New Approach to Safer Laboratory Waste Management: AI-Assisted Sensor System for Hazardous Chemical Recognition and Risk Prevention

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Chemical waste disposal in shared laboratories remains a major safety challenge because it often depends on handwritten labels, incomplete records, and user judgment. These limitations make it difficult to verify bottle contents and prevent incompatible mixing, while recent chemical incidents caused approximately $1 billion in property damage. This study proposes an integrated waste-management safety system centered on software-based tracking and hazard prevention, with a TENG-based liquid chemical recognition sensor for unknown or mixed waste. The software normalizes each chemical, uses AI to check incompatibility, guides users to the correct container, and records disposal history. For unlabeled or mixed waste, a TENG sensor identifies the contents before disposal. The sensor uses a metal electrode with chemically durable FEP and PTFE films as dual sensing channels, producing distinct triboelectric signatures for different liquids. Commonly used hazardous liquids, including hydrochloric acid and sodium hydroxide, were measured 50 times each and analyzed via FFT (Fast Fourier Transform). Within this recognition framework, each of the 12 target substances is evaluated separately using its characteristic FFT template, and the input spectrum is used to determine whether that substance is present or absent with a data-calibrated threshold. Each sample yields a consistent output for both pure and mixed inputs. Under 5-fold cross-validation, the system achieved a macro F1 score of 0.93 across the 12 targets and an accuracy of 0.96 comparable to prior TENG sensing studies. The system was deployed in a faculty laboratory for two weeks. With an initial cost of $150 and a replacement cost of $2, these results demonstrate a new deployable approach to chemical waste management.

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