Dissertation Defense

Development and optimization of a wireless portable nanoparticle-based sensor array system for non-invasive lung cancer detection

Dong Dinh, Industrial and Systems Engineering, PhD Candidate

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Abstract

This dissertation presents the development and optimization of a wireless portable nanoparticle-based sensor array system for non-invasive lung cancer detection through breath analysis. Lung cancer remains the leading cause of cancer-related mortality worldwide, with over 1.8 million deaths annually. Early detection is crucial, as five-year survival rates can reach 85% for stage I diagnoses compared to merely 15% for stage IV. Current detection methods face limitations including invasiveness, radiation exposure, high costs, and limited accessibility, creating an urgent need for alternative approaches.

The research was conducted in two phases. First, a wireless portable sensor array system was developed by integrating nanostructured chemiresistive sensors based on functionalized gold nanoparticles with a low-current multichannel electronics board and a Raspberry Pi. This portable system enabled real-time data collection, wireless transmission to cloud databases, and remote monitoring capabilities—key features for point-of-care applications. Extensive testing demonstrated the system's capability to differentiate between human breath samples with and without lung cancer-specific volatile organic compounds (VOCs), achieving classification accuracies up to 88% using machine learning algorithms. The wireless functionality facilitated continuous data collection across multiple sampling stations and environments, showcasing its potential for deployment in diverse clinical settings.

In the second phase, the system was optimized using a novel Fuzzy Genetic Algorithm (Fuzzy-GA) approach for feature selection. The optimized system was evaluated with real patient data from two distinct populations (Cooper University Hospital, USA, and Xiamen City First Hospital, China), demonstrating robust classification performance across different patient demographics and clinical contexts. The Fuzzy-GA method effectively reduced the number of required sensors while maintaining or improving classification accuracy, with the best models achieving up to 97% accuracy using Convolutional Neural Networks.

Comprehensive signal variation testing validated the system's resilience under challenging conditions, including Gaussian noise, amplitude modulation, baseline drift, cross-sensor interference, and random data loss. The system maintained high performance even with an 81% reduction in sensor count, demonstrating the effectiveness of the optimization approach.

This research contributes to the field of non-invasive cancer detection by developing a portable, wireless breath analysis system with potential applications in early lung cancer screening. The optimized sensor array system offers a promising alternative to conventional detection methods, with advantages including non-invasiveness, potential cost-effectiveness, and accessibility. Future research directions include large-scale clinical trials, longitudinal studies, integration with additional biomarkers, and exploration of applications for detecting other diseases.