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BioBreath Matrix Advancing Respiratory Biomarker Analysis Through Innovative Matrix Technology

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ABSTRACT

Non-communicable diseases (NCDs) are responsible for a substantial proportion of global mortality, highlighting the need for accessible and continuous health monitoring technologies. Human breath contains numerous volatile organic compounds (VOCs) that reflect physiological and metabolic conditions. This study aimed to develop BioBreath Matrix, a non-invasive breath analysis platform capable of integrating multiple VOC biomarkers with artificial intelligence to support comprehensive health assessment.

The proposed system utilizes a multivariate sensor array consisting of MQ-3, MQ-135, and MQ-138 sensors, together with a DHT22 sensor for environmental compensation. Four key breath biomarkers—acetone, nitric oxide, isoprene, and ammonia—were selected based on their associations with metabolic, respiratory, cardiovascular, and renal health conditions. Sensor signals were processed through feature extraction techniques and analyzed using Random Forest and Support Vector Machine (SVM) algorithms. The analytical outputs were subsequently integrated into a Composite Health Score and visualized through a real-time health monitoring dashboard.

The developed prototype successfully demonstrated the acquisition, processing, and interpretation of multidimensional breath biomarker data within a unified framework. The system enabled simultaneous biomarker monitoring, AI-assisted health classification, and real-time visualization of health indicators through an interactive dashboard.

In conclusion, BioBreath Matrix demonstrates the feasibility of combining breath biomarker sensing and machine learning for non-invasive health assessment. The platform provides a foundation for future clinical validation and may contribute to the development of personalized, real-time, and preventive healthcare technologies.

Keywords: breath analysis; volatile organic compounds; machine learning; non-invasive monitoring; digital health; biosensing

1. INTRODUCTION

Non-communicable diseases (NCDs), including cardiovascular diseases, diabetes, chronic respiratory disorders, and kidney-related conditions, remain among the leading causes of mortality worldwide. Early detection and continuous monitoring are essential for reducing disease burden and improving healthcare outcomes. However, many conventional diagnostic methods rely on blood sampling, laboratory analysis, or specialized medical equipment, which can be invasive, costly, and impractical for routine health assessment. Consequently, there is increasing interest in developing non-invasive technologies capable of providing rapid and accessible health information.

Human breath has emerged as a promising medium for health monitoring because it contains hundreds of volatile organic compounds (VOCs) generated through physiological and metabolic processes (Amann et al., 2014; de Lacy Costello et al., 2014). Previous studies have demonstrated that specific breath biomarkers are associated with various health conditions. Acetone has been linked to glucose metabolism and diabetes (Saasa et al., 2019; Wang & Wang, 2013), nitric oxide is commonly associated with airway inflammation and respiratory diseases (Cameli et al., 2020), isoprene reflects cholesterol synthesis and cardiovascular status (Koc et al., 2011), while ammonia may indicate kidney or liver dysfunction (Wilson, 2018). These findings suggest that breath analysis has significant potential as a non-invasive diagnostic and screening approach.

Despite these advances, most existing breath-analysis systems focus on a single biomarker or a single disease category (Wilson, 2018). Furthermore, many commercial and laboratory-based technologies require expensive instrumentation and lack the capability for continuous personal health monitoring. As a result, current approaches often fail to provide a comprehensive assessment of an individual's overall physiological condition. This limitation highlights an important research gap: the need for an intelligent platform capable of integrating multiple breath biomarkers into a unified health assessment framework.

To address this challenge, this study proposes BioBreath Matrix, a multidimensional breath-analysis platform that combines sensor fusion and machine learning to generate meaningful health insights from a single exhaled breath sample. The conceptual framework of the system is based on the integration of multivariate gas sensing, environmental compensation, feature extraction, artificial intelligence, and health score generation. By simultaneously analyzing multiple VOC biomarkers, the system aims to capture complex physiological patterns that may not be detectable through individual biomarkers alone. Random Forest and Support Vector Machine (SVM) algorithms are employed to interpret multidimensional sensor data and support intelligent health classification.

