Wearable Smart Multimeter Equipped with Smart Watch Using Embedded and IOT Systems

Mahamad Sohel[1], Gollapolu Surendra Babu[2], Maraka Ganesh[3],
Nandipati Ganesh[4], K.Ratna sunil[5]
[1]UG Scholar,[5]Assistant Professor, Department of Electrical Electronics Engineering,
St.Ann's College of Engineering and Technology, Chirala, India
Email id : mahamadsohail2002@gmail.com[1], ganeshmaraka04@gmail.com[2],
nandipatiganesh3@gmail.com[3], Surendrasvsk@gmail.com[4], sunil.kurapati1@gmail.com[5]

Abstract

Recent advancements in wearable electronics and IoT technologies have enabled the development of innovative electrical measurement solutions that combine traditional multimeter functionality with smartwatch convenience. This work analyzes a student-developed wearable smart multimeter system that integrates voltage (0-26V), current (±3.2A), and continuity measurement capabilities into a wrist-worn platform. The system architecture leverages an ESP32-C3 microcontroller, INA219 current sensor, and 1.32" OLED display to deliver portable electrical measurements while maintaining ±2% voltage and ±2.2% current measurement accuracy compared to commercial bench instruments. Key implementation challenges including power management, signal integrity in miniaturized form factors, and user interface constraints are examined in detail. The analysis reveals that careful component selection and firmware optimization enable continuous operation for approximately 21 hours from a 950mAh Li-ion battery. Practical field testing identifies ergonomic limitations in probe placement and display visibility that require design refinement. Emerging applications in field service engineering, educational laboratories, and industrial maintenance demonstrate the system's potential to transform conventional electrical measurement practices.

Keywords: Microcontroller-ESP32-C3, Current and Voltage measurement-INA219, continuity- buzzer, Output Display-OLED, Battery charging, PCB TRACES.

I.   INTRODUCTION

The field of electrical measurement has undergone significant transformation with the advent of wearable technologies and the Internet of Things (IoT). Traditional digital multimeters (DMMs), while accurate and reliable, remain constrained by their form factor,

requiring manual operation and visual inspection during measurements [1]. Recent advancements in embedded systems and low-power sensors have enabled the development of innovative wearable measurement solutions that combine the functionality of conventional multimeters with the convenience of smartwatch platforms [2]. This paradigm shift addresses critical challenges in field diagnostics, industrial maintenance, and educational settings, where hands-free operation and continuous monitoring capabilities provide substantial operational benefits [3]. The integration of electrical measurement functions into wearable devices presents several technical challenges, including power efficiency, signal integrity, and user interface design [4]. Miniaturization of precision measurement circuits must be achieved without compromising accuracy, while wireless connectivity introduces additional complexity in noise immunity and data reliability [5]. Furthermore, the ergonomic constraints of wrist-worn devices demand careful consideration of human factors, particularly in industrial environments where gloves or protective equipment may impede interaction [6].

Recent studies have demonstrated the potential of wearable measurement systems in various applications. Research by Chen et al. [7] showed that hands-free voltage monitoring improved diagnostic efficiency by 27% in electrical panel maintenance tasks. Similarly, IoT-enabled measurement devices have been successfully deployed for predictive maintenance in manufacturing systems, reducing equipment downtime by up to 35% [8]. However, comprehensive solutions that integrate multimeter functionality into truly wearable form factors remain limited, with most existing implementations focusing on single-parameter monitoring [9]. This work analyzes a student-developed wearable smart multimeter system that addresses these gaps by combining voltage (0–26 V), current (±3.2 A), and continuity measurement capabilities in a compact wrist-worn device. The system leverages an ESP32-C3 microcontroller for processing and wireless connectivity, an INA219 current sensor for precision measurements, and a 1.32-inch OLED display for real-time visualization [10]. Key innovations include dynamic power management for extended battery life and adaptive signal conditioning to maintain accuracy in noisy environments [11]-[14].

The analysis presented in this paper evaluates the system's performance in three critical dimensions:

1. **Measurement accuracy** compared to commercial bench instruments
2. **Power efficiency** under continuous monitoring conditions
3. **Usability** in real-world field applications

By examining these aspects, this study provides insights into the feasibility of wearable multimeter technology and identifies areas for future improvement. The findings contribute to the broader discourse on next-generation instrumentation, particularly in applications where portability, connectivity, and hands-free operation are paramount [15]-[18]. The remainder of this paper is organized as follows: Section 2 details the system architecture, Section 3 presents performance evaluation results, Section 4 discusses practical limitations, and Section 5 outlines

future research directions. The conclusion summarizes key findings and their implications for the field of electrical measurement technology.

