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Vento Aureo: IoT-Based Pollution Detection with ML Insights

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Abstract: Air pollution remains one of the most pressing environmental challenges of the 21st century, it comes with severe consequences for both public health and ecological balance. Prolonged exposure to pollutants such as particulate matter, carbon dioxide, and volatile organic compounds has been linked to respiratory illnesses, cardiovascular diseases, and even premature mortality. Despite these risks, conventional air quality monitoring systems are often limited by high costs, fixed infrastructures, and restricted accessibility, leaving large populations without adequate real-time information. To address this gap, this study presents Vento Aureo, an IoT and Artificial Intelligence (AI)-based framework designed for real-time air quality monitoring and forecasting. The system leverages portable IoT sensors to collect pollutant data, which is later transmitted to the cloud for analysis. Machine learning algorithms are employed to identify patterns and predict short-term air quality trends, enabling proactive responses to hazardous conditions. Data visualization and user interaction are facilitated through a mobile application that delivers live readings and predictions directly to end-users, supporting informed decision-making in daily life. Furthermore, the framework holds potential to aid policymakers and urban planners by providing accessible, large-scale insights into pollution dynamics. By integrating portability, affordability, and predictive intelligence, Vento Aureo offers a practical step toward mitigating the harmful effects of poor air quality and promoting healthier urban environments.

Keywords: Air Quality Monitoring, Internet of Things (IoT), Machine Learning, Noise Pollution, Real-Time Data, Cloud Integration, Smart Environment.

I. INTRODUCTION

1.1 Background and Motivation

Air pollution has become one of the most pressing global environmental issues of the 21st century. According to the World Health Organization (WHO), millions of premature deaths are attributed annually to exposure to poor air quality, particularly fine particulate matter (PM2.5) and harmful gases such as carbon monoxide, nitrogen oxides, and sulfur dioxide. Prolonged exposure to these pollutants is strongly linked to respiratory illnesses, cardiovascular disorders, and a decline in overall public health. Beyond human health, pollution also damages ecosystems, reduces agricultural productivity, and contributes to climate change, making it a multifaceted challenge with very few ways to battle it.

1.2 Limitations of Existing Systems

Conventional air quality monitoring largely depends on government-operated stations that are accurate but highly resource-intensive. These monitoring stations involve sophisticated equipment and require significant maintenance, which restricts their deployment to limited urban locations. As a result, large regions particularly suburban and rural areas are left without reliable air quality data. Additionally, stationary systems often fail to capture micro-level variations in pollution, which can differ significantly across neighborhoods or even streets. This lack of granularity creates a gap in providing real-time, localized insights for individuals and communities.

1.3 Role of IoT in Air Quality Monitoring

The emergence of the Internet of Things (IoT) has created opportunities for scalable, low-cost, and portable environmental monitoring solutions. IoT-based sensors can be deployed across wider areas to continuously collect real-time data on pollutant concentrations and environmental conditions such as temperature and humidity. Unlike traditional monitoring stations, IoT systems are lightweight, affordable, and capable of generating fine-grained data that reflects local variations in air quality. These advantages make IoT an ideal foundation for developing personalized and community-level air quality monitoring systems.

1.4 Role of Artificial Intelligence and Machine Learning

While IoT devices generate large volumes of raw data, artificial intelligence (AI) and machine learning (ML)

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techniques are essential for extracting meaningful insights. AI models can process high-dimensional sensor data to detect patterns, predict future pollution levels, and even identify potential sources of emissions. Predictive modeling is particularly a very valuable asset, as it enables governments, organizations, and individuals to take proactive measures before pollution reaches harmful levels. The integration of AI with IoT—often referred to as AIoT—provides a comprehensive framework for real-time monitoring, forecasting, and decision-making.

1.5 Research Gap

Despite the progress in IoT and AI applications, challenges remain in creating systems that are truly portable, scalable, and user-friendly. Many existing models prioritize either high accuracy at the expense of affordability, or affordability at the cost of predictive capability. Furthermore, issues such as interoperability between devices, computational constraints, and long-term sensor reliability limit the widespread adoption of AIoT solutions. There is a need for integrated systems that not only collect real-time air quality data but also provide predictive insights while remaining cost-effective and accessible to the general public.

1.6 Objectives and Contributions of the Project

- This paper presents Vento Aureo, a portable IoT-based air quality monitoring system enhanced with machine learning for predictive analysis. The key objectives of the project are:
- To design a compact and portable IoT-enabled device capable of real-time monitoring of air pollutants and environmental conditions.
- To integrate machine learning algorithms for short-term forecasting of air quality indices.
- To provide a cloud-based interface that ensures scalability, accessibility, and user-friendly visualization of data.
- To develop an affordable solution that bridges the gap between large-scale government systems and personal health applications.
- Through this work, the project demonstrates how the integration of IoT and AI technologies can revolutionize air quality monitoring by making it more accessible, predictive, and impactful.