The objectives of this research are to develop a compact and non-invasive breath analysis device capable of detecting four key VOC biomarkers, implement a supervised machine-learning framework for health classification, evaluate system performance under different physiological conditions, and establish a composite health score that translates complex biomarker information into an intuitive indicator for users. Through this approach, BioBreath Matrix seeks to advance the field of breath diagnostics and contribute toward future personalized, preventive, and real-time healthcare technologies.

2. LITERATURE REVIEW

Breath analysis has gained considerable attention as a non-invasive approach for health assessment due to the presence of volatile organic compounds (VOCs) that reflect physiological and metabolic processes. Advances in gas sensing technologies and analytical methods have enabled researchers to identify specific breath biomarkers associated with various diseases and health conditions. Compared with conventional diagnostic procedures, breath-based monitoring offers advantages such as rapid analysis, user comfort, and the potential for continuous health assessment (Amann et al., 2014).

Previous studies have demonstrated the clinical relevance of several VOC biomarkers. Acetone has been widely investigated as a biomarker for diabetes and metabolic disorders because its concentration in exhaled breath correlates with fat metabolism and blood glucose regulation (Saasa et al., 2019). Nitric oxide is commonly used as an indicator of airway inflammation and has been applied in the monitoring of asthma and other respiratory diseases. Isoprene has been associated with cholesterol biosynthesis and cardiovascular function, while ammonia has been linked to kidney and liver dysfunction. These findings support the feasibility of using breath biomarkers as indicators of physiological health status (Cameli et al., 2020).

In parallel with biomarker research, developments in electronic nose (e-nose) systems and gas sensor arrays have expanded the capability of breath analysis platforms. Many studies have employed metal oxide semiconductor (MOS) sensors due to their low cost, portability, and sensitivity to a wide range of gaseous compounds. Furthermore, machine learning techniques such as Support Vector Machine (SVM), Random Forest, Artificial Neural Networks, and Deep Learning models have been increasingly adopted to improve classification accuracy and identify complex patterns within multidimensional sensor data (Wilson, 2018).

Despite these advances, several limitations remain. Most existing breath-analysis systems focus on a single biomarker or a single disease category, restricting their ability to provide a holistic assessment of health. Additionally, many high-accuracy breath diagnostic platforms rely on sophisticated laboratory instruments such as gas chromatography–mass spectrometry (GC-MS), which are expensive and unsuitable for routine personal monitoring. Although machine learning has improved predictive performance, the integration of multiple biomarkers into a unified and user-friendly health assessment framework remains relatively limited.

BioBreath Matrix addresses these gaps by combining multivariate VOC sensing, environmental compensation, and machine learning within a single platform. Rather than targeting one disease, the system simultaneously evaluates four clinically relevant biomarkers—acetone, nitric oxide, isoprene, and ammonia—to provide a broader representation of physiological health. The integration of Random Forest and SVM algorithms with a composite health scoring framework enables the transformation of complex sensor data into actionable health insights. Consequently, this research contributes to the growing field of intelligent breath diagnostics by proposing a practical, non-invasive, and scalable approach for personalized health monitoring.

3. RESEARCH METHODOLOGY

3.1 Research Design

This study employed an experimental research design to develop and evaluate BioBreath Matrix, a non-invasive breath analysis platform for health assessment. The research integrated hardware development, breath biomarker sensing, environmental compensation, machine learning, and dashboard visualization within a unified framework. The experimental design was selected to investigate the feasibility of detecting multiple volatile organic compounds (VOCs) and transforming sensor responses into meaningful health insights through artificial intelligence. The system was evaluated under three physiological conditions: resting baseline, stress-induced activity, and post-exercise state.

3.2 Participants / Samples

A pilot study was conducted using volunteer participants recruited through convenience sampling. Participants were healthy individuals with no known acute respiratory illnesses during the testing period. Breath samples were collected under controlled environmental conditions to minimize external interference. For each participant, measurements were obtained during resting, stress-induced, and post-exercise conditions to generate variations in physiological states. The collected breath samples served as the dataset for model training and system evaluation.