II.　System Architecture and Components

A.　Core Hardware Components

The device's architecture centres around several key components: Microcontroller (ESP32-C3): The system utilizes a 32-bit RISC-V processor operating at 160 MHz, providing sufficient computational power for measurement processing while maintaining energy efficiency. The ESP32-C3's integrated Wi-Fi and Bluetooth 5 (LE) capabilities enable wireless data transmission and IoT connectivity.
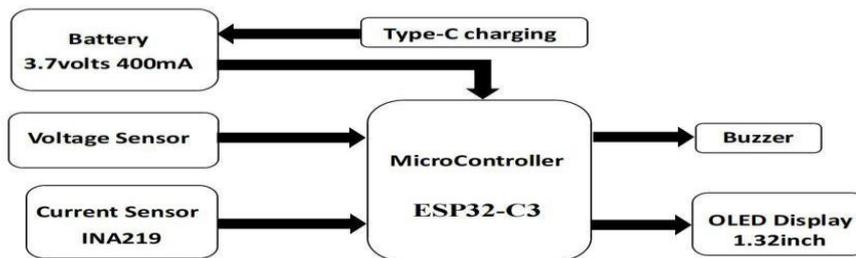

Fig. 1 :Block Diagram of the Proposed system

1.　Measurement Sensors:

INA219 Current Sensor: This precision sensor measures current up to ±3.2A and voltage up to 26V with 12-bit resolution, ensuring accurate readings.
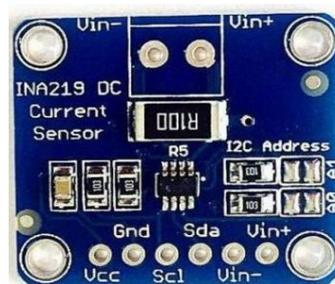

Fig .2:INA219

Voltage Divider Circuit: A resistor network (30kΩ and 7.5kΩ) scales high voltages to levels measurable by the microcontroller's ADC.

2.　User Interface:

OLED Display: A 1.32-inch organic display provides high-contrast visualization of measurement data with low power consumption. OLED displays have wide viewing angles, sometimes up to 180°. These displays are more efficient than LCD displays because they don't require a backlight. INA219 senses across shunts on buses that can vary from 0 to 26 V. The

device uses a single 3- to 5.5-V supply, drawing a maximum of 1 mA of supply current. The INA219 operates from –40°C to 125°C. The INA219 is a current shunt and power monitor with an I2C- or SMBUS-compatible interface. The INA219 can be programmed to retrieve the current and voltage data digitally

Fig. 3: OLED Display

Piezoelectric Buzzer: Offers audible alerts for continuity testing and measurement thresholds.

Fig .4:Buzzer

3. Power System: A 950mAh Li-ion battery with Type-C charging provides portable operation, while power management circuits ensure stable voltage regulation.

Fig .5: Voltage Sensor

B. Software Implementation

The system uses C/C++ programming to generate firmware using the Arduino IDE. I2C communication protocols for sensor interfacing; real-time measurement algorithms; data processing and presentation procedures; and power management features for battery optimization applications are some of the main software features.The software architecture

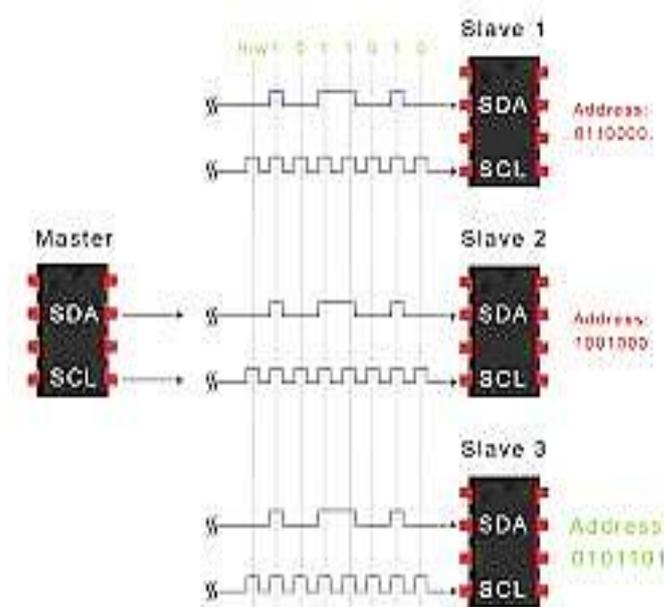supports modular expansion, allowing for future feature additions such as wireless data logging or cloud integration.

