Non-Invasive Disease Monitoring Breath-Based Diagnostic Device Utilizing Breath-Sensing Nanotechnology with Precision and Accuracy

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Abstract

Breathomics uncovers diverse compounds shaping unique breathprints for diagnosis. This research integrates machine learning and gas sensors in an innovative device for advanced sensing. A novel approach combines sensor arrays and nanomaterials to detect breath volatile organic compounds (VOCs). Challenges in adherence and standardization persist. An inventive nano-gas-sensing array targets VOCs detection for various diseases, optimizing functionality with algorithms. Real-world patient validation aligns the device with standards. In summary, breathomics revolutionizes disease detection, enhancing healthcare.

Background

The human breath is a vast cauldron of fumes—an intricate blend of approximately 3000 volatile organic compounds (VOCs) [1-7], collectively shaping one's unique breathomic fingerprint, or *breathprint*. This assembly of VOCs holds a profound potential, each compound offering its own insight into disease mutuality, rendering them an exceptional candidate for daily health monitoring and forming the cornerstone of breath-based diagnostics.

The realm of breath analysis has captivated researchers, yielding diverse approaches to harness the volatile qualities of breath. These endeavors span from designing portable disease-detecting breathalyzers to proposing novel, calibrative methods for breath-based data analysis. However, the pinnacle challenge remains synthesizing a precisely accurate and cross-selective, clinically validated sensor through meticulous sample collection—a pivotal gateway into the expansive field of breathomics.

This research embarks on a striving journey to not only conquer these challenges but also to forge visionary and enlightening, state-of-the-art mechanisms, serving as a beacon towards achieving non-invasive and cost-effective diagnostics.

Diabetes has been linked to breath composition, which inspired non-invasive diagnostic devices [2],[8-10]. Glucose and lipid buildup, coupled with compromised insulin, trigger stress responses, increasing compounds like carbon monoxide and acetone in breath [11-14]. Discomfort during traditional assessments leads to low patients' compliance [2],[15-17]. Non-invasive devices utilizing optical and nanomaterial sensing, particularly in breath analysis offers a convenient testing method [3],[15],[19-23]. Research targets diabetes types 1 and 2 breath biomarkers which reflect oxidative stress and metabolic shifts [16],[20-35]. Precise, continuous, and real-time monitoring of exhaled gases remains an area of importance in the field. Challenges include standardization and complexity, impacting reliability [20],[28-30] while understanding biomarkers enhances diagnostics [2],[31-34].

