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IOT-SEMS: An IoT-Driven Energy Management Solution for Industry 4.0

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Abstract: The rising demand for energy efficiency in industrial environments has led to the emergence of intelligent monitoring and control systems. This research presents the development of an IoT-based Smart Energy Management System (SEMS) tailored for industrial applications. The system integrates a Raspberry Pi, Arduino microcontroller, TCS3200 colour sensor, and a 4-channel relay module to enable real-time monitoring, classification, and control of electrical devices based on energy usage and operational conditions. The Raspberry Pi serves as the central processing unit, while the Arduino interfaces with sensors and actuators to collect data and execute control signals. The TCS3200 colour sensor is employed to detect status indicators such as device operating states or color-coded signals on machinery, enabling context-aware automation. The 4-channel relay provides the switching mechanism to control multiple loads efficiently. Through Wi-Fi connectivity, the system transmits data to the cloud, allowing for remote access, real-time alerts, and performance analytics. Experimental results validate the system's ability to optimize energy usage, enhance operational control, and support predictive maintenance in industrial setups. This work contributes a scalable and cost-effective solution for intelligent energy management in Industry 4.0 ecosystems.

I. INTRODUCTION

In the era of Industry 4.0, the need for intelligent and energy-efficient systems has become increasingly vital, particularly in industrial environments where power consumption is high and continuous operation is critical. Traditional energy management approaches often lack the flexibility, real-time monitoring capabilities, and automation required to optimize energy usage and ensure operational sustainability. As industries move towards smart infrastructure, the integration of Internet of Things (IoT) technologies offers a promising solution for efficient and dynamic energy management. This research focuses on the development of an IoT-based Smart Energy Management System (SEMS) specifically designed for industrial applications. The proposed system utilizes a Raspberry Pi as the central processing unit, in conjunction with an Arduino board for sensor interfacing and control operations. A TCS3200 color sensor is incorporated to detect color-coded operational signals from machinery or control panels, providing a novel method of condition-based device control. Additionally, a 4-channel relay module is employed to manage the power supply to multiple industrial loads, enabling remote and automated switching. The integration of IoT technologies allows for real-time monitoring, control, and data transmission over wireless networks. By combining hardware components with cloud connectivity, the system enables energy analytics, remote diagnostics, and predictive maintenance capabilities. This not only improves energy efficiency but also enhances the reliability and responsiveness of industrial operations. The goal of this work is to design a cost-effective, scalable, and user-friendly energy management solution that leverages smart sensing and automation to meet the growing demands of modern industrial systems. The proposed system aims to serve as a practical foundation for intelligent energy control in smart factories and other industrial facilities.

II. LITERATURE REVIEW

The growing demand for intelligent and efficient energy management systems in industrial and residential environments has accelerated the adoption of Internet of Things (IoT) technologies. These systems aim to reduce energy wastage, improve operational control, and enable real-time monitoring and automation.

Early developments in this field focused on integrating GSM technology with energy metering and appliance control. Saikia [1] proposed a GSM-enabled smart energy meter that facilitated remote monitoring and appliance automation, laying the foundation for wireless energy management. Cheng et al. [2] evaluated the operational state of energy meters, emphasizing the need for accurate measurement and diagnostics. In a related study, Edward [3] introduced a password-protected relay system for secure load control, ensuring both safety and access control in energy systems.

The transition towards open and scalable systems was addressed by Sahana et al. [4], who demonstrated the use of open IoT protocol stacks for home energy management. Arasteh et al. [5] explored broader applications in smart cities, highlighting the scalability and interoperability of IoT-based systems across urban infrastructures. Wireless Sensor Networks (WSNs) also play a vital role in IoT-based energy management. Kumar et al. [6] reviewed routing protocols for WSNs, noting their impact on communication efficiency in large-scale sensor deployments. Focusing on intelligent control, Kaiwen et al. [7] proposed a smart appliance control system utilizing WSNs to enhance automation in smart buildings. Cloud computing and big data analytics have also become critical enablers. Zhao et al. [8] proposed a cloud-based network architecture to support big data services, which is essential for real-time energy analytics. Comprehensive surveys by Liu et al. [9] and Al-Shammari et al. [10] provided insights into various IoT applications, including energy management, highlighting the convergence of sensors, communication protocols, and cloud services. Singh et al. [11] specifically developed an IoT-based smart energy meter aimed at efficient consumption monitoring and real-time control, which is particularly relevant to industrial scenarios. Rao et al. [12] proposed a smart energy management framework tailored for smart cities, demonstrating that IoT systems can extend beyond individual households to city-wide implementations. Furthermore, Bhuiyan et al. [13] integrated machine learning algorithms with IoT-based smart home energy management systems, enabling predictive control and energy optimization through intelligent decision-making.

