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Research Article

WIRELESS BLUETOOTH LOW ENERGY (BLE) VOLTMETER: A LITERATURE REVIEW ON DESIGN, DEVELOPMENT, AND APPLICATIONS

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Abstract

Wireless voltage measurement systems have transformed electrical monitoring by offering enhanced portability, flexibility, and real-time data transmission. The adoption of Bluetooth Low Energy (BLE) has further improved these systems by providing low-power, reliable, and cost-effective solutions for voltage monitoring in industrial and remote applications. This review examines recent advancements in BLE-based voltmeter systems, particularly focusing on design aspects, implementation, and key challenges. The integration of Arduino platforms with BLE modules has enabled the development of efficient wireless voltmeter solutions. This paper provides an in-depth analysis of BLE voltmeter technology, discussing communication challenges, power efficiency concerns, and its widespread applications in industrial automation, automotive technology, smart grids, and renewable energy. BLE-based voltage monitoring is expected to play a crucial role in the next generation of smart measurement systems, particularly in Internet of Things (IoT)-based monitoring frameworks.

Keywords: Wireless Bluetooth Low Energy (BLE), Voltage Monitoring, Arduino, Real-time Data Transmission, Industrial Applications, Wireless Communication, Cost-effective Monitoring, Embedded Systems, Smart Grid Technology, IoT, Power Efficiency, Sensors, Energy Management, Smart Metering, Power System Monitoring, Renewable Energy..

INTRODUCTION

Wireless technologies have significantly improved monitoring and control systems, particularly in electrical measurements. Traditional voltage meters require wired connections, which often lead to inflexibility and physical constraints. With the evolution of wireless technologies, the focus has shifted toward remote, real-time voltage monitoring systems that enhance convenience and efficiency. Among various wireless communication methods, Bluetooth Low Energy (BLE) has gained prominence due to its low power consumption, cost-effectiveness, and ease of integration with embedded systems (IEEE, 2020; Johnson et al., 2019).

Arduino-based platforms combined with BLE modules such as HC-05 and HM-10 have emerged as widely used solutions for designing wireless voltmeters. These systems capture analog voltage data, convert it into digital form, and transmit it wirelessly to a mobile device or computer (Williams et al., 2018; Varma & Kumari, 2020). This paper presents a detailed review of BLE-based wireless voltmeter systems, covering their working principles, applications, challenges, and future directions.

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DESIGN AND IMPLEMENTATION OF BLE-BASED VOLTMETER SYSTEMS

Fundamental Working Principle

A BLE-based voltmeter system consists of three core components:

- Voltage sensing circuit (e.g., voltage divider)
- Microcontroller unit (e.g., Arduino Nano, ESP32)
- BLE module for wireless transmission

The voltage measurement process involves converting high input voltages into a range suitable for an analog-to-digital converter (ADC). The Arduino ADC (0-5V) is commonly used, requiring a voltage divider circuit to scale down higher voltages (IEEE, 2020). The microcontroller processes this data and transmits it over BLE to a paired mobile device or computer for real-time monitoring (Shaban et al., 2019; Waghmare & Deshmukh, 2017).

The advantage of BLE lies in its low energy consumption, which extends the operational life of battery-powered voltage meters (Lee & Shin, 2020). Additionally, BLE's short-to-medium range communication allows for reliable indoor and industrial monitoring applications (Garcia et al., 2021).

Integration of BLE with Arduino

The integration of BLE modules with Arduino-based voltmeters has been explored in multiple studies. For instance, Williams et al. (2018) designed a BLE-based real-time voltage measurement system that enabled remote monitoring of industrial equipment. The system utilized BLE modules (HC-05, HM-10) to wirelessly transmit voltage data to a centralized monitoring platform.

Other studies (Varma & Kumari, 2020) have demonstrated multi-device integration using BLE mesh networks, where multiple voltage sensors communicate with a central BLE gateway. This feature is particularly useful in industrial automation, power grids, and renewable energy systems (Shaban et al., 2019).

APPLICATIONS OF BLE-BASED WIRELESS VOLTMETER SYSTEMS

Industrial Monitoring Systems

Industries rely on voltage monitoring to detect electrical fluctuations and prevent equipment failure. BLE-based wireless voltmeters enhance predictive maintenance, reducing downtime and maintenance costs (Varma & Kumari, 2020).

For example, BLE-enabled voltmeters deployed in manufacturing plants allow engineers to monitor real-time voltage trends across multiple devices. This data can be processed using AI-driven predictive analytics to anticipate equipment malfunctions before they occur (Zubair et al., 2020).

Automotive Applications

BLE-based voltage monitoring plays a crucial role in electric vehicles (EVs). These systems track battery voltage levels, ensuring optimal charging and discharge cycles (Lee & Kim, 2020).

A study by Lee and Shin (2020) highlighted the use of BLE voltmeters in EV charging stations, where real-time voltage monitoring helped optimize charging cycles, reducing energy wastage and extending battery lifespan.

Smart Grid and Renewable Energy

BLE-based wireless voltmeters have been implemented in smart grids and renewable energy applications (Shaban et al., 2019). For instance, BLE sensors can monitor voltage levels in solar panels and wind turbines, transmitting data to a central monitoring system for real-time adjustments (Garcia et al., 2021).

A study by Bhandari & Saini (2019) explored BLE-based monitoring in solar farms, concluding that such systems significantly improved energy efficiency and reliability.

Consumer Electronics and IoT Devices

BLE-based wireless voltmeters have also found applications in consumer electronics, particularly in smart home automation and IoT-enabled devices (Zhang et al., 2020). BLE voltmeters embedded in smart plugs and home energy meters allow users to track energy consumption via a mobile app, improving energy management.

CHALLENGES AND LIMITATIONS

Communication Range

Although BLE theoretically supports a 100m range, real-world applications suffer from signal attenuation due to walls and interference (Patel et al., 2019). A BLE mesh network can overcome this limitation by relaying data through multiple nodes, effectively extending coverage (Brown & Baugh, 2020).

Power Consumption

Despite BLE's low power consumption, battery life remains a concern in long-term monitoring applications. Optimizing BLE systems with deep sleep modes and energy harvesting techniques (e.g., solar charging) has been proposed to extend battery life (Russell & Stojanovic, 2017).

CONCLUSION

The integration of Bluetooth Low Energy (BLE) with wireless voltmeter systems has enhanced electrical monitoring across multiple industries. BLE-based voltmeters provide a cost-effective, low-power, and real-time solution for industrial automation, electric vehicles, smart grids, and IoT applications. However, challenges such as limited range and power constraints require further optimization. Future advancements in BLE technology, AI-driven analytics, and energy-efficient designs will further improve the efficiency and scalability of BLE-based voltage monitoring systems.

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CONFLICTS OF INTEREST

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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