_k, n)$

**Step 23:** **Break;**

**Step 24:** **Case 6:** Current_step = "All chargeable as well as programmable appliance"

**Step 25:** **if** (chargeable and programmable appliance are fully charged)

**Step 26:** Once charged should be off

**Step 27:** **Break;**

**Step 28:** **Case 7:** Current_step = "Maximum load"

**Step 29:** Smart meter will control it and stabilize.

**Step 30:** End of while loop

**Step 31:** End of while loop

**Step 32:** End if

**Step 33:** End if

**Step 34:** End case

## EXPERIMENTAL RESULTS AND DISCUSSION

This implementation model used an IoT-enabled system through a GSM-enabled gateway. These Autonomous sensors attached to power outlets collect and route power consumption data to the GSM-enabled gateway as well as control the appliances, for example, we have in this experiment controlled the bulb using a dashboard from Adafruit that acts as a broker.

In the setup below, the NodeMCU functions as a data aggregator, collecting data from motion sensors, as well as energy sensors. This data is transmitted to the GSM/GPRS gateway which pushes the data to the cloud via MQTT protocol. The selection of this protocol is primarily because it is a light-weight and faster scheme which makes it a suitable option for devices with limited memory and processing capabilities. Real-time analytics is carried out in the cloud to extract insights from the data. Mobile API acts as a subscriber which accesses information and provides visualization for end users. We also developed an algorithm that enables users to not only understand their usage patterns but also remotely control their appliances at any time. Mobile phones are used to remotely turn on and off the led bulb via a machine-to-machine interface, as well as to provide real-time visualization of household energy consumption patterns. The devices and resources (Figure 2) used are:

- ESP8266 NodeMCU.
- 2 Channel Relays.
- Jumper Cables.
- Led Bulb.
- Motion and Presence Sensor.
- Adafruit IO.
- MQTT Dashboard
- IFTTT Android App.

The results obtained from the above experiment have demonstrated that the data from the sensor has a significant role in minimizing the total power consumed in a set of household appliances.

After knowing the total individual consumption and total power consumption, the IFTTT Android application can control their appliances at any time.

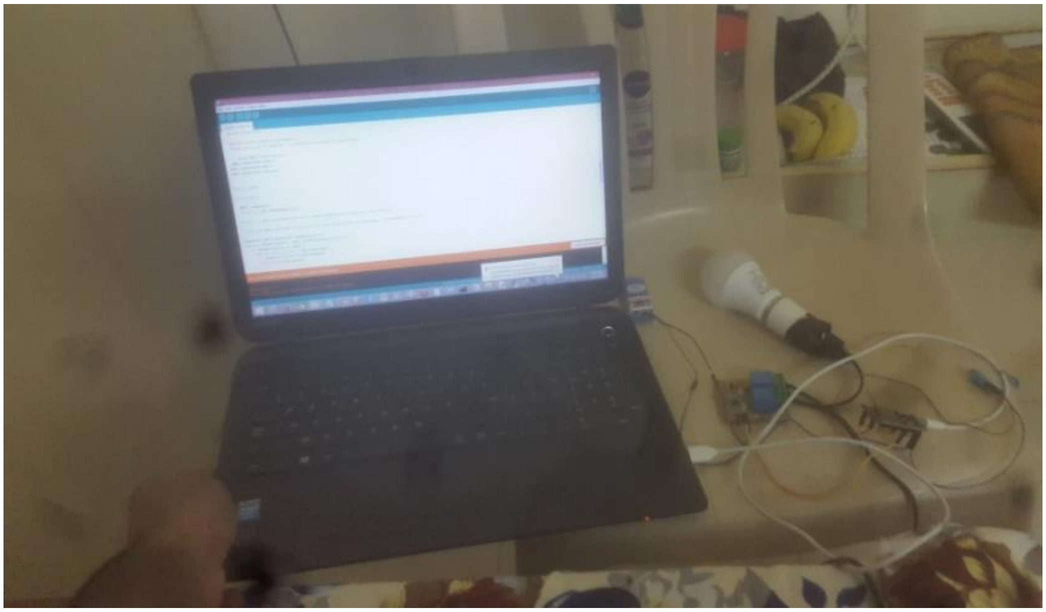

**Figure 2:** The developed experimental setup as shown.

## CONCLUSION AND RECOMMENDATION

An architecture and a monitoring scheme are proposed and implemented in this paper. The consumption of household appliances was evaluated and simulated using data from a group of appliances. Real-Time appliances consume less due to sensing technology integrated into the proposed model, whereas the remaining groups of appliances consume only at certain times of the day, due to the nature of their operations. For each group of appliances, the architecture established a promising model, a methodology that not only understands their usage patterns but also remotely controls their appliances at any time. The monitoring scheme is simple to implement. As a result, this algorithm is recommended in any other domain that necessitates remote and close monitoring and control.

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