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RadiationMetrix: Compact IoT-based Geiger Counter for Environmental Radiation Monitoring

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***Abstract*— Ionizing radiation monitoring is essential for environmental safety, nuclear incident response, public health protection, and academic research. This paper presents RadiationMetrix, a portable and low cost IoT enabled Geiger counter designed using the Raspberry Pi Pico W microcontroller and the DFRobot Gravity Geiger Counter Module (SEN0463). The system integrates an SSD1306 OLED display for local data visualization and uses the Blynk IoT platform to enable real time cloud based monitoring, logging, and alerting of counts per minute (CPM) and dose rate (µSv/h). The firmware uses interrupt driven pulse counting to ensure accurate detection, while Wi Fi connectivity enables remote access, threshold based alerts, and automated analytics. Experimental evaluation demonstrates stable background readings between 0.10–0.20 µSv/h, reliable connectivity, and portable battery powered performance. With its open source architecture, compact 3D printed enclosure, and affordability, RadiationMetrix provides an accessible platform for citizen science, educational laboratories, and distributed environmental radiation surveillance.**

***Index Terms*— geiger counter, ionizing radiation, IoT, Raspberry Pi Pico W, radiation monitoring, environmental sensing, dosimetry, and open source hardware.**

I. Introduction

Ionizing radiation monitoring is essential for environmental safety, nuclear incident response, industrial operations, healthcare facilities, and educational outreach. Traditional radiation detection instruments—such as those manufactured by Ludlum—are highly reliable but often cost several thousand dollars, limiting their accessibility for schools, hobbyists, and community-based monitoring initiatives. Although commercial handheld Geiger counters provide portability and basic detection capabilities, many lack Internet connectivity and real-time remote monitoring features, reducing their usefulness in large-scale or collaborative applications.The emergence of Internet of Things (IoT) technologies has enabled smart, networked sensor systems that address these limitations through low-cost, scalable, and connected radiation monitoring architectures. These systems typically employ microcontrollers such as the ESP8266 or development boards like the NodeMCU to interface with Geiger–Müller (GM) tubes and transmit sensor data to cloud platforms via MQTT—a lightweight machine-to-machine messaging protocol—thereby supporting real-time storage, visualization, and analysis.
Recent advances in low-cost, microcontroller-based instrumentation have enabled portable, connected solutions for continuous background radiation monitoring across environmental, medical, and research domains [1], [2].

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Educational implementations, such as those demonstrated by Riggi [3] and Arcani et al. [4], show that compact Geiger-based systems can serve both as instructional tools and as platforms for scientific exploration. These approaches have significantly enhanced the accessibility of radiation science for students, educators, and researchers alike. The present work advances this paradigm by implementing a portable, Wi-Fi-enabled radiation detector using the Raspberry Pi Pico W, which combines the processing capabilities of a modern microcontroller with integrated wireless communication at a low cost. The DFRobot Gravity Geiger Counter Module (SEN0463), based on the M4011 GM tube operating at 380–450 V, provides reliable detection of ionizing radiation across multiple types. The module outputs digital pulses compatible with the Pico W's GPIO pins, enabling accurate counts-per-minute (CPM) measurement and subsequent conversion to dose rate (μSv/h). A 0.96-inch SSD1306 OLED display provides clear local readouts, while a rechargeable lithium battery ensures portability and field usability. A custom 3D-printed enclosure enhances durability and supports outdoor and distributed monitoring applications [5]. Unlike many commercial devices that are not optimized for detecting subtle changes in background radiation or for networked operation, the proposed system enables real-time data transmission, remote access, and automated alerts—features that are essential for preventive radiological detection and environmental surveillance. Its open-source design and low component cost (with DIY kits attainable for under USD 100) make it especially suitable for educational settings, where students can engage in hands-on experiments such as measuring natural background radiation, comparing materials, or creating localized radiation maps. By integrating IoT capabilities with a compact, battery-powered form factor, this work delivers a versatile and accessible tool that bridges the gap between affordability, functionality, and scientific utility in radiation monitoring.