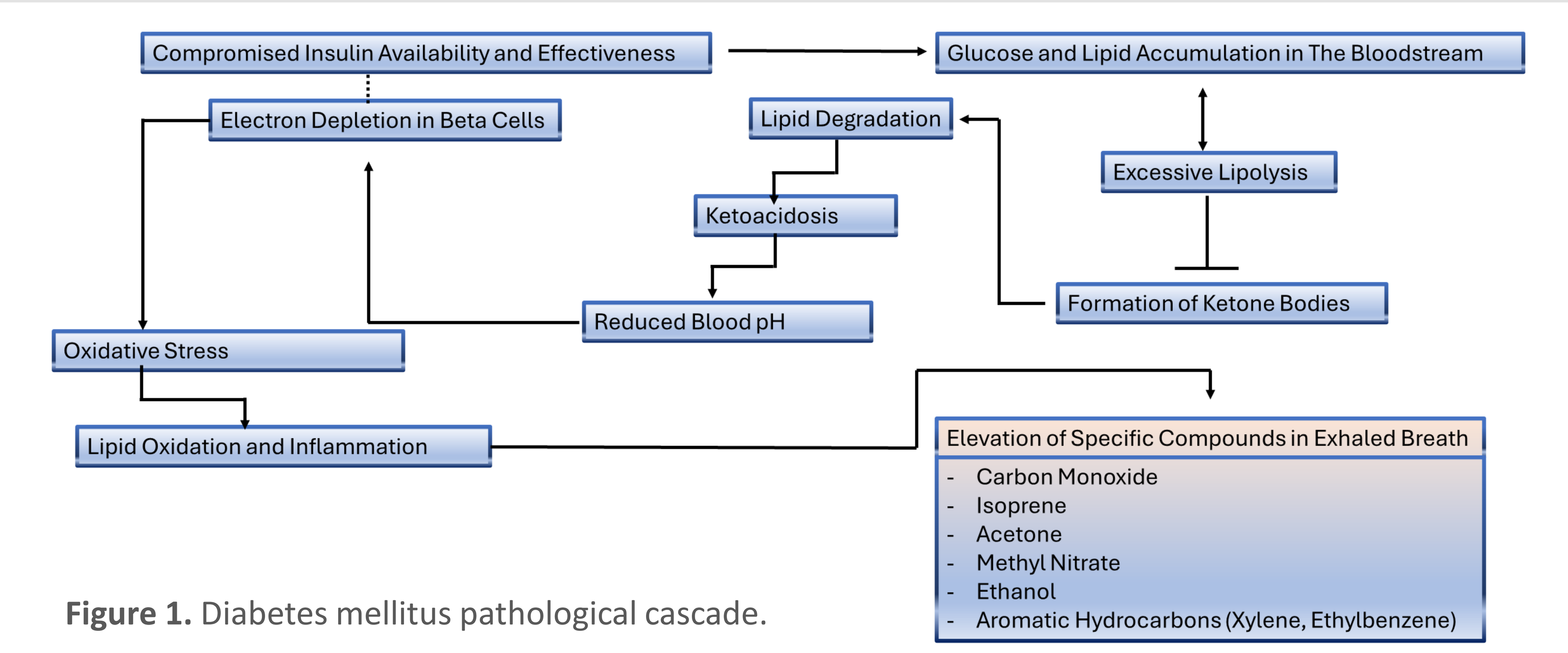

Figure 1. Diabetes mellitus pathological cascade.

Research Objectives

- Introducing revolutionary breathalyzer for diagnostics which involves utilizing sensor array, nanotechnology, data analysis for accurate biomarker detection, and incorporating algorithms like 3D analysis for precision.
- Offering a portable, non-invasive device for health monitoring and disease diagnosis transforming the potential for healthcare.
- Detection of respiratory, malignant, neurodegenerative, metabolic, and infectious diseases.

Methodology

- A device was fabricated (the Morbometer) utilizing 4 of Winsen Electronics' MQ-Gas Sensing Series sensors (MQ-7 for CO, MQ-5 for ethylbenzene, MQ-135 for acetone, MQ-2 for ethylene).
- Precise signal readings was achieved via logarithmic filtering tailored algorithms to extract features.
- AI was applied using Advanced Arduino UNO-based machine learning and fuzzy logic approach for VOC and health patterns recognition.
- The device was encased in a portable custom 3D-printed case with an LCD screen to display results.
- The device integrates data acquisition, filtering, feature extraction, machine learning, and casing for versatility.