In summary, the literature illustrates the evolution from basic GSM-based control systems to advanced, cloud-integrated IoT frameworks. These studies collectively underscore the significance of combining embedded systems, wireless communication, cloud analytics, and smart sensors to build scalable and responsive energy management solutions—motivating the development of this research using Raspberry Pi, Arduino, TCS3200 color sensors, and relay modules for industrial applications.

III. ARCHITECTURE MODEL

The proposed IoT-based Smart Energy Management System utilizes a layered architecture that integrates sensing, processing, and cloud communication for real-time monitoring and control of industrial energy usage. The system architecture is depicted in Figure 1 and comprises the following key components.

1) Analog Meter: The energy consumption of industrial devices is initially measured using a traditional analog energy meter. This meter visually indicates power usage through a dial or numeric readout, which forms the basis for optical sensing.
2) TCS3200 Colour Sensor: A TCS3200 colour sensor is employed to interpret the color-coded or dial-based output of the analog meter. It converts the visual signal into frequency data corresponding to color intensity, enabling digital interpretation of analog readings.
3) Arduino Board: The Arduino microcontroller serves as the intermediate processing unit. It receives frequency data from the colour sensor, processes it to extract meaningful energy consumption metrics, and transmits the processed data to the next layer. The Arduino also manages communication between sensor modules and the Raspberry Pi.
4) Raspberry Pi: The Raspberry Pi plays a central and indispensable role as the system's main processing and communication hub. Its integration brings both computational intelligence and network connectivity to the system, enabling real-time data handling, decision-making, and remote access. The Raspberry Pi serves as the main controller, aggregating data from the Arduino board, which collects sensor input from the TCS3200 colour sensor. It processes, formats, and prepares this data for cloud transmission. Its processing power allows for local computations, data logging, and potential pre-analysis without relying solely on external servers. Equipped with built-in Wi-Fi capabilities, the Raspberry Pi uploads the processed data to Thing-Speak, a cloud-based IoT platform. It handles API requests and ensures a seamless bridge between the physical layer (sensors and controllers) and the digital layer (cloud, app, or web interface). As a Linux-based microcomputer, the Raspberry Pi supports various programming languages and IoT libraries, making it highly adaptable. This flexibility allows developers to expand the system easily—for example, by integrating more sensors, relays, or control logic for more complex industrial environments. The Raspberry Pi is capable of real-time data acquisition, processing, and communication. It plays a key role in ensuring that decisions—such as activating or deactivating relays—are made promptly based on sensor readings and predefined thresholds.
5) Thing-Speak (API):The processed data is uploaded to Thing-Speak, a cloud-based IoT platform, using RESTful APIs. Thing-Speak acts as the cloud server where energy data is stored, visualized, and analysed in real time.
6) Wi-Fi module: Wi-Fi plays a critical role in the proposed architecture for the development of an IoT-based Smart Energy Management System. It serves as the core communication medium that links the physical sensing and control layers (Arduino, Raspberry Pi) with the cloud platform (ThingSpeak) and end-user interfaces (webpage or mobile app). Wi-Fi allows the Raspberry Pi to continuously upload sensor data—processed from the Arduino and TCS3200 sensor—to the ThingSpeak cloud platform. This ensures that energy consumption metrics are available in real time for monitoring, visualization, and analysis.