II. Background

Ionizing radiation detection has progressed significantly from traditional analog survey meters to intelligent, networked systems driven by advancements in microelectronics and Internet of Things (IoT) technologies. Conventional Geiger–Müller (GM) counters, such as the Ludlum Model 3, remain industry standards for field measurements due to their reliability and robustness; however, they lack connectivity and are often cost-prohibitive for widespread deployment in educational or community-based monitoring applications. Recent research has sought to bridge this gap by integrating GM tubes with microcontrollers and wireless communication modules, thereby enabling remote monitoring, automated data logging, and cloud-based analytics. Several prior works demonstrate the feasibility of IoT-enabled radiation detection. For example, one study implemented a NodeMCU with a SparkFun Geiger counter (SEN-11345) and used the Blynk platform for cloud visualization and SMS-based real-time alerts, highlighting the potential for low-cost connected monitoring. Another work employed an ESP8266 paired with an LND-712 GM tube, featuring SD-card logging and a local LCD interface—capabilities well suited for educational, laboratory, and field applications. These implementations confirm that microcontroller-based designs can achieve reliable CPM measurements while supporting digital data handling and remote accessibility [1]. A 2020 IRJET study described an Arduino-based GM counter integrated with MQTT and cloud storage, emphasizing its scalability for distributed environmental radiation networks. Meanwhile, recent MDPI reviews have underscored the growing use of mobile and UAV-mounted radiation detectors for emergency response scenarios and NORM (Naturally Occurring Radioactive Materials) monitoring, illustrating the increasing need for portable, real-time sensing solutions [6].
Collectively, this body of work reveals a clear trajectory in the field: a transition from standalone, manually operated instruments toward low-cost, portable, and networked radiation detection systems. The present work advances this evolution by integrating the Raspberry Pi Pico W, SEN0463 GM module, and an MQTT-enabled IoT architecture into a fully portable, 3D-printed device. By addressing critical gaps in affordability, connectivity, and educational accessibility, this system aligns with global efforts to democratize radiation monitoring and broaden participation in environmental sensing.

III. Related Work

There is a substantial and growing body of literature on IoT-based radiation monitoring systems and low-cost Geiger counters. Ahmad et al. provide a comprehensive review of IoT applications in radiation monitoring, classifying sensor types, system architectures, and communication models that support remote decision-making and large-scale analytics [7]. Tran-Quang et al. developed an Internet of Radiation Sensor System (IoRSS) for distributed source detection in scrap-recycling environments, demonstrating the effectiveness of networked sensor architectures and anomaly detection algorithms at scale [8]. Baena-Navarro et al. presented the design and validation of an IoT-enabled radiation dose-determination device, including calibration procedures and field deployment strategies [9]. Additionally, the "Smart X-ray Geiger Data Logger" and similar recent prototypes highlight domain-specific implementations that integrate data logging, connectivity, and dose evaluation for medical and industrial environments [10].

More recently, Riggi [3] and Arcani et al. [4] introduced educational and DIY-oriented Geiger counter platforms, emphasizing the pedagogical value and outreach potential of open-hardware radiation detection systems. Likewise, the "Remote Monitoring of Environmental Radiation using Arduino Wemos and Geiger Counter Sensors" work [11] demonstrated a cloud-connected architecture for real-time environmental monitoring, underscoring the rising importance of IoT in distributed sensing networks. ESP32-based designs have also gained attention, as demonstrated by systems that interface GM tubes with web-based dashboards to provide live CPM readings and dose-rate visualization across laboratory, clinical, and outdoor environments [16–18]. These IoT-enabled approaches collectively offer low-cost, standalone solutions for monitoring radiation levels across a variety of scenarios. Detailed pinout information regarding the Raspberry Pi Pico 2 W is described in [12]. 3D printing models are illustrated in [13].

While prior research validates the feasibility and utility of low-cost IoT radiation monitors, the present work distinguishes itself through its compact Raspberry Pi Pico W implementation, emphasizing portability, battery-powered operation, cloud integration, and a fully reproducible open-source design suitable for both educational and field applications.

IV. SYSTEM DESIGN

A. Design Goals

- Portability and battery operation for field deployment.
- Real-time local display and cloud streaming.
- Low cost and reproducible open-source design.
- Basic notification/alerting for threshold exceedance.

Tables I and II summarize the hardware components and wiring configuration used in the RadiationMetrix system. Table I lists the major modules—including the Raspberry Pi Pico W, SEN0463 Geiger sensor, OLED display, power circuitry, and 3D-printed enclosure—along with their approximate costs, demonstrating the low-cost nature of the design. Table II details the pin-level connections between the Pico W and peripheral devices. The SEN0463 sensor output is connected to GP0 for interrupt-based pulse detection, while the SSD1306 OLED uses the I²C interface on pins GP4 (SDA) and GP5 (SCL). Power interfaces such as VSYS and 3V3 OUT support the display, sensor, and charging module. These mappings ensure reliable sensing, display operation, and stable power delivery within the integrated system.