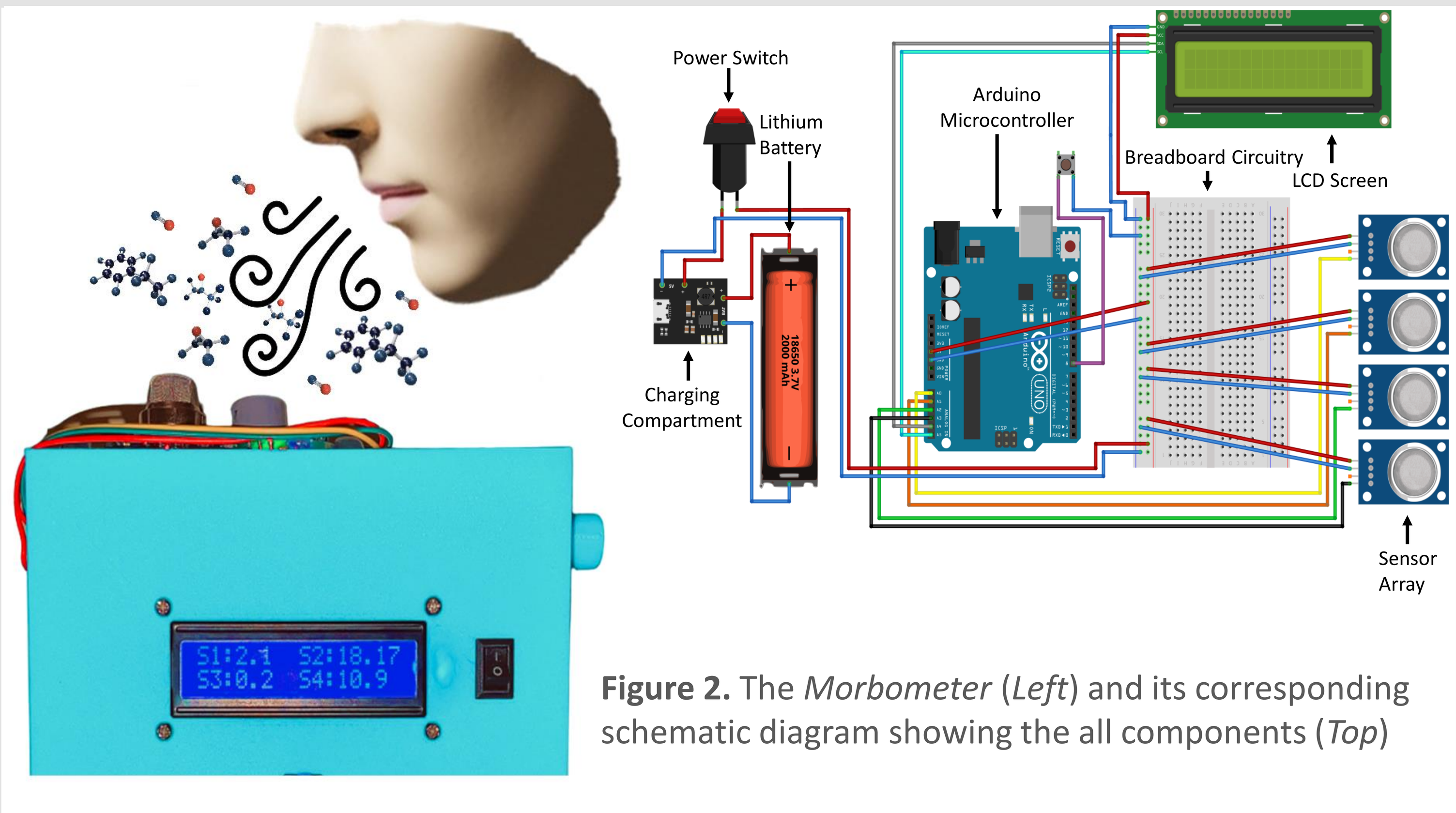

Figure 2. The *Morbometer* (*Left*) and its corresponding schematic diagram showing the all components (*Top*)

Results

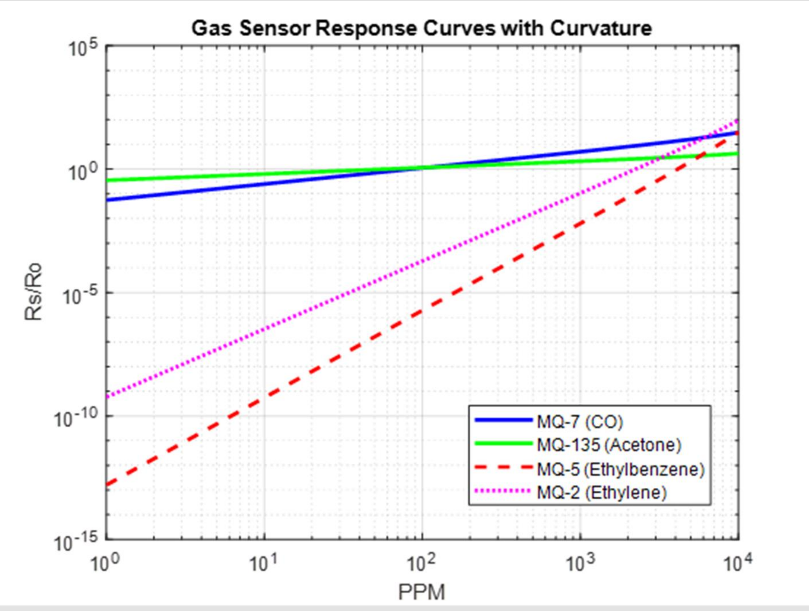

Figure 3. Logarithmic relations between the sensor's voltaic signals and their corresponding gas concentration based on the following equations:

MQ-7 (CO): $PPM = 84.77 \times (\frac{R_S}{R_o})^{0.65}$

MQ-135 (Acetone): $PPM = 57.80 \times (\frac{R_S}{R_o})^{0.25}$

MQ-5 (Ethylbenzene): $PPM = 4122.20 \times (\frac{R_S}{R_o})^{3.5}$

MQ-2 (Ethylene): $PPM = 2233.15 \times (\frac{R_S}{R_o})^{-2.75}$

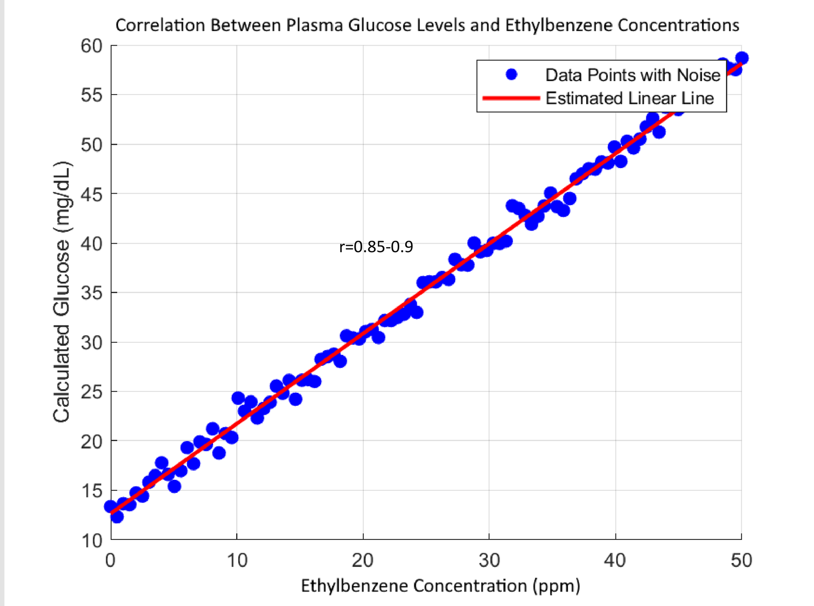

Figure 4. Linear regressed relation between ethylbenzene concentrations in breath and plasma glucose levels in the blood. Actual clusters of data are illustrated along with the correlation coefficient. The graph is based on a previous study's results [35].