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Using Wi-Fi connectivity, users can access energy data from any location through a web browser or mobile application. This enhances operational flexibility, allowing industrial managers or facility operators to monitor power usage and respond to faults or inefficiencies without being physically present. Wi-Fi eliminates the need for complex and expensive wired networking, especially in retrofitted industrial environments. This wireless communication simplifies installation and supports scalability, making it ideal for expanding the system to additional sensors or locations. Wi-Fi facilitates seamless integration with Thing-Speak, an IoT cloud platform used in this system. Through RESTful API calls over Wi-Fi, data is transmitted efficiently and securely, enabling advanced data logging, analytics, and visualization features.

7) Web Interface / Smart Application: Users can access live and historical energy data via a web portal or mobile application. This front-end interface communicates with Thing-Speak APIs to display readings, trends, and alerts, offering a user-friendly interface for remote monitoring and energy management.

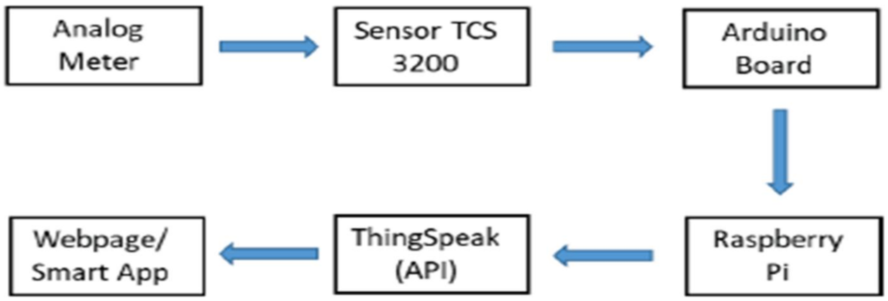

Fig 1 : Architecture Model

This architecture facilitates real-time data acquisition from legacy analog meters, digital processing through embedded controllers, and remote visualization via cloud services. It enables efficient, low-cost retrofitting of traditional energy meters into smart monitoring systems suitable for industrial IoT applications.

Fig 2 : Working Model

IV. RESULTS & CALCULATION

The fundamental unit used to measure electrical energy is the kilowatt-hour (kWh), which is equal to consuming 1000 watts over a period of one hour. In this system, one unit of electricity corresponds to 3200 LED pulses, based on the specifications of the energy meter.

Let:

- **B** represent the number of LED blinks detected,
- **U** represent the number of energy units consumed,
- **C** denote the cost per unit of electricity (in INR), and
- **P** represent the prepaid balance.

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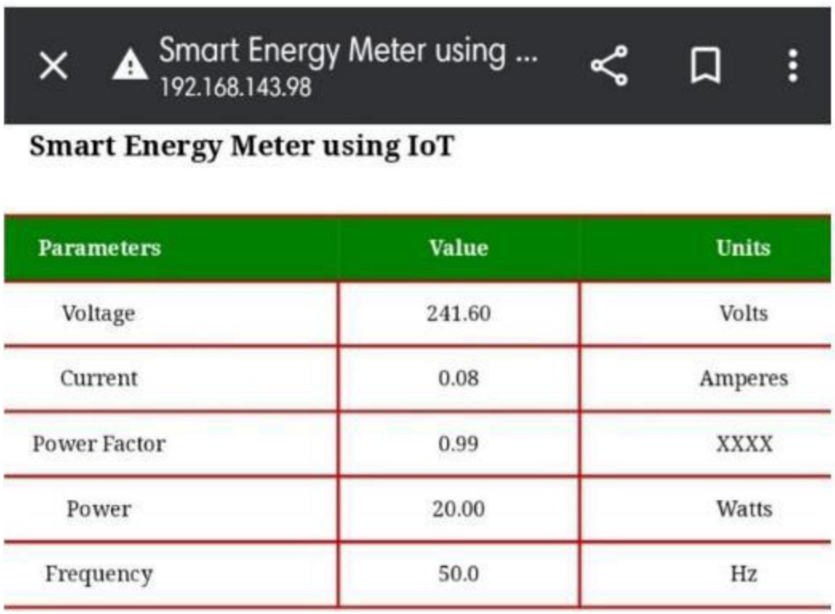
The system follows these calculations:

- **Units Consumed**:
  $$U = \frac{B}{3200}$$
- **Total Cost of Consumption**:
  $$T = U \times C$$
- **Remaining Prepaid Balance**:
  $$\hat{U} = P - T,$$
  which can also be written as:
  $$T = P - (U \times C)$$

In practical application, the system tracks energy usage and the remaining balance **hourly**. When the prepaid balance drops close to a preset minimum threshold, an **SMS alert** is automatically sent to the user to notify them of the low balance.



