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Generative AI-Enhanced Industrial IoT System for Automated Carbon Emission Monitoring and Hazard Prediction

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Abstract: Industrial carbon emissions significantly impact environmental sustainability and human health, creating an urgent need for advanced systems capable of efficient monitoring and mitigation. This study proposes an artificial intelligence-based carbon capture and surveillance framework that combines IoT-enabled embedded systems with machine learning techniques for continuous industrial emission supervision. The architecture utilizes an ESP32 microcontroller integrated with essential environmental sensors, including the MQ135 gas sensor for air quality assessment, the DHT11 sensor for temperature and humidity measurement, and a flame sensor for hazard detection. Real-time sensor readings are transmitted to the ThingSpeak cloud platform, allowing remote access and monitoring through mobile devices. A Python-driven machine learning model analyzes the collected data to identify, categorize, and forecast pollution conditions with improved precision. When emission values surpass established safety limits, the system generates immediate alerts to support rapid intervention measures. Through the integration of edge-level sensing and cloud-based intelligence, the proposed framework offers an economical, expandable, and efficient approach to industrial carbon management while improving workplace safety. This research highlights the importance of AI-powered IoT systems in promoting smarter environmental governance and sustainable industrial operations.

Keywords: *Industrial Emissions, IoT, ESP32, Carbon Monitoring, Machine Learning, Thingspeak Cloud, Industrial Safety.*

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I. INTRODUCTION

Industrialization has been a driving force behind economic development, but it has also emerged as a major contributor to environmental pollution. Among various pollutants, carbon emissions from industries account for a significant portion of global greenhouse gases, directly impacting climate change, air quality, and human health. The World Health Organization (WHO) and Intergovernmental Panel on Climate Change (IPCC) consistently highlight that uncontrolled carbon emissions accelerate global warming, intensify natural disasters, and increase respiratory and cardiovascular health risks in urban populations. Therefore, effective carbon monitoring and management systems have become a global necessity. Traditionally, carbon emission monitoring relied on manual inspections, periodic sampling, and laboratory analysis. While these approaches provided baseline data, they suffered from limitations such as delays in detection, lack of real-time insights, and high operational costs. With the advent of the Internet of Things (IoT), real-time sensing and wireless communication technologies have transformed environmental monitoring systems. IoT-based platforms enable continuous emission data collection, instant transmission, and intelligent analysis, thereby enhancing the accuracy and timeliness of pollution management strategies. However, most existing systems focus only on data acquisition and monitoring, without integrating predictive analytics or automated hazard prevention mechanisms. The integration of Artificial Intelligence (AI) into IoT-based carbon monitoring opens new possibilities for proactive environmental management. Machine learning algorithms can analyze large-scale sensor data, classify pollution levels, and predict hazardous conditions before they escalate. By leveraging AI, industries can transition from reactive responses to preventive strategies, thereby improving both environmental sustainability and workplace safety. The motivation behind this project arises from the urgent need to bridge the gap between conventional monitoring and intelligent, data-driven decision-making in emission control. Industrial accidents caused by hazardous gas leaks, excessive carbon concentrations, or fire outbreaks continue to pose severe threats. By embedding multiple environmental sensors—MQ135 for air quality, DHT11 for temperature and humidity, and a flame sensor— into an AI-enabled IoT framework, industries can not only monitor but also predict and mitigate risks in real time.

II. PROPOSED SYSTEM

The proposed system is an AI-powered, IoT-based carbon emission monitoring and alert platform developed for industrial applications. It utilizes the ESP32 microcontroller

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as the central unit, integrated with multiple environmental sensors—MQ135 for air quality and harmful gas detection, DHT11 for temperature and humidity measurement, and a flame sensor for identifying potential fire hazards. These sensors continuously collect real-time data on environmental parameters and pollutant levels within industrial zones. The collected data is transmitted wirelessly to the ThingSpeak Cloud, where it is stored, processed, and visualized through interactive dashboards. Users can remotely monitor emission trends and environmental conditions in real time using the ThingSpeak interface, enabling improved situational awareness and data-driven decision-making. To enhance intelligence and prediction capability, the system integrates a Python-based machine learning model that analyzes incoming sensor data and classifies emission risk levels into Safe, Warning, and Critical categories. Based on these predictive insights, the system issues automatic alerts via the cloud platform or through local outputs such as buzzers and LEDs, ensuring timely notifications and preventive actions. This intelligent, low-cost, and scalable solution not only ensures continuous monitoring but also supports predictive maintenance, proactive safety management, and regulatory compliance. By combining AI analytics with IoT-based sensing through ThingSpeak, the proposed system offers a more responsive, reliable, and efficient approach than traditional emission monitoring methods.