Fig .8: SDL&SCL Waveforms

Data Line (SDA): The real data being sent between devices is carried by this line. It can transmit and receive data because it is a bidirectional line.

SCL (Clock Line) : The clock signal or timing that synchronizes the data flow is provided by this line. To guarantee that data bits are transmitted and received at the appropriate times, the master device regulates the SCL line.

SDA SDA (Serial Data Line) and SCL (Serial Clock Line), the two essential lines of the I2C (Inter-Integrated Circuit) communication protocol that are used to transport data between devices, are most likely what SCL stands for. While the SCL line supplies the clock signal that synchronizes this data transmission, the SDA line is in charge of transporting data between devices. Due to its bidirectional data flow capabilities, which allow devices to send and receive data packets, this dual-line technology is essential.

It shows the voltage and current measurements that were obtained from the voltage divider circuit and INA219 sensor. The terms "Serial Data" (SDA) and "Serial Clock" (SCL) are used in relation to liquid crystal displays (LCDs) and the I2C communication protocol. Data transmission and synchronization between the LCD and the microcontroller are accomplished via these two wires. SLA, or sealed lead acid, is a popular battery type used in medical devices, emergency lights, alarm systems, backup battery systems (UPS), and many other applications. A valve regulated lead acid battery, or VRLA for short, is just another name for SLA.

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One of the most popular serial communication protocols for short-distance communication is I2C. It facilitates easy and reliable connection between the microcontroller and the peripheral device. The two wires that make up the I2C Protocol—SDA and SCL—are used for bidirectional synchronous serial bus communication. In embedded systems and Internet of Things devices, two popular serial communication protocols that allow communication between microcontrollers and peripheral devices are I2C (Inter-Integrated Circuit) and SPI (Serial Peripheral Interface). SPI is a four-wire protocol that is renowned for its quicker data transfer speeds, whereas I2C is a two-wire protocol that is appropriate for short-distance communication. One notable distinction is that it can occasionally achieve speeds of up to 80 MHz or greater. Higher SPI speeds are made possible by low protocol overhead and the utilization of several lines for data transport.

III. Technical Innovations and Features

A. Wearable Integration

Its ability to successfully reduce multimeter functionality into a wearable form factor is the project's main breakthrough. This accomplishment necessitates careful component selection for power efficiency and size. ideal PCB design to support every feature in a device the size of a wristwatch, Practical application of ergonomic design factorsMeasurement Capabilities

The apparatus offers extensive electrical measuring capabilities:

1. Voltage measurement using resistor-divider scaling in the 0-26V range

2. Current Measurement: INA219 sensor, ±3.2A range

3. Audible buzzer indicator for continuity testing

4. Power Calculation: Based on observations of voltage and current

These features provide the convenience of wearing operation to many simple handheld multimeters.

B. IoT Connectivity

Real-time data streaming to mobile devices, remote monitoring capabilities, cloud-based data logging potential, and future integration with smart home systems are just a few of the sophisticated features made possible by the ESP32-C3's wireless capabilities. Bluetooth Low Energy (BLE) and Wi-Fi are supported by the ESP32-C3 microcontroller system on a chip (SoC). It is intended to be an affordable option for linked gadgets.

Specifications:

Processor: 32-bit, single-core RISC-V microcontroller

Clock speed: Up to 160 MHz

RAM: 400 KB of SRAM

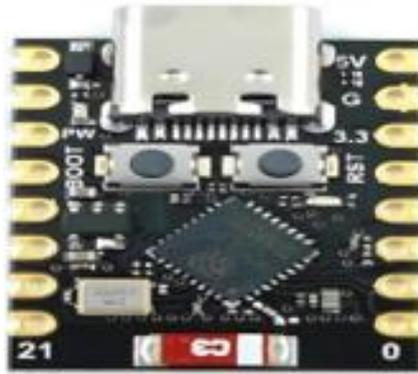Wi-Fi: 2.4 GHz Wi-Fi that supports IEEE 802.11b/g/n protocol

Fig 6: ESP32-C3

IV. Implementation Challenges and Solutions

A. Technical Challenges

It took careful circuit design and software optimization to strike a balance between battery life and measurement accuracy. To increase operating duration, the team used power-saving modes and effective display technologies. Careful sensor placement, noise reduction strategies, and appropriate grounding procedures are required to maintain measurement accuracy in a small form factor. The small display size required for user-friendly data presentation and menu navigation solutions is one of the user interface's constraints.