Parameters	Value	Units
Voltage	241.60	Volts
Current	0.08	Amperes
Power Factor	0.99	XXXX
Power	20.00	Watts
Frequency	50.0	Hz

Fig 3 : Display Results of smart energy meter

V. CONCLUSION

This research presents the successful development of an IoT-based Smart Energy Management System tailored for industrial applications, leveraging the capabilities of a Raspberry Pi, Arduino board, TCS3200 color sensor, and a 4-channel relay module. The system is designed to monitor energy consumption in real-time, interpret analog meter readings using a color sensor, and automate load control based on intelligent logic and threshold values. By integrating cloud connectivity via Wi-Fi and utilizing platforms such as ThingSpeak for remote monitoring, the proposed model ensures energy usage is both visible and manageable from any location.

The use of low-cost, open-source hardware makes the solution affordable and scalable, making it suitable for both small and medium-scale industrial environments. Furthermore, features like prepaid monitoring, automated switching, and SMS alert notifications improve operational efficiency and energy accountability. In conclusion, this system demonstrates a practical, efficient, and intelligent approach to industrial energy management in the era of Industry 4.0, with significant potential for future enhancements through the incorporation of machine learning and predictive analytics.

REFERENCES

[1] L. C. Saikia, "GSM enabled smart energy meter and automation of home appliances", Proceedings of the International Conference on Energy, Power and Environment: Towards Sustainable Growth (ICEPE), June 12-13, 2015.

[2] Y. Cheng et al., "Running state evaluation of electric energy meter", IEEE Workshop on Electronics, Computer and Applications, May 8-9, 2014.

[3] O. O. Edward, "An Energy Meter Reader with Load Control Capacity and Secure Switching Using a Password Based Relay Circuit", Proceedings of the Annual Global Online Conference on Information and Computer Technology, Dec 3-5, 2014.

[4] M. N. Sahana et al., "Home energy management leveraging open IoT protocol stack", Proceedings of the IEEE Recent Advances in Intelligent Computational Systems (RAICS), Trivandrum, India, Dec 10-12, 2015.

[5] H. Arasteh et al., "IOT-based smart cities: A survey", Proceedings of the IEEE 16th International Conference on Environment and Electrical Engineering (EEEIC), Florence, Italy, June 7-10, 2016.

[6] A. Kumar et al., "Location-Based Routing Protocols for Wireless Sensor Networks: A Survey", Wireless Sensor Network, Vol. 9 (1), 2017.

[7] C. Kaiwen et al., "An intelligent home appliance control-based on WSN for smart buildings", Proceedings of the IEEE International Conference on Sustainable Energy Technologies (ICSET), Hanoi, Vietnam, Nov 14-16, 2016.

[8] M. Zhao et al., "A Cloud-Based Network Architecture for Big Data Services", Proceedings of 2nd International Conference on Big Data Intelligence and Computing and Cyber Science and Technology Congress, Aug 8-12, 2016.

