World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(REVIEW ARTICLE)

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Development of an IoT-based smart energy management system for industrial applications

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World Journal of Advanced Research and Reviews, 2024, 23(01), 765–769

Publication history: Received on 31 May 2024; revised on 07 July 2024; accepted on 09 July 2024

Article DOI: https://doi.org/10.30574/wjarr.2024.23.1.2054

Abstract

The traditional approach to energy meter reading is a antiquated practice that is plagued by inefficiencies, inaccuracies, and unnecessary expenses. The costs of manual meter reading are invariably passed on to consumers, adding to their financial burden. Smart energy meters offer a viable solution, but the astronomical cost of replacing existing meters with new ones poses a significant hurdle. However, this paper proposes a innovative solution that leverages the power of IoT technology and Raspberry Pi devices to transform legacy meters into smart prepaid meters without the need for costly replacements. This ground breaking approach enables remote meter monitoring, mobile app control, automated notifications, and seamless integration with existing infrastructure. By harnessing the potential of IoT, this solution revolutionizes energy metering, making it more efficient, convenient, and cost-effective for consumers.

Keywords: IoT; Energy Management; Sustainability, Cloud Computing; Real-time Monitoring; Artificial Intelligence

1. Introduction

The traditional method of electrical meter reading for billing purposes [1] relies on human workers physically visiting homes and buildings, which requires a significant workforce and time [2]. This approach is prone to errors [2], can be delayed by adverse weather conditions, and may result in lost or misplaced paper bills [3]. In densely populated countries like India, this process is particularly challenging and resource-intensive [4], leading to increased operational costs for energy providers and higher electricity bills for consumers [5].

This paper proposes a solution to address these issues by utilizing smart energy meters with embedded systems, specifically Raspberry Pi and color sensors (TCS 3200), to automatically track electricity usage [6]. This innovative approach enables consumers to monitor their energy consumption remotely through a customized webpage or mobile app, allowing them to take control of their energy usage and preferences.

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The developed system offers a convenient and automated way to access individual user's meter readings on a daily or monthly basis, eliminating the need for manual intervention [6]. This is made possible by continuously monitoring and recording energy meter readings in a non-volatile memory. Additionally, the system provides real-time meter readings, accessible by the owner/user through a personalized account on an energy meter webpage [7]. Furthermore, the system enables remote disconnection of power supply to a house or building when necessary, enhancing control and efficiency.

2. Architectural model

The device uses a light sensor (TCS 3200) to read data directly from the meter, which is then transmitted to an Arduino board. The Arduino board sends the data to a Raspberry Pi, which uploads it to the Thing Speak cloud platform. The data can then be accessed and viewed on the Thing Speak website or through a mobile application, providing a convenient and remote way to monitor the meter readings.

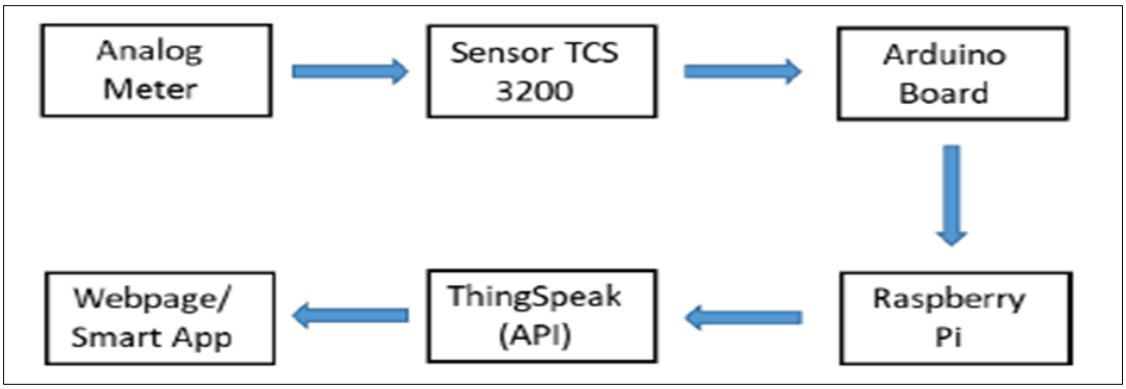

Figure 1 Architectural System

The system's architecture is illustrated in Fig. 1. Household appliances consume energy, which is constantly measured by an energy meter and displayed on the meter. The meter's LED blinks to count energy units, with 3200 blinks equivalent to one unit. The Raspberry Pi 3 acts as the main controller, monitoring the energy meter's LED blinks to track consumption. A customized webpage and Smart App allow users to monitor energy usage, calculate costs, and set a prepaid threshold value via Wi-Fi. When this threshold is near depletion, the system sends a notification to the consumer, promoting energy awareness. Users can recharge or increase their threshold as needed; failure to do so will result in automatic disconnection of electricity supply. The webpage allows users to update their threshold value at any time, and a monthly bill is generated and sent to both the customer and service provider via SMS on the first day of each month.