III. HARDWARE INTEGRATION

The proposed AI-powered IoT-based emission monitoring system is built around the ESP32 microcontroller, serving as the central unit for data collection and communication. It integrates multiple sensors, including MQ135 (air quality), MQ6 (flammable gas), and DHT11 (temperature and humidity), to capture real-time environmental conditions. An optional ESP32-CAM module enhances the setup by enabling visual surveillance within industrial premises. Each sensor is powered by a regulated supply and calibrated for precision. The ESP32 periodically acquires readings from all sensors, applies preprocessing techniques like noise filtering and signal smoothing, and formats data with timestamps. If any measured value exceeds safety thresholds, on-site alerts are immediately triggered via buzzers and LEDs, ensuring prompt local response.

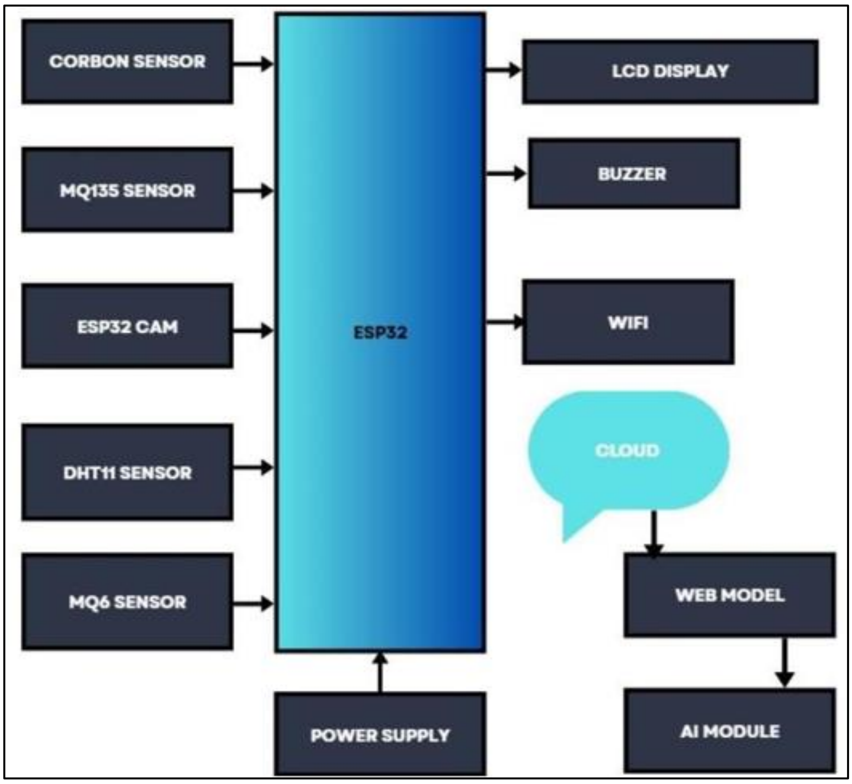

Fig 1.Flowchart Diagram

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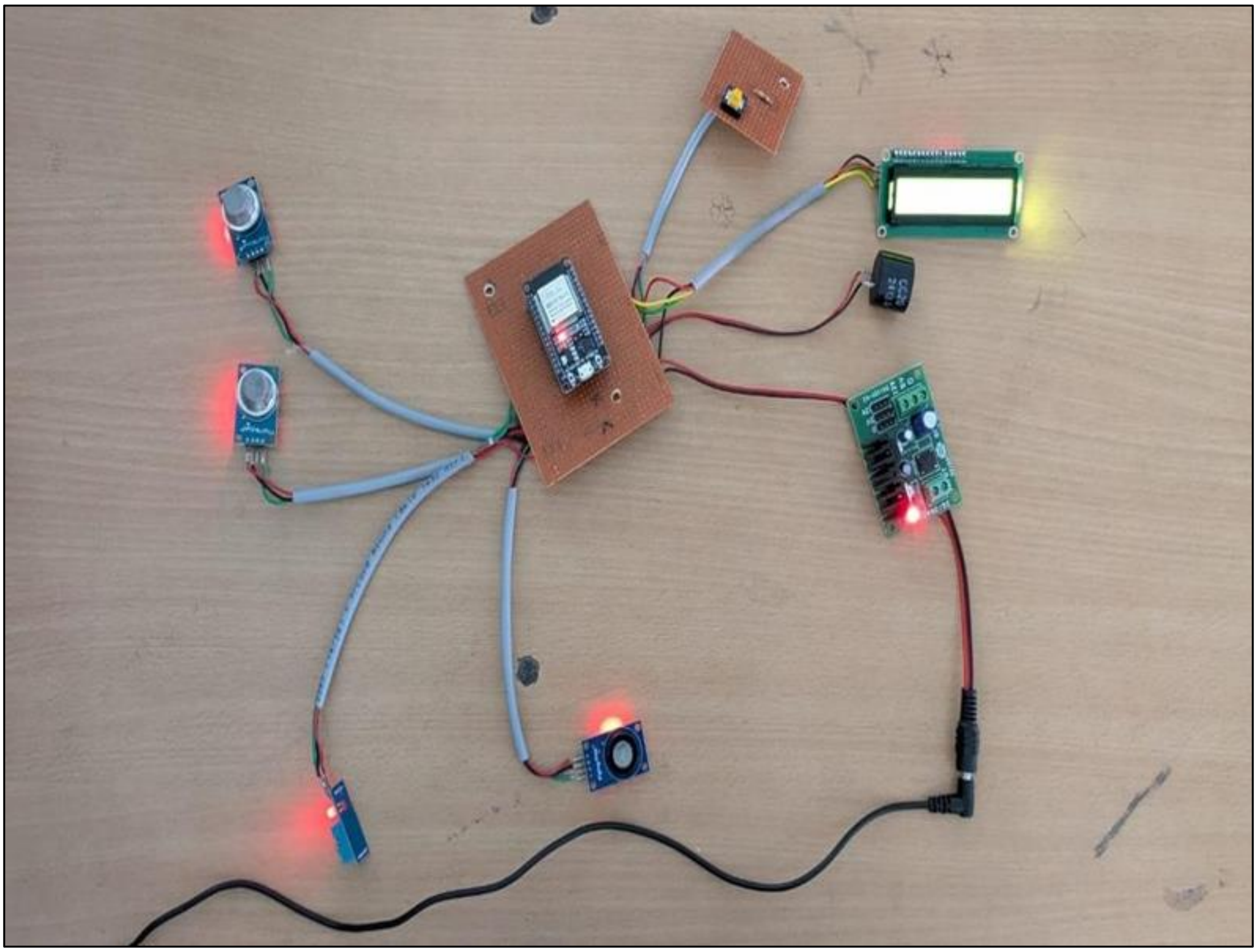

Fig 2 **:** AI-Enabled Carbon Monitoring and Hazard Prediction System

IV. RESULT AND DISCUSSION

The AI-enabled carbon monitoring and hazard prediction system was successfully implemented and tested under controlled industrial-like conditions. The sensors—MQ135, DHT11, and flame detector—demonstrated reliable performance in capturing real-time environmental data. The MQ135 effectively detected variations in air quality by measuring the concentration of harmful gases such as CO_2 and NOx, while the DHT11 provided accurate readings of ambient temperature and humidity, which are essential for correlating emission variations with atmospheric conditions. The flame sensor added a safety layer by promptly identifying potential fire hazards associated with industrial processes. The collected data was transmitted seamlessly to the ThingSpeak Cloud, where remote monitoring through a web and mobile interface was validated. This ensured that real-time environmental parameters were accessible to users and authorities, enabling continuous visibility of emission levels. The machine learning model, developed in Python, was trained using historical datasets of pollution levels and tested against the collected live data. It achieved high accuracy in classifying emission conditions into normal, moderate, and hazardous categories. The results revealed that the system could not only detect and monitor real-time carbon emissions but also predict potential hazards before they escalated. This predictive capability significantly enhances industrial safety by reducing the risk of accidents due to uncontrolled emissions or fire outbreaks. Furthermore, the integration of IoT with AI enabled a scalable, low-cost, and energy-efficient framework suitable for industrial applications. In comparison to existing monitoring systems that primarily provide raw data without intelligent analysis, this solution offers substantial improvements in automation, prediction, and decision-making support. The system demonstrated robustness, low latency in data transfer, and reliability in triggering alerts when predefined thresholds were exceeded. The findings highlight the potential of combining embedded IoT devices with AI models to establish a next-generation carbon management solution. This integration not only addresses environmental concerns by reducing harmful emissions but also contributes to achieving sustainability goals aligned with smart industrial development and regulatory compliance.