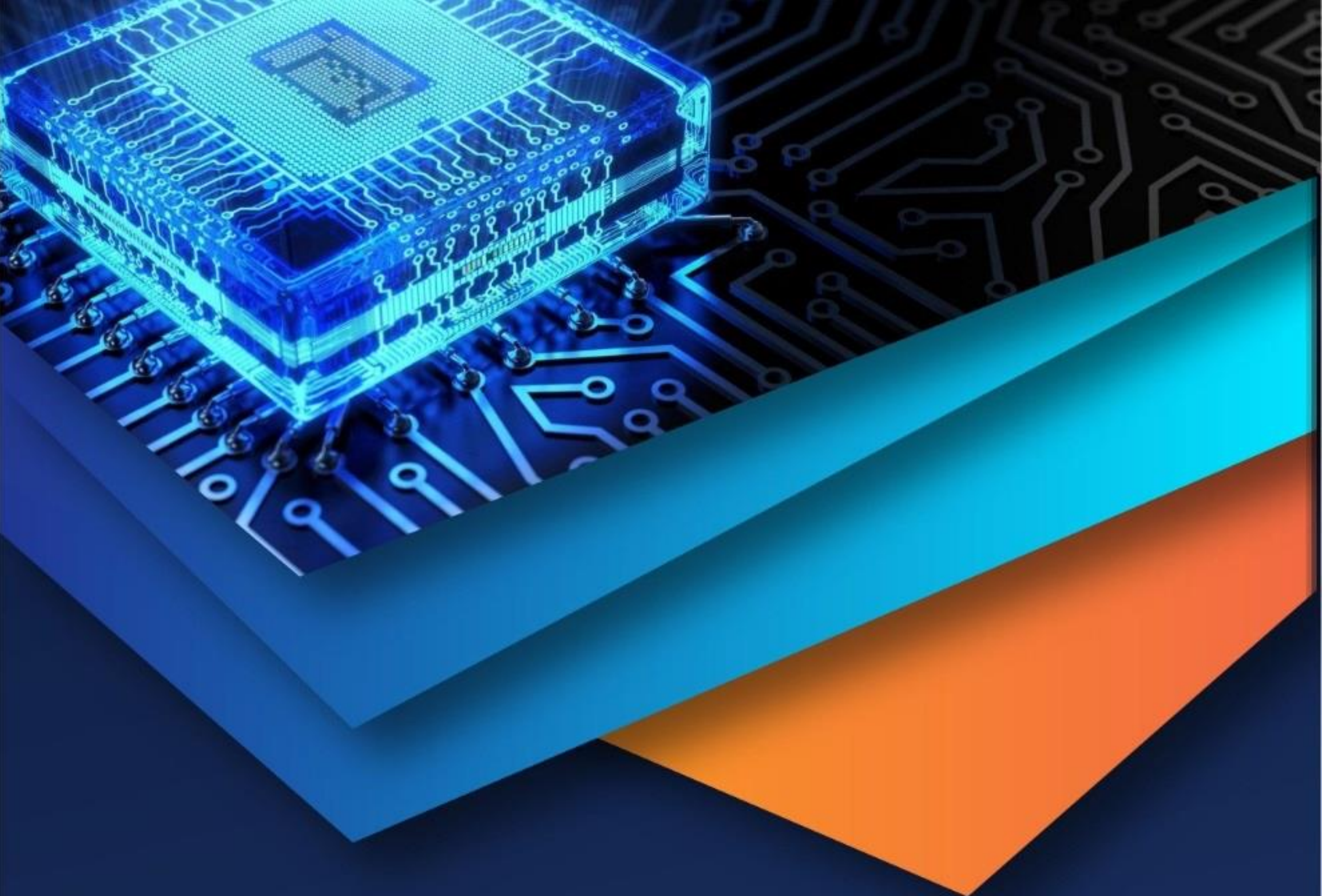
[9] J. Liu et al., "A survey on IoT technologies and applications", IEEE Internet of Things Journal, vol. 3, no. 6, pp. 1024-1034, Dec 2016.

[10] M. A. Al-Shammari et al., "Smart home energy management system using IoT technology", Journal of Engineering Research and Applications, vol. 7, no. 3, pp. 1-6, 2017.

[11] A. K. Singh et al., "IoT based smart energy meter for efficient energy management", International Journal of Advanced Research in Computer Science and Software Engineering, vol. 6, no. 6, pp. 1-6, 2017.

[12] S. S. Rao et al., "IoT enabled smart energy management system for smart cities", Journal of Intelligent Information Systems, vol. 49, no. 2, pp. 1-15, 2018.

[13] M. R. Bhuiyan et al., "IoT based smart home energy management system using machine learning algorithm", Journal of Intelligent & Robotic Systems, vol. 97, no. 1, pp. 1-18, 2020



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