Real-Time Radiological Mapping and Remote Hazard Monitoring System Using ESP32-S3, Radiacode RC-110, and Cellular IoT

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ABSTRACT

Ensuring the safety of emergency response teams, first responders, and technical operators prior to their deployment in hazardous environments remains a critical challenge during industrial accidents, radiological incidents, and nuclear facility maintenance operations. Traditional scouting and surveying methods frequently expose personnel to unseen radiological threats and invisible airborne hazards due to a lack of prior intelligence. To fundamentally mitigate these life-threatening risks, this paper presents the design, implementation, and field evaluation of a low-cost, highly modular remote monitoring system tailored for real-time radiological data acquisition, robust cellular transmission, and advanced spatial visualization. The primary objective of this ongoing research is to develop a lightweight, adaptable sensing payload capable of autonomously scanning terrain and transmitting live telemetric data to a remote command center, thereby preventing the unnecessary exposure of human operators to high-risk areas.

The core hardware architecture of the current system centers on an ESP32-S3 microcontroller, which communicates seamlessly via Bluetooth Low Energy (BLE) with a high-performance Radiacode RC-110 scintillation spectrometer. For continuous and reliable long-range wireless communication, an integrated SIM7670G-4G cellular module is employed to transmit the acquired sensor data over standard cellular networks. To facilitate spatial data collection and evaluate mobility during the initial field testing phases, the hardware payload is temporarily deployed on an agile remote-controlled (RC) ground vehicle chassis. During active operation, precise geographical coordinates and real-time radiological measurements are

streamed continuously to a custom Geographic Information System (GIS) hosted on a dedicated virtual machine (VM). The GIS platform processes the incoming data feed utilizing spatial interpolation algorithms to dynamically render multi-layer, real-time radiation heatmaps. This critical feature enables safety commanders to instantly visualize radiological anomalies, identify localized hot spots, and accurately evaluate exposure boundaries from a safe, remote location.

Looking forward, the system architecture is deliberately designed for extensive scalability. Future development phases will incorporate the integration of multi-gas and particulate air quality sensors to provide comprehensive chemical and environmental hazard mapping. Additionally, the system will implement localized data logging mechanisms to ensure resilience against cellular network drop-outs, featuring an automated batch-upload recovery protocol upon network restoration. Ultimately, the physical payload will transition from the current RC platform to specialized unmanned aerial vehicles (UAVs) and advanced unmanned ground vehicles (UGVs) to navigate complex terrains. Initial results demonstrate that the synergy of affordable microcontrollers, high-precision scintillation detectors, cellular IoT connectivity, and modern GIS software creates an highly efficient, scalable, and indispensable tool for radiological protection, early threat detection, and the significant enhancement of situational awareness in critical infrastructures.