Integrated Optoelectronic System for Environmental Monitoring of Heavy Metals Using Engineered Bacteria

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Pollution caused by heavy metals is a major global concern because these substances persist in the environment, cannot be broken down naturally, and pose toxicity risks to both ecosystems and human health. Traditional methods for detecting heavy metals are highly accurate and sensitive, but they require expensive instruments, complex sample preparation, skilled operators, and laboratory conditions, which make them less suitable for field use or fast testing. To overcome these limitations, researchers have started exploring alternative sensing technologies that are cheaper, easier to use, portable, and capable of providing results in real-time. One promising option is the use of whole-cell bacterial biosensors. This approach relies on genetically engineered bacteria that produce a visible signal, such as bioluminescence or fluorescence, when they detect certain contaminants. Despite their potential, these biosensors face challenges such as weak signal detection, low stability, and difficulty in being used outside of the laboratory because the equipment for detecting their signals - like plate readers, fluorometers, or luminometers - is not portable or robust enough for field applications.

In this study, we present a novel and potentially portable optoelectronic system based on Silicon Photomultipliers (SiPMs), specifically designed for use with engineered bacteria to detect heavy metal pollutants. The system integrates both hardware components (for signal detection and power management) and software modules (for calibration and data analysis), making it suitable for on-site environmental monitoring while maintaining performance levels comparable to laboratory-grade instruments. The system was validated using low-intensity bioluminescent emissions produced by genetically engineered *E. coli* in response to mercury (Hg^{2+}) exposure. The results demonstrated excellent sensitivity, with the device capable of detecting Hg^{2+} concentrations as low as 0.25 μg/L - approximately four times below established regulatory limits. This ability to detect bioluminescent signals, combined with a customized and flexible data collection framework, makes the system highly adaptable. By changing the engineered bacterial strain, it can be reconfigured to detect different environmental contaminants, thus extending its range of potential applications.