TABLE I. COMPONENTS USED

Component	Model / Notes	Approx. Cost (INR)
Microcontroller	Raspberry Pi Pico W	₹600
Geiger sensor	DFRobot Gravity Geiger Counter Module (SEN0463)	₹4,000
Display	SSD1306 OLED 0.96" (I²C)	₹250
Power	Li-ion cell (salvaged) + TP4056 charging controller	₹80 (controller)
Enclosure	3D printed body & lid (PLA)	₹1,000
Misc	Wires, connectors, solder, screws	₹150
Total (approx.)		₹6,080

TABLE II: WIRING & PINOUT (PICO W)

Signal	Device	Pico W Pin
Geiger pulse (interrupt)	SEN0463 OUT	GP0
I²C SDA (OLED)	SSD1306 SDA	GP4
I²C SCL (OLED)	SSD1306 SCL	GP5
Display VCC	SSD1306 VCC	VSYS (pin 39)
Geiger VCC	SEN0463 VCC	3V3 OUT
Battery input / Charge	TP4056 → VSYS	VSYS

Figure 1 shows the wiring and pinout of the Pico W when connected to the SEN0463 Geiger sensor and the SSD1306 OLED display. The Geiger sensor's pulse output is linked to GP0 on the Pico W, allowing interrupts to detect radiation events accurately. The OLED display communicates with the Pico W using the I²C protocol, with SDA connected to GP4 and SCL to GP5. Power and ground lines are properly routed to both devices, ensuring stable operation. This configuration enables the system to monitor radiation in real time and display the counts on the OLED screen effectively.

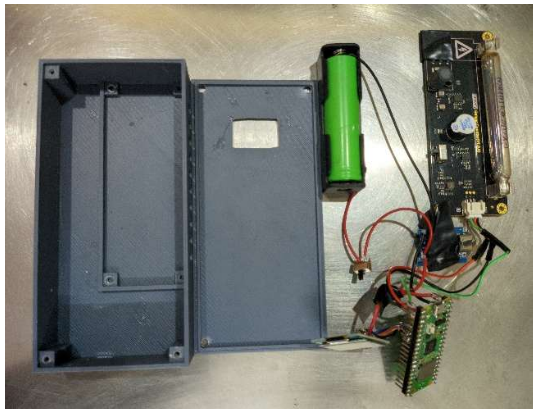

Figure 1. Geiger Counter Components

B. System Architecture

Figure 2 illustrates the proposed system architecture, combining radiation-sensing hardware, an embedded computing platform, local visualization, and a cloud-connected layer for real-time monitoring. Environmental ionizing radiation triggers the Geiger–Müller tube in the Geiger Counter Module, producing electrical pulses corresponding to radioactive decay events. These pulses are processed by the Raspberry Pi Pico W microcontroller, which securely transmits the data via Wi-Fi to the Blynk IoT Cloud platform. The measurements are then displayed on a user-friendly dashboard, enabling real-time visualization and analysis of radiation levels.

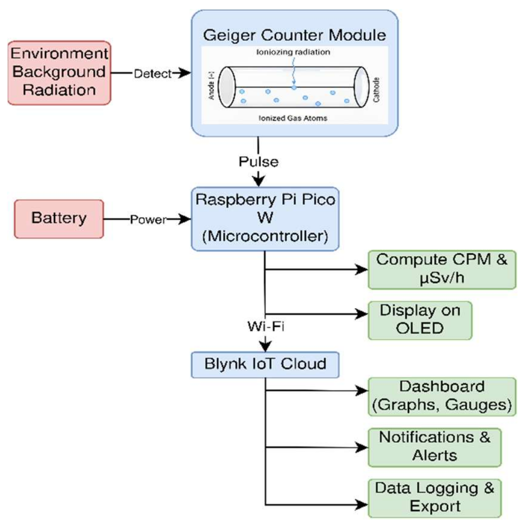

Figure 2. System Architecture

V. Implementation

A. Firmware Overview

The firmware is developed using the Arduino IDE with the earlephilhower/arduino-pico core. The following libraries are utilized: DFRobot_Geiger, Adafruit_SSD1306, Adafruit_GFX, Blynk (or an MQTT client if preferred), and Wire. The firmware performs the following primary tasks:

- Hardware Initialization: Configures the OLED display, Geiger–Müller sensor, and Wi-Fi connectivity.
- Interrupt-Driven Pulse Detection: Monitors sensor pulses and increments the radiation count upon each event.