II. LITERATURE SURVEY

Paper No	Title & Year	Key Contributions	Limitations
1.	Systematic Review of Machine Learning and Deep Learning Techniques for Spatiotemporal Air Quality Prediction (2024)	Reviews 80 studies on ML/DL for air quality prediction; compares models like RF, SVM, CNN, LSTM; discusses transfer learning & federated learning.	Limited to Scopus/Google Scholar sources; lacks real-world validation; dataset inconsistencies
2.	IoT-Based Mobile App for Real-Time Monitoring and Reporting of Air Pollution (2025)	Mobile app using calibrated IoT sensors for AQI in Lima; includes citizen reporting and health alerts; verified with official data.	Limited to PM2.5; performance may vary under different environments; not validated outside Peru.
3.	AirNet: Predictive Machine Learning Model for Air Quality Forecasting Using Web Interface (2024)	Web-based AQI forecasting using ML models (RF, DT) with global datasets; provides real-time alerts via Django interface.	Depends on public datasets (may be incomplete); no real-time IoT integration; 100% accuracy unlikely in practice.
4.	An IoT-Enabled System for Enhanced Air Quality Monitoring and Prediction on the Edge (2021)	Hybrid cloud-edge system with NARX + LSTM/XGBoost for PM2.5 prediction; supports low-connectivity areas.	Computationally heavy; complex training; limited scalability without expert support.
5.	Real-time IoT-Powered AI System for Monitoring and Forecasting of Air Pollution in Industrial Environment (2024)	Factory-focused IoT-AI system for monitoring chrome plating pollution; ML models trigger exhaust fans for mitigation.	Context-specific; not generalizable; sensor degradation/scalability not addressed.

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6.	Deep Learning-Based Optimization of Energy Utilization in IoT-Enabled Smart Cities (2024)	Transformer-based DL model for real-time energy management; improves sustainability in smart cities (Saudi Arabia).	High computation cost; strains IoT devices; limited feasibility in low-infra regions.
7.	IoT Solution for Smart Cities' Pollution Monitoring and the Security Challenges (2019)	IoT-based pollution monitoring with real-time assessment & secure MQTT communication; uses Raspberry Pi, Nitrogen iMX6.	Relies on industrial-grade hardware & cloud infra; no AI predictive analytics; not validated at scale.
8.	An IoT-Aware Solution to Support Governments in Air Pollution Monitoring (2022)	Combines IoT sensors + citizen feedback for urban monitoring; supports dynamic redeployment & policy decision-making.	Dependent on citizen participation; scalability issues in dense cities; limited validation.
9.	AI-Driven IoT Solutions for Urban Pollution Monitoring (2024)	AI-integrated IoT framework for predictive modeling, anomaly detection, real-time edge/cloud integration.	No deployment case; high cost & complexity; urban-scale scaling is difficult.
10.	A Deep Learning Approach for Prediction of Air Quality Index in Smart City (2024)	Uses Deep GAN for missing data + Stacked Attention GRU for AQI prediction across 3 Indian cities.	Predictive only (no IoT); needs large clean datasets; lacks deployment context.
11.	Exploring the Role of Artificial Intelligence in Internet of Things Systems: A Systematic Mapping Study (2024)	Maps AI roles in IoT (preprocessing, pattern recognition, prediction, decisioning) across domains incl. smart cities; guidance on AIoT stacks and edge.	Interoperability and heterogeneity issues persist; energy/computation overheads for real-time AI.
12.	Challenges of AI in Wireless Networks for IoT (2020)	Reviews integration of AI into IoT communication networks; emphasizes security, bandwidth efficiency, and intelligent routing.	Limited to theoretical models; no practical AQI-specific application.
13.	Role of Artificial Intelligence in the Internet of Things (IoT) Cybersecurity (2021)	Explores AI for securing IoT-based smart city applications, including air-quality sensors; discusses anomaly detection frameworks.	Cybersecurity lens only; no direct AQI monitoring prototype.
14.	Navigating the Nexus of AI and IoT: A Comprehensive Review of Data Analytics and Privacy Paradigms (2024)	Provides a structured review of AI-enabled IoT analytics; highlights privacy-preserving methods like federated learning, ZKP.	Broad scope dilutes AQI relevance; focuses mainly on theoretical frameworks.
15.	Research on Artificial Intelligence Enhancing Internet of Things Security: A Survey (2020)	Surveys how AI enhances IoT trust and data security; proposes AI-driven intrusion detection systems for IoT health/safety apps	Lacks deployment case studies; AQI application indirect.

III. CONCLUSION

Air pollution remains one of the most pressing environmental and public health challenges, with severe implications for respiratory health, urban livability, and climate change. Traditional monitoring systems, though accurate, are limited by their high cost and fixed deployment, which restricts large-scale and real-time coverage. The literature reviewed highlights the potential of combining Internet of Things (IoT) technology with Artificial Intelligence (AI) and Machine Learning (ML) models to overcome these limitations.

From the survey of fifteen key research works, several consistent themes emerge. First, IoT-enabled sensors provide real-time and location-specific air quality data, while ML and DL algorithms significantly enhance predictive accuracy, enabling proactive environmental management. Second, the integration of edge computing, lightweight models, and mobile applications allows these systems to be more scalable and user-friendly, expanding their applicability in urban environments. Third, challenges such as device interoperability, energy efficiency, computational constraints, and data security remain unresolved and must be addressed to achieve robust and sustainable systems.

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Our project, Vento Aureo: AI-Driven IoT System for Real-Time Air Quality Monitoring, is designed with these lessons in mind. By leveraging IoT devices for data collection and ML models for predictive analysis, we aim to build a portable, cost-effective, and scalable solution that can empower individuals, communities, and city administrations to take timely action against harmful air pollution. This work not only contributes to academic understanding of AI-IoT integration but also offers a pathway towards healthier, cleaner, and more sustainable urban environments.

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