3.3 Instruments and Materials

The BioBreath Matrix prototype consisted of both hardware and software components.

Hardware Components

1. ESP32 microcontroller as the central processing unit
2. MQ-3 gas sensor for acetone detection
3. MQ-135 gas sensor for nitric oxide and ammonia detection
4. MQ-138 gas sensor for isoprene detection
5. DHT22 sensor for temperature and humidity compensation
6. Medical-grade silicone breathing interface

Software Components

1. Arduino IDE for microcontroller programming
2. Python programming language for data preprocessing and machine learning
3. Random Forest algorithm
4. Support Vector Machine (SVM) algorithm
5. Interactive dashboard for data visualization and health score presentation

3.4 Data Collection Procedures

Data collection followed a standardized workflow. Participants exhaled into the BioBreath Matrix device through a dedicated breath interface. Sensor responses were recorded and transmitted to the processing unit. Simultaneously, environmental parameters including temperature and humidity were measured and used for signal compensation.

The collected sensor signals underwent preprocessing and feature extraction to remove noise and improve data quality. Breath measurements were obtained under three experimental conditions: resting baseline, stress-induced condition, and post-exercise condition. The processed data were subsequently stored in a structured dataset for machine learning analysis.

3.5 Data Analysis

Sensor outputs were analyzed using a machine learning framework designed to classify physiological conditions based on multidimensional VOC patterns. Feature extraction techniques were applied to convert raw sensor responses into meaningful numerical variables.

Two supervised learning algorithms, Random Forest and Support Vector Machine (SVM), were employed to analyze the dataset. Random Forest was selected for its ability to model complex nonlinear relationships and reduce the effects of sensor noise, whereas SVM was utilized for its effectiveness in distinguishing between different physiological states. Model outputs were integrated into a Composite Health Score representing overall health status.

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The analytical workflow consisted of signal acquisition, environmental compensation, feature extraction, machine learning classification, health score generation, and dashboard visualization. This approach enabled the transformation of breath biomarker data into actionable health insights suitable for future non-invasive health monitoring applications.

4. RESULTS

This study successfully developed and integrated the BioBreath Matrix prototype as a non-invasive breath-analysis platform . The findings of this research are summarized as follows

1.The system combines a multivariate gas sensor array, environmental compensation module, machine-learning framework, composite health score generation, and real-time dashboard visualization within a single architecture.

Table 1. System Components and Functional Performance

Component	Function	Result
MQ-3 Sensor	Acetone Detection	Successfully Integrated
MQ-135 Sensor	Nitric Oxide & Ammonia Detection	Successfully Integrated
MQ-138 Sensor	Isoprene Detection	Successfully Integrated
DHT22 Sensor	Temperature & Humidity Compensation	Successfully Integrated
Random Forest	Biomarker Pattern Analysis	Successfully Implemented
Support Vector Machine (SVM)	Health Classification	Successfully Implemented
Dashboard System	Real-Time Health Visualization	Successfully Implemented

As shown in Table 1, all hardware and software components were successfully integrated into the proposed BioBreath Matrix architecture. The sensor array was capable of acquiring multidimensional breath-related signals, while the environmental compensation module reduced the influence of temperature and humidity variations during operation.

2. Results of the Proposed Prototype Design The Biometrix Device is a portable system designed to analyse human breath and monitor health in real time.It uses a soft silicone mask and a one-way valve to ensure accurate and hygienic air collection.The device contains advanced gas sensors that detect compounds related to different health conditions.Data is processed by an AI system using machine learning to generate a health score. Overall, it represents a modern solution for personalised and preventive healthcare. The overall design of the proposed prototype is presented in Figure 1.