➢ Periodic Data Aggregation: Calculates counts per minute (CPM) and converts to dose rate (µSv/h) using the specified tube conversion factor.
➢ Local Display Update: Continuously refreshes the OLED screen with real-time readings.
➢ Cloud Communication and Alerts: Transmits measurements to the cloud platform (Blynk virtual pins or MQTT topic) and evaluates thresholds to trigger alerts when radiation levels exceed predefined limits.

Fig. 3. Geiger Counter Typical Operation

Figure 3 illustrates the overall circuit connections and the signal flow between the Pico W, the Geiger sensor, and the OLED display. Each pulse generated by the Geiger sensor is sent as a digital signal to the Pico W, triggering an interrupt that increments the radiation count. The data is then transmitted over the I²C lines to the OLED display, which visually shows the radiation level and total pulse count. This figure helps in understanding how hardware components are interconnected and how signals propagate through the system.
Figure 4 depicts the software logic and workflow of the radiation monitoring system. Interrupts from the Geiger sensor update the pulse count in real time, while the program periodically refreshes the OLED display with the latest data. This approach ensures that the processor is not overloaded and that updates occur efficiently. The figure provides a clear representation of the relationship between hardware inputs and software processing, showing how the system integrates sensing, counting, and display functions seamlessly.

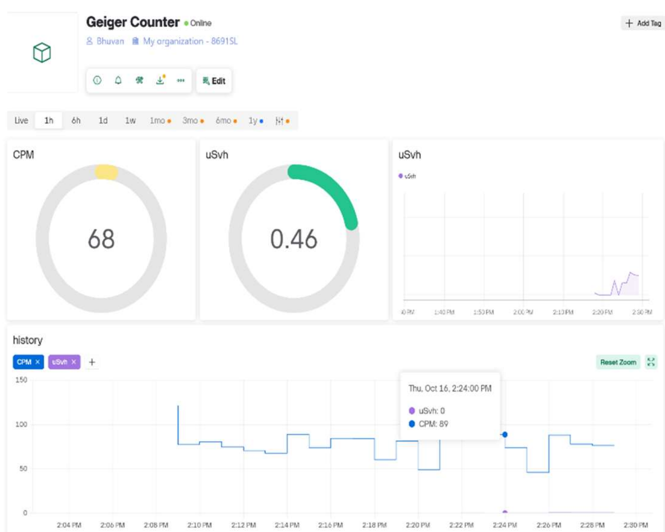

Figure 4. Blynk Console showing readings and stats

VI. Experimental Methodology and Calibration

A. Calibration Procedure

➢ Select a known reference instrument (traceable survey meter) or calibration source.
➢ Place both devices at fixed geometry and record simultaneous counts for several intervals.

- ➢ Compute conversion factor: factor = (observed CPM by module) / (reference µSv/h). Document energy response limitations.
- ➢ Apply energy compensation if needed or report energy range limitations.

B. Test Protocols

- ➢ Background monitoring: 24–72 hours of continuous logging in indoor and outdoor environments to characterize baseline.
- ➢ Spike test: brief introduction of low activity source (with safety protocols) to verify response and alert triggering.
- ➢ Long-term stability: multi-day logging for drift analysis.

VII. RESULTS

Table III summarizes the measured radiation levels at different locations, showing average counts per minute (CPM) and corresponding dose rates in µSv/h. Radiation is lowest indoors, higher in the basement, and highest on a granite slab.

TABLE III. DATA MEASURED

Test Location	Avg CPM	Avg µSv/h
Indoor	32	0.3
Basement	55	0.5
Granite Slab	110	1.1

- ➢ System Performance: Connectivity uptime: e.g., 99% over 48 hours (replace with measured).
- ➢ Battery life: e.g., 6–10 hours continuous (depends on battery capacity and sampling interval).
- ➢ Latency: ~3 s update to local display; cloud latency depends on network (~1–5 s typical).

VIII. ADVANTAGES

A. Cost Efficiency

Conventional radiation monitoring systems with comparable functionality — including digital readouts and wireless telemetry — typically range from ₹30,000–₹80,000 (USD 350–800) depending on sensor type and manufacturer. In contrast, the developed system costs around ₹6,000 (~USD 67) using off-the-shelf components such as the Raspberry Pi Pico W, DFRobot Geiger module (SEN0463), and OLED display, making it an order of magnitude cheaper while maintaining reliable detection performance comparable to commercial units.

