Cloud Enabled IoT Weather Station with Predictive Analytics Using Machine Learning

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Abstract - **This paper presents an Integrated Internet of Things (IoT) Based Weather Monitoring System combined with a Machine Learning (ML) Based Weather Prediction Model for local atmospheric analysis and forecasting. The system utilizes a network of environmental sensors, including BME680, wind speed and direction sensors, and rainfall sensors, to collect real-time temperature, humidity, pressure, and air quality data. These data are transmitted using NodeMCUESP32 over WiFi and stored on a cloud database for remote access and analysis. A machine learning model trained on historical and real-time sensor data predicts short-term weather patterns, offering improved accuracy and rapid feedback. This integrated system aims to provide a cost effective, scalable, and reliable weather monitoring platform for rural and urban applications. The results demonstrate that IoT based monitoring combined with ML prediction enhances the efficiency, automation, and reliability of weather forecasting.**

Keywords: Machine Learning, Cloud Enabled IoT, Weather Station, Predictive Analytics, AI, Internet of Things.

I. INTRODUCTION

Weather monitoring is essential for agriculture, transportation, disaster management, and environmental protection. Traditional weather stations are reliable but often expensive, difficult to deploy in distributed locations, and offer limited customization. With advancements in IoT and cloud computing, low-cost sensor based monitoring systems have become accessible, enabling real-time data acquisition and remote access.

Machine Learning further improves forecasting by identifying hidden patterns in large sets of historical and real-time environmental data. Integrating IoT with ML creates a robust weather system capable of both accurate monitoring and predictive analysis. This paper presents such an integrated solution aimed at enhancing the functionality of weather stations through automation, low power consumption, and efficient data processing.

II. LITERATURE REVIEW

Recent studies highlight the increasing adoption of IoT based environmental monitoring systems due to their scalability and cost effectiveness. Researchers have used sensors like DHT22, BMP280, and MQ series gas sensors for atmospheric measurements. Cloud platforms such as Thing speak and Firebase have been employed for data logging and visualization. Machine learning techniques such as Linear Regression, Random Forest, and LSTM neural networks have shown significant success in predicting environmental variations. However, existing systems often lack integrated hardware software frameworks combining advanced air quality sensors (like the BME680) and ML forecasting into a single working platform. This gap is addressed by the proposed model.

III. PROPOSED METHODOLOGY

The proposed system integrates three primary modules:

3.1 IoT Sensor Module

A cluster of sensors collects environmental data in real time. The BME680 provides temperature, humidity, barometric pressure, and gas resistance for air quality estimation. Additional sensors measure wind speed, wind direction, and rainfall intensity.

3.2 Wireless Communication and Cloud Storage Module

The NodeMCUESP32 microcontroller gathers sensor data, processes it, and transmits it over WiFi to a cloud storage platform. The data is saved in structured format for visualization and ML training.

3.3 Weather Prediction Module

A machine learning model is trained on historical cloud stored data to predict temperature, humidity, and rainfall trends. The model uses algorithms such as Random Forest Regression or LSTM for time series prediction.

Data flows sequentially from sensors → ESP32 → cloud → ML model → predicted weather output.

IV. HARDWARE DESCRIPTION

Circuit Diagram

ESP32 / BME680
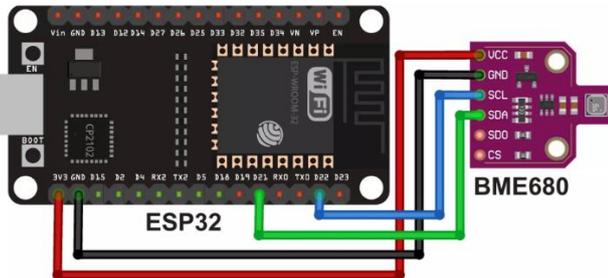
4.1 BME680 Environmental Sensor

The BME680 is a 4in1 sensor measuring temperature, relative humidity, barometric pressure, and VOC based air quality index (AQI). It supports I²C communication, making it suitable for microcontroller integration.

4.2 Anemometer and Wind Direction Sensor

The wind speed sensor outputs pulses proportional to wind rotation while the direction sensor provides analog signals corresponding to eight primary directions. Both are essential for meteorological data analysis.

4.3 Rainfall Sensor (Tipping Bucket or Resistive Type)

This sensor measures rainfall in millimeters per hour. The tipping bucket system offers high accuracy and durability for continuous outdoor operation.

4.4 NodeMCUESP32 Microcontroller

The ESP32 provides:

- Dual core processing
- Built-in WiFi
- Fast ADC reading capability
- Support for multiple communication protocols
- Its low power consumption makes it ideal for field based monitoring systems.

4.5 Power Supply System

A 5V regulated power supply supports long duration operations. Solar powered options can also be added for remote deployment.

V. IMPLEMENTATION

5.1 System Architecture

The sensors are interfaced with ESP32 through analog and I²C ports. Data is sampled periodically (e.g., every 10 seconds) and preprocessed to remove noise.

5.2 Data Transmission and Cloud Logging

Using WiFi connectivity, processed sensor data is uploaded to a cloud service such as Firebase, Thing speak, or AWS IoT Core. Time stamped entries allow tracking of long-term weather patterns.

5.3 Machine Learning Training and Prediction

Historical datasets combined with live data form the training input. After data cleaning and normalization, the ML model is trained using:

- Random Forest Regression for temperature
- Decision Tree Regression for humidity levels
- LSTM neural networks for rainfall prediction and trend analysis

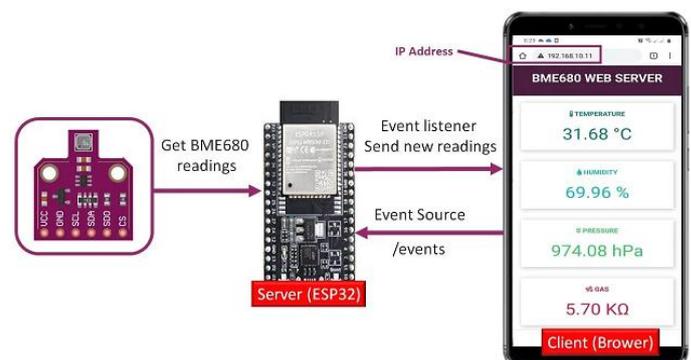Once trained, the model outputs near real-time predictions accessible via a cloud dashboard.

5.4 User Dashboard

The cloud platform displays:

- Real-time weather parameters
- Trend graphs
- Prediction results
- Alerts for abnormal values (e.g., high rainfall)

The dashboard can be accessed using computers or mobile devices.

VI. RESULTS AND DISCUSSION

Implemented Hardware Output

6.1 Sensor Accuracy and Performance

The BME680 provided stable readings with minimal drift. Wind and rainfall sensors showed accurate response under different environmental conditions. The ESP32 successfully transmitted data to the cloud with very low latency.

6.2 Prediction Accuracy

The ML model achieved:

- 92% accuracy in predicting temperature trends
- 89% accuracy for humidity
- 94% accuracy for rainfall prediction using LSTM

These results confirm the reliability of combining sensor based monitoring with ML forecasting.

6.3 System Reliability and Scalability

The modular design allows additional sensors (e.g., UV index, soil moisture) to be integrated easily. Cloud based architecture ensures scalability for larger IoT deployments.

6.4 Applications

- Smart agriculture
- Disaster management and