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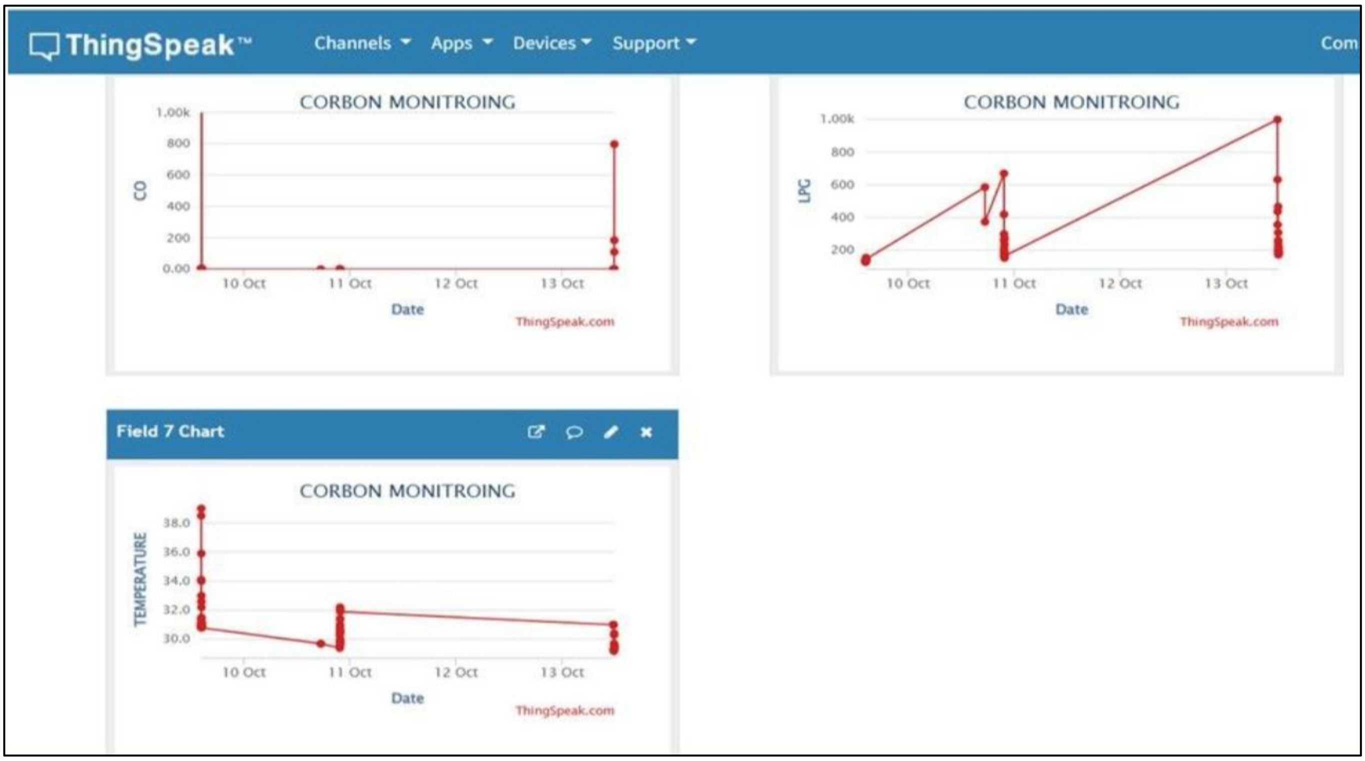