Figure 1 Prototype Design

3 . Results of the System Operational Framework Design. The machine-learning framework successfully processed sensor responses through feature extraction and classification stages. Both Random Forest and Support Vector Machine (SVM) algorithms were implemented to analyze biomarker patterns associated with different physiological conditions. The analytical outputs were subsequently combined into a Composite Health Score designed to provide an interpretable representation of overall health status. The system development process was designed as illustrated in Figure 2

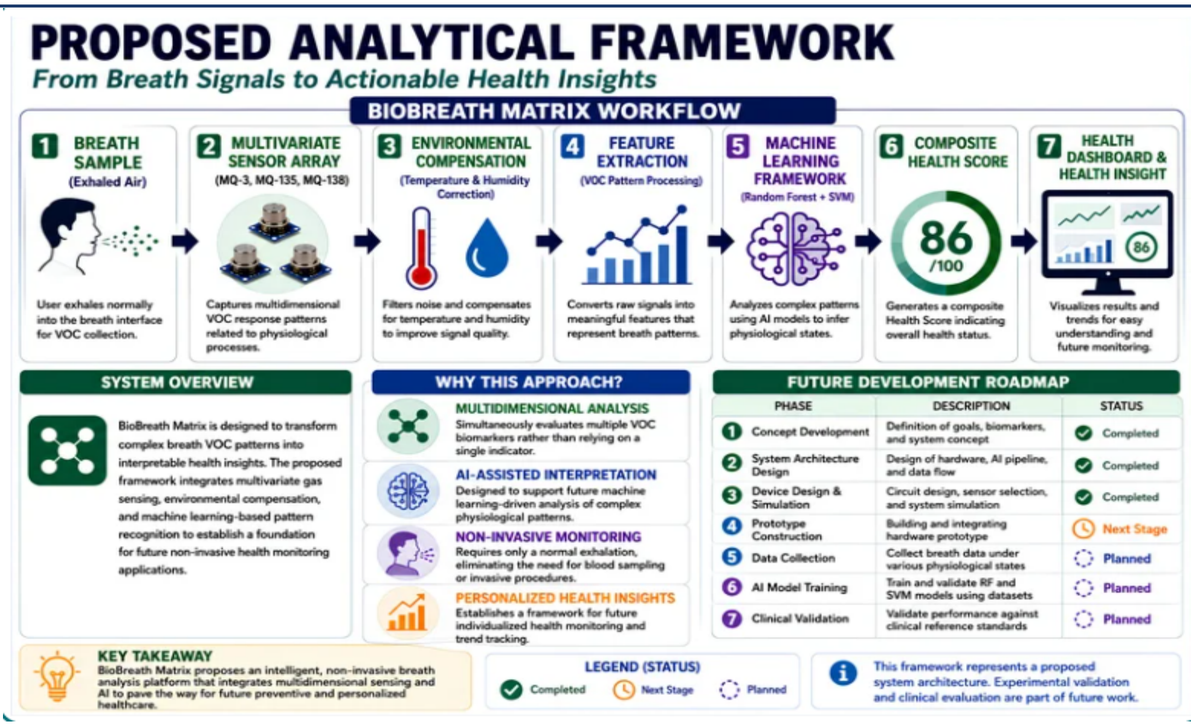

Figure 2 Proposed Analytical Framework

4. Results of the Dashboard Interface Design. The researchers developed a user interface to present the system outputs and health assessment resultsthe dashboard interface successfully visualized biomarker measurements, health scores, and physiological indicators in real time. The developed visualization platform improved user accessibility by transforming complex sensor information into understandable health insights.

Figure 3. BioBreath Matrix dashboard displaying biomarker concentrations, composite health score, and physiological health indicators in real time.

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Overall, the BioBreath Matrix prototype demonstrated the technical feasibility of integrating breath biomarker sensing, artificial intelligence, and health-data visualization into a portable and non-invasive monitoring platform.

5. DISCUSSION

The findings of this study demonstrate the feasibility of integrating breath biomarker sensing, environmental compensation, machine learning, and health visualization within a single non-invasive platform. The successful development of BioBreath Matrix supports the growing body of research indicating that exhaled breath can serve as a valuable source of physiological and metabolic information (Amann et al., 2014).