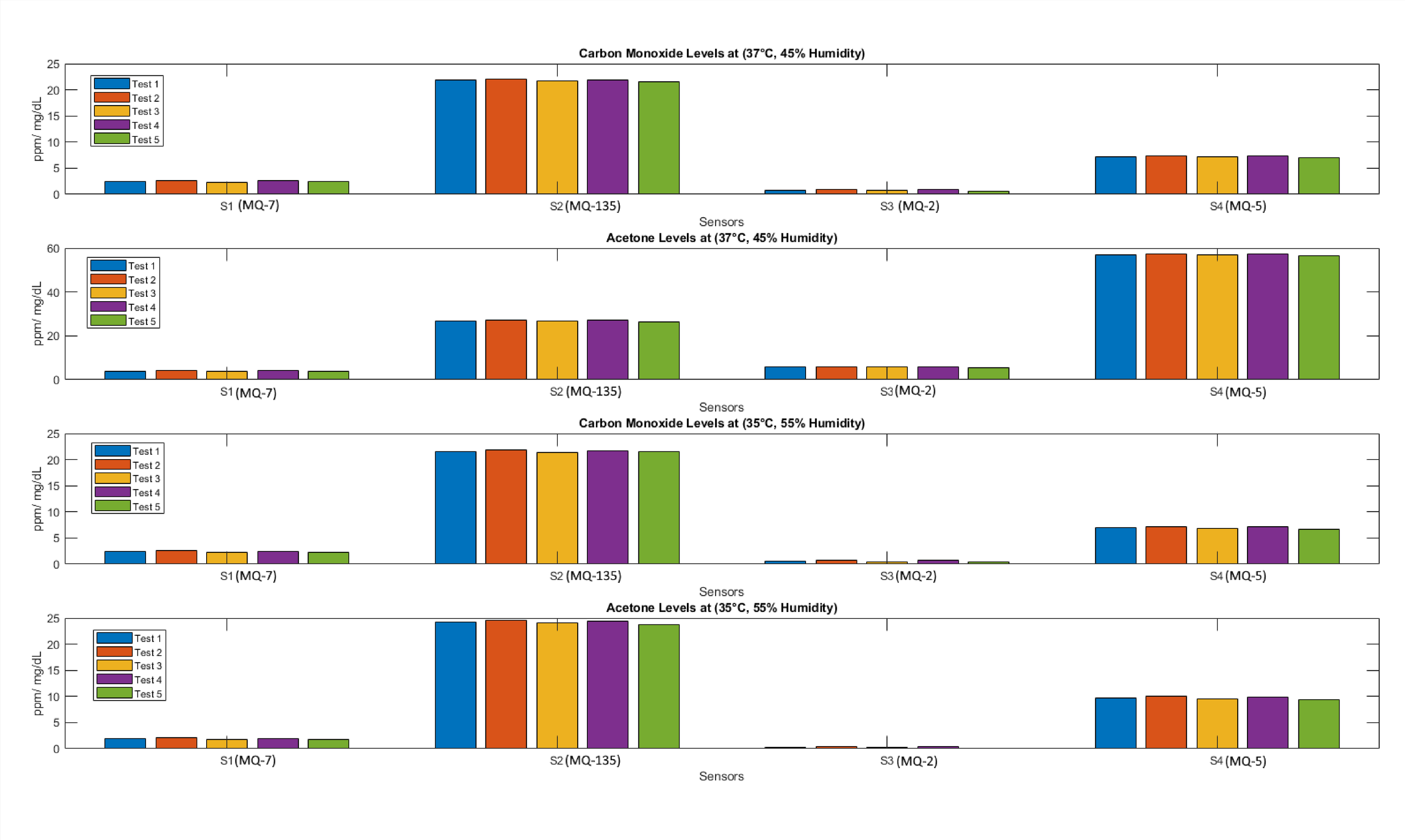

Figure 5. Carbon monoxide and acetone sensor readings measured under varied temperature and humidity conditions for distinct sensors. The obtained data confirms effective gas detection, differentiation, repeatability, and safety applications of the sensors, underlining the importance of precise calibration and real-world validation for reliability.

Conclusion

In conclusion, breathomics and breath-based diagnostics encompass diverse disciplines: chemistry, pathology, nanotechnology, AI studies, data analysis, and metabolomics. Understanding these fields is crucial for creating a device for disease detection. ***The Morbometer***, our proposed solution, merges these areas to address real-world challenges and based upon our results has proved efficacy and validity. Its integration in medical and personal care offers effective disease detection.

Future work

- Developing an innovative nano-gas-sensing array to detect various exhaled VOCs in breath.
- Focus on early disease diagnosis for a range of diseases, using algorithmic and AI methods like MNIST, SVM, and nearest neighbor techniques aiming to optimize device functionality for precise results via breathprinting and profiling.
- Validation through real-world patient examples to improve data features and extraction techniques. Seeking certifications from key organizations to meet international clinical standards.

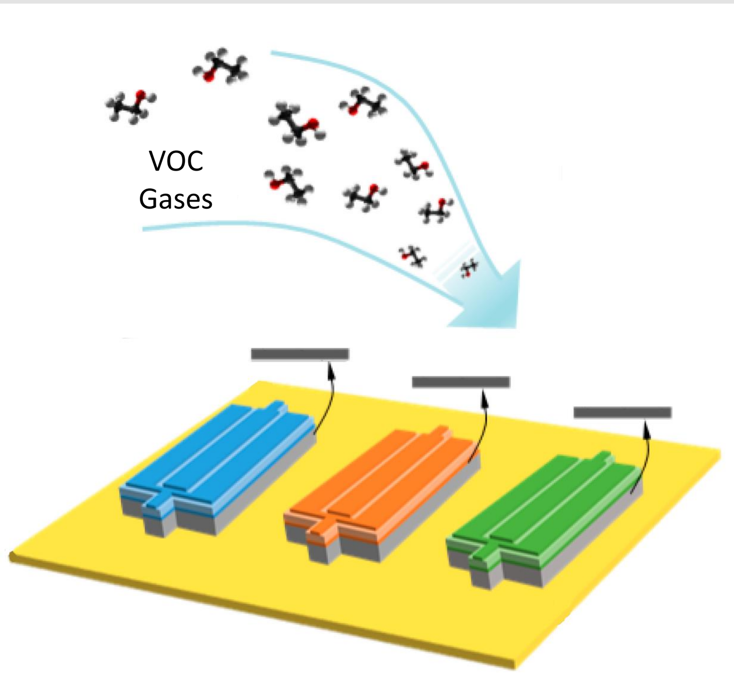

Figure 6. Vision of a nano-sensing technology array for precise and accurate, real-time monitoring and rendering of diagnosis.

References