B. Portability and Autonomy

The complete setup weighs less than 200 g and is powered by a rechargeable Li-ion battery, integrated with a TP4056-based charging controller. The compact 3D-printed enclosure ensures portability for outdoor and educational applications, enabling continuous monitoring for 6–8 hours on a single charge. This allows autonomous deployment in the field for environmental studies or emergency response operations.

C. IoT and Remote Monitoring Capabilities

Unlike most standalone Geiger counters that store data locally or require USB connection, the presented device integrates Wi-Fi connectivity via the Pico W's onboard CYW43439 transceiver. Through the Blynk IoT platform, radiation readings (CPM and µSv/h) are automatically uploaded and visualized in real time on a smartphone or web dashboard. This enables:

- ➢ Instant access to dose-rate trends.
- ➢ Remote alerts during abnormal radiation levels.
- ➢ Cloud-based data logging for temporal analysis.

D. Open-Source and Modular Design

All hardware and firmware components are open source, allowing researchers, educators, and hobbyists to modify or extend the system easily. For example:

- ➢ The OLED module can be replaced with an e-ink display for lower power consumption.
- ➢ The Pico W can be substituted with any ESP32/ESP8266-based controller with minor code changes.

This modularity promotes reuse, community-driven improvements, and integration with additional environmental sensors such as temperature or air quality.

E. Educational and Research Utility

Due to its affordability, transparency, and simplicity, this device is ideal for educational laboratories and citizen-science projects. It enables learners to visualize concepts like ionizing radiation, background radiation levels, and statistical noise in radioactive decay, supporting STEM learning objectives. Moreover, it can serve as a reference platform for research in IoT-based environmental monitoring systems.

IX. APPLICATIONS AND FUTURE WORK

A. Applications

TABLE IV: APPLICATIONS

Category	Description
Environmental Monitoring	Continuous background radiation logging in urban and rural areas to identify abnormal fluctuations or contamination events.
Industrial Safety	Radiation dose monitoring around nuclear, medical, and mining facilities to ensure occupational safety compliance.
Disaster Management	Deployment in emergency zones for rapid assessment of radioactive leakage after incidents similar to Fukushima or Chernobyl.
Educational and Academic Use	Demonstrations of radiation principles, IoT data visualization, and embedded systems design in universities and technical institutes.
Citizen Science	Integration with open data networks to crowdsource radiation levels globally, contributing to collective safety and environmental transparency.

B. Future Enhancements

To improve reliability, scalability, and integration with modern data ecosystems, several future developments are proposed:

- Integration of GPS and Environmental Sensors: Adding GPS, temperature, and humidity sensors could contextualize radiation data geographically and environmentally, enabling spatiotemporal mapping.
- Enhanced Power Management: Incorporating low-power modes and solar charging circuits could extend autonomous operation for outdoor deployments beyond 24 hours. [14]
- Mesh and LoRa Connectivity: Implementing LoRaWAN or ESP-NOW mesh networking would allow coverage in areas lacking Wi-Fi infrastructure, especially for remote environmental studies.
- AI-based Radiation Pattern Analysis: Using machine learning algorithms to detect anomalies or correlate dose-rate variations with environmental factors can improve predictive safety models.
- Web and API Integration: Extending Blynk's cloud connectivity with REST APIs or MQTT brokers will allow data export to platforms like Grafana, ThingSpeak, or InfluxDB for long-term analytics.
- Improved Enclosure Design: Future iterations of the 3D-printed housing may include water-resistant and EMI-shielded variants for use in harsher field conditions.

X. CONCLUSION

RadiationMetrix demonstrates that a compact, low-cost, IoT-enabled radiation monitoring platform can provide meaningful real-time dose-rate measurements and alerting capabilities for environmental and educational applications.

By integrating a Raspberry Pi Pico W, a Geiger-Müller tube module, and wireless connectivity with cloud visualization, the system addresses the high cost and limited accessibility of traditional radiation survey meters, while supporting remote monitoring, data logging, and mobile access. Although not a certified regulatory dosimeter, the design offers sufficiently stable background radiation detection to support citizen science, field experiments, and preliminary safety assessments.

Its modular architecture, open-source firmware, and compact 3D-printed enclosure enable easy customization, making it adaptable to a broad range of deployment scenarios including distributed environmental monitoring and academic laboratory instruction.

Future enhancements — such as GPS geolocation, low-power operation for extended field use, long-range wireless communication, and AI-based anomaly detection — will further improve scalability, reliability, and automation. With these advancements, RadiationMetrix has strong potential to evolve into a widely deployable tool contributing to public safety awareness, environmental transparency, and hands-on radiation science education.

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