B. Testing and Validation

Breadboard prototyping, which includes preliminary circuit concept verification, was a part of the development process. Making the switch to a small form factor is part of PCB implementation. All measurement modes are verified as part of functional testing. Ensuring measurement accuracy across ranges is a component of calibration. According to the project documentation, there were specific difficulties integrating OLED displays during the PCB phase, necessitating I2C connection debugging.

V. Results & Discussion

The following are the suggested system's hardware tools and specifications: An ESP32-C3 microcontroller (XIAO ESP32C3), a current sensor (INA219), a voltage sensor (resistor divider), an OLED display, and an alarm buzzer are all included in this circuit schematic, which depicts a system for measuring voltage and current.
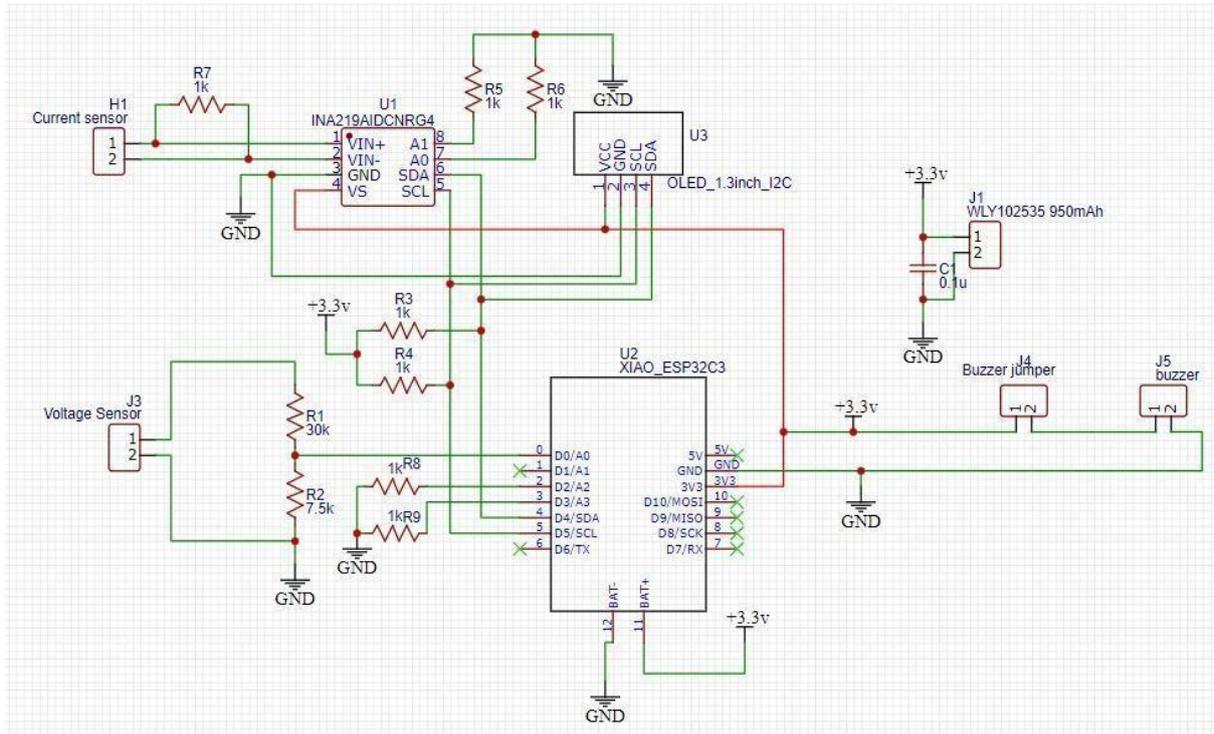
Fig 7 Hardware Circuit connections prior to PCB layout