Fig 3 : Carbon Monitoring Graph 1

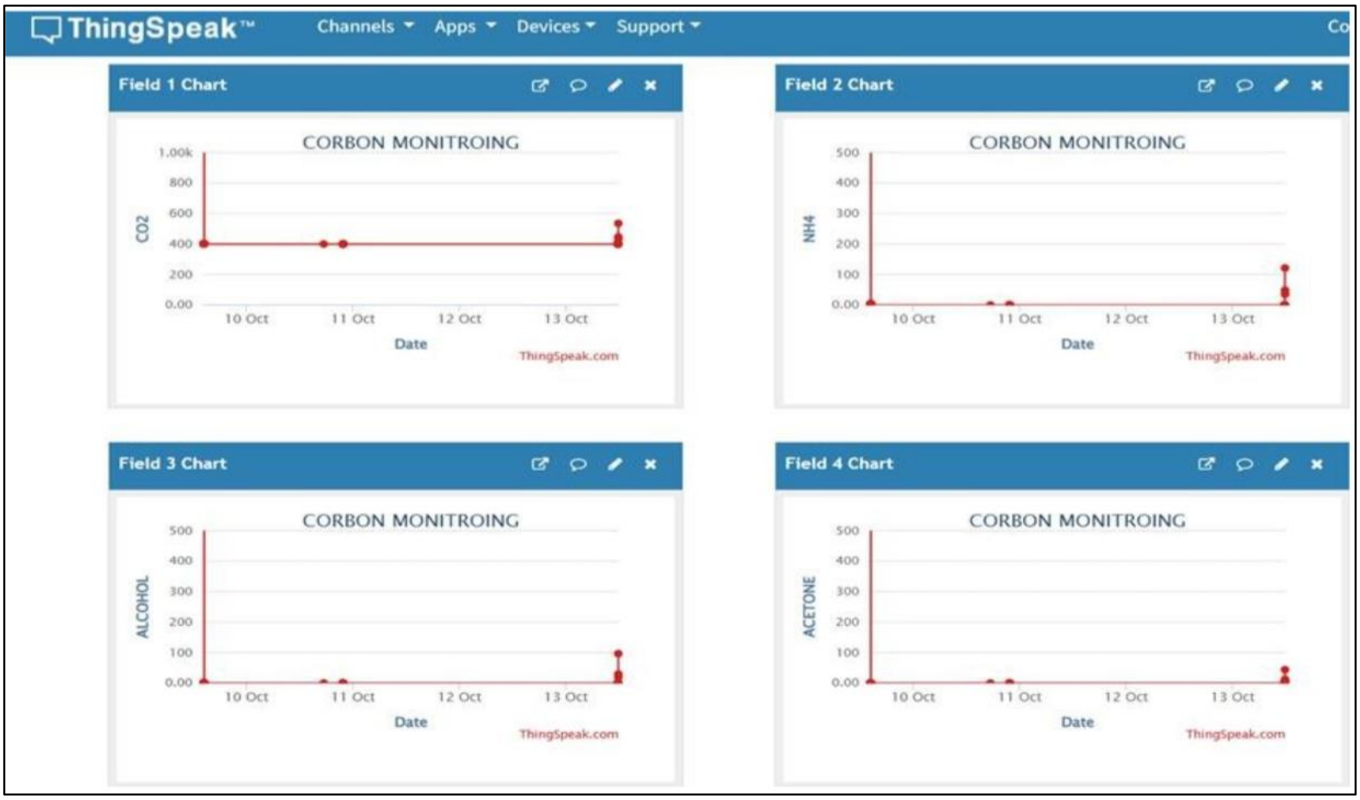

Fig 4 : Carbon Monitoring Graph 2

V. CONCLUSION

The AI-enabled carbon monitoring and hazard prediction system demonstrates an effective integration of IoT and artificial intelligence for addressing industrial carbon emissions and safety concerns. By employing low-cost sensors such as MQ135, DHT11, and a flame detector, along with the ESP32 microcontroller, the system successfully monitored real- time environmental parameters and transmitted data to the ThingSpeak Cloud for continuous remote access. The use of machine learning enhanced the system's capability by enabling accurate classification and

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prediction of emission levels, thereby ensuring proactive alerts and timely preventive measures. Experimental results highlight the system's robustness, scalability, and reliability in detecting hazardous conditions while supporting sustainable industrial practices. Overall, this intelligent framework not only improves environmental monitoring but also contributes to reducing carbon footprints, enhancing workplace safety, and advancing the development of smart, eco-friendly industrial systems aligned with Industry 4.0 goals.

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