Unlike many existing breath-analysis systems that focus on a single biomarker or disease category, the proposed platform simultaneously evaluates four clinically relevant VOC biomarkers: acetone, nitric oxide, isoprene, and ammonia.

This multidimensional approach enables a broader assessment of physiological conditions and aligns with recent research emphasizing the importance of multi-biomarker analysis for improving health monitoring accuracy (de Lacy Costello et al., 2014).

The integration of Random Forest and Support Vector Machine (SVM) algorithms further enhances the system's analytical capability. Previous studies have shown that machine learning techniques are effective in identifying complex relationships among sensor responses. By incorporating these algorithms into the BioBreath Matrix framework, the system is capable of transforming raw sensor signals into interpretable health information and supporting intelligent health classification .

Another important contribution of this work is the development of a Composite Health Score and dashboard interface. Traditional sensor systems often produce large amounts of technical data that may be difficult for users to interpret. In contrast, the proposed framework converts multidimensional biomarker measurements into a simplified health indicator, thereby improving accessibility and supporting personalized health monitoring.

From a practical perspective, the use of low-cost sensors and compact hardware architecture improves the potential for scalability and future deployment in portable or wearable healthcare applications. This characteristic distinguishes the system from many laboratory-based breath diagnostic technologies that require expensive analytical instruments.

Nevertheless, several limitations should be acknowledged. The current study primarily focuses on prototype development and framework implementation. Although the selected biomarkers are supported by existing literature, extensive clinical validation has not yet been conducted. In addition, metal oxide semiconductor sensors may be affected by cross-sensitivity and environmental factors despite compensation mechanisms. Future studies should include larger participant populations, calibration against clinical-grade analytical instruments, and long-term validation under real-world conditions.

6. CONCLUSION

This study presented BioBreath Matrix, a non-invasive breath-analysis platform designed to integrate multivariate VOC sensing, machine learning, and real-time health visualization within a unified framework. The system was developed to address limitations of conventional health monitoring approaches by providing a portable and user-friendly solution capable of analyzing multiple breath biomarkers simultaneously.

The proposed platform successfully incorporates acetone, nitric oxide, isoprene, and ammonia sensing together with environmental compensation, feature extraction, Random Forest and Support Vector Machine (SVM) algorithms, and a Composite Health Score framework. Through this integration, BioBreath Matrix transforms complex breath biomarker data into interpretable health insights that can be visualized through an interactive dashboard.

The study contributes to the field of intelligent breath diagnostics by demonstrating the feasibility of combining sensor fusion and artificial intelligence for non-invasive health assessment. In addition to supporting multidimensional biomarker analysis, the proposed framework provides a foundation for future personalized health monitoring systems and preventive healthcare applications.

Future research should focus on large-scale participant studies, clinical validation against established medical standards, and optimization of sensor performance. Further development may also enable miniaturization and integration into wearable devices for continuous real-time health monitoring.

In conclusion, BioBreath Matrix represents a promising step toward accessible, intelligent, and non-invasive healthcare technologies, bridging the gap between advanced respiratory biomarker analytics and practical everyday health monitoring.

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AUTHOR CONTRIBUTIONS

Author	Contribution (CRediT Taxonomy)
Thanadon Srijan	Conceptualization, Methodology, Data Curation, Writing – Original Draft
Esararat Bootsri	Investigation, Formal Analysis, Resources
Supachote Purintanavut	Supervision, Writing – Review & Editing, Funding Acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest regarding the publication of this research. The study was conducted independently without financial support, sponsorship, or commercial involvement from any organization, institution, or company. The authors have no financial or personal relationships that could have influenced the research outcomes.

DATA AVAILABILITY STATEMENT

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

ETHICAL APPROVAL AND CONSENT TO PARTICIPATE

Not applicable. This study focused on the design and development of a prototype system and did not involve human participants, clinical samples, or personal data collection.

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