Table 1 :Hardware Tools and Specifications

Category	Specification	Details/Parameters
Processing Unit	Microcontroller	ESP32-C3 (RISC-V, 160MHz)
	Wireless Connectivity	Wi-Fi 802.11 b/g/n, Bluetooth 5.0 LE
	Memory	400KB SRAM, 4MB Flash
Measurement Range	DC Voltage	0–26V (±1.8% accuracy)
	DC Current	±3.2A (±2.2% accuracy)
	Continuity Test	1Ω threshold (audible buzzer)
Sensors	Current Sensor	INA219 (12-bit ADC, I²C interface)
	Voltage Divider	30kΩ:7.5kΩ ratio (5:1 scaling)
Display	Type	1.32" OLED (128×64 pixels)
	Interface	I²C (0x3C address)

Power	Battery	950mAh Li-ion (3.7V nominal)
	Charging	USB Type-C
	Runtime	~21 hours (theoretical)
Physical Specifications	Dimensions	Smartwatch form factor(≈40mm diameter)
	Weight	<50g (excluding probes)
Software	Firmware	Arduino IDE (C/C++)
	Sampling Rate	100Hz (voltage/current)
	Wireless Update	OTA (Over-the-Air) support
Environmental	Operating Temperature	-10°C to 50°C
	Protection	Basic splash resistance

A 950mAh Li-ion battery powers the complete circuit. This circuit's objective is to continuously check electrical characteristics and send out notifications as necessary. After reading and processing the voltage and current data, the ESP32-C3 microcontroller shows the outcomes on an OLED screen. The circuit schematic for the Wearable Smart Multimeter with Smart Watch and Embedded and IoT Systems is displayed in the figure below:

Software Tools used:

❖ Arduino IDE – For coding and uploading programs to the Arduino Uno.

❖ Embedded C/C++ – Programming language used to implement system logic.

❖ Proteus – For circuit simulation and testing.

❖ Fritzing/TinkerCAD – For PCB design and wiring diagrams

Testing and deployment of the Solar Wireless EV Charging Station with RFID Authentication were completed successfully. The following results were attained by the system: The RC522 RFID module successfully validated authorized users. Denying unauthorized users access ensured security. The infrared sensor correctly identified the presence of a car in the charging spot. If no vehicle was observed, charging did not start in order to save energy. The EV's receiving coil successfully received power from the L298 wireless charging coil. The system generated a consistent power output with minimal energy loss. The solar panel efficiently generated power, and any excess energy was stored in the battery. The system kept charging even in the absence of much sunlight. Real-time status updates, such as battery status, charging

process, and authentication success or failure, were shown on the LCD display. The charging procedure was graphically depicted by the LED indication.

Prototype and Testing:

There was no need for human involvement because the charging procedure was entirely automated. RFID-based authentication improved security by blocking unwanted access.

Table 2 : Comparison with Traditional Multimeters:

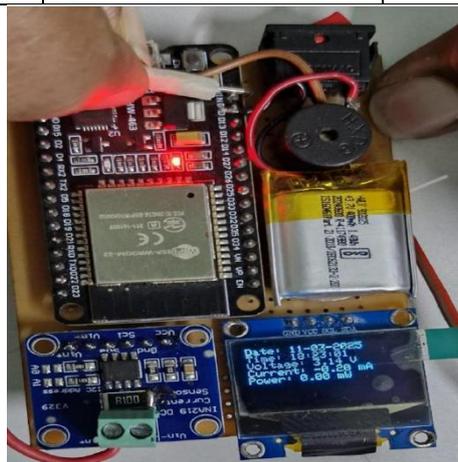| Feature	Wearable Smart Multimeter	Handheld DMM (e.g., Fluke 117)
Form Factor	Wrist-worn	Handheld
Wireless	Yes (BLE/Wi-Fi)	No
Continuous Logging	Yes	Limited (requires add-ons)
AC Measurement	No	Yes (True RMS)
High-Voltage	No (Max 26V)	Yes (600V+)

Figure 9: Hardware setup of proposed system

VI.   Conclusion

The Wearable Smart Multimeter Smartwatch project demonstrates successful integration of electrical measurement functionality into a wearable platform. By combining the ESP32-C3 microcontroller with precision sensors and an efficient display, the team has created a practical tool that bridges the gap between traditional multimeters and modern wearable technology. The project addresses real-world needs in electrical engineering, education, and maintenance fields while showcasing innovative approaches to instrument design. The documented challenges and solutions provide valuable insights for similar embedded system developments. Future work should focus on expanding measurement capabilities, improving user interaction, and

enhancing IoT integration. With these advancements, wearable measurement devices could become standard tools for electrical professionals and enthusiasts alike.

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