3. Smart energy meter system

The Electronic Meter Automation Device (EMAD) consists of four main components: a Raspberry Pi, an Arduino board, a TCS 3200 Color Sensor, and a 4-channel relay. These components are ingeniously integrated into a compact design, allowing the entire system to fit seamlessly within a standard meter housing.

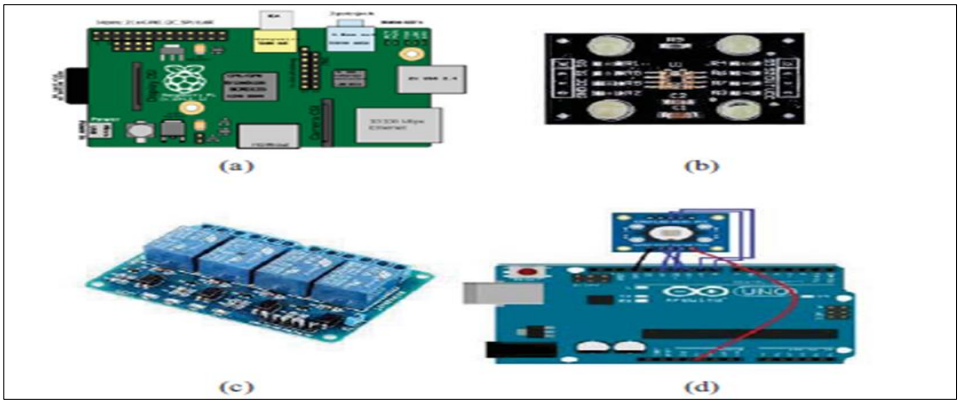

Figure 2 Hardware Components (a) Raspberry Pi, (b) Color Sensor (TCS 3200), (c) Channel Relay, (d) Arduino

3.1. Energy Meter

An energy meter, also known as a watt-hour meter, measures the electrical energy consumption of consumers. Utility companies install these meters in homes, offices, industries, and organizations to track electricity usage and charge accordingly. Modern energy meters, such as prepaid electricity meters or smart energy meters, not only measure energy consumption but also calculate instantaneous electricity bills and track parameters like produced and consumed units.

3.2. The procedure of Energy Units Calculation

Traditional analog meters require manual readings, which is an outdated practice still prevalent in many homes and buildings. These meters have an LED that blinks at a rate corresponding to energy consumption, increasing in speed with higher usage. The developed system modernizes this process by utilizing a color sensor (TCS 3200) to automatically count the LED blinks, sending the data to a Raspberry Pi for calculation of parameters like energy units consumed.[8] The results are displayed via Thing Speak API as graphs and visualized on a customized website and smart app, enabling remote monitoring and control of the main supply. This innovative system enhances existing electric meters, making them reliable and smart. The components of the Electronic Meter Automation Device (EMAD) are described in the following sections.

3.3. Microcontroller: Raspberry Pi 3

Raspberry pi board is the heart of the developed EMAD system. It reacts to the 5V supply given by opto-coupler and keeps on counting the LED blinking. It then calculates the net

recharge available and cost of using the electricity. This data is continuously stored and displayed on the webpage so that a user can monitor his/her energy consumption or take actions according to its preferences. It is also responsible to reacts when the threshold is breached and sends the SMS to consumers.

3.4. Mobile Application

A smart mobile App has been developed for the system. The App can be used in Android as well as in iOS platform. A consumer can visualize the data of the EMAD device once

mounted to an electric meter. A user can recharge or cut off the meter using this smart App. An EMAD device is capable of handling two-way communication with the grid, i.e. if a consumers' house/building is also producing the power using some renewable energy sources (Solar, Wind etc.), then the final bill will be calculated based on the power produced and consumed. It is also possible to introduce the different pricing scheme which varies with time and the day. As time and energy information is communicated at regular intervals, the energy consumption and cost can be regulated.

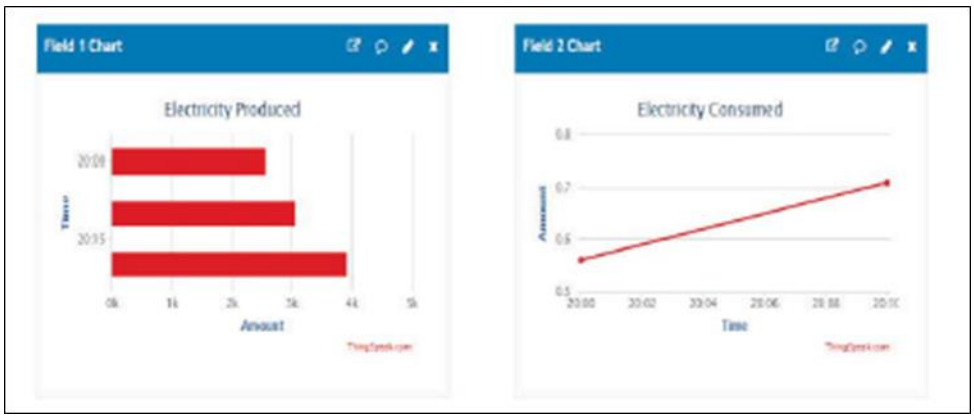

Figure 3 Data visualization using thinkspeak

3.5. ThingSpeak

ThingSpeak is an open-source IoT platform that enables devices to store and retrieve data using HTTP protocol over the internet or LAN. It facilitates the development of various applications, including: Sensor logging , Location tracking, Social networking of devices with status updates In this project, ThingSpeak API is utilized for Logging in data and Visualizing data in graphical form (as shown in Fig. 3)

3.6. WIFI Module

In IoT applications, Wi-Fi acts as the heart of it. In this work, Wi-Fi is used to communicate with the smart App for changing the threshold value and to ON & OFF the energy meter. The energy units' consumption is also communicated through this and displayed on the webpage. The Consumers are able to access the raspberry board and meter with help of Wi- Fi. The pricing details of per units are communicated to consumers using Wi-Fi in their smart App.

3.7. Webpage (HTML)

For this work, a webpage, using Hypertext Markup Language (HTML), has been designed to visualize and operate energy meter functioning and consumption. Fig. 4. shows a screenshot of the developed webpage. A Web server has been set up to store the data and to receive HTML documents for the Web browser.

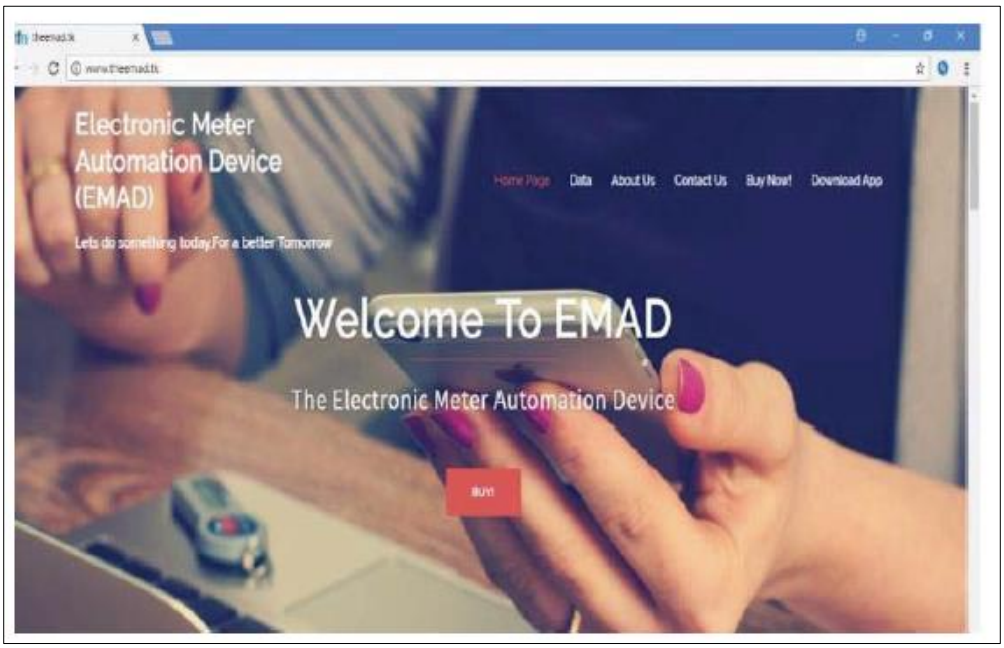

Figure 4 Web Interface for Tracking Meter Functionality and Energy Usage

4. Energy units calculation

The basic unit of electricity is the Kilowatt hour (KWh), equivalent to 1000 watts for 1 hour. In this context:

1 unit of power consumption is equivalent to 3200 LED blinks, as per the meter specification. Let:

- B denote the number of LED blinks
- U denote the number of units of electricity consumed
- C denote the cost (INR) of per unit electricity (1 kWh)
- P denote the prepaid amount

Then:

- The number of units consumed (U) can be calculated as: $U = B / 3200$
- The cost of total electricity consumed (T) will be calculated as: $T = U \times C$
- The updated prepaid balance (Ú) can then be given by: $Ú = P – T$
- The remaining prepaid amount (T) can be calculated as: $T = P - U \times C$

For practical purposes, the developed system calculates the remaining prepaid amount and energy units on an hourly basis. If the remaining prepaid amount (T) approaches a predetermined threshold, an SMS notification is sent to the consumer.

5. Conclusion

This paper has introduced a smart energy management system leveraging IoT technology. The developed Electronic Meter Automation Device (EMAD) can upgrade traditional meters to smart meters, enabling remote access and control through a dedicated webpage and mobile app. The system features automatic meter shutoff when the prepaid limit is reached and SMS notifications for low balance alerts. Our future plans include large-scale data collection and deploying smart meters in local households to gather feedback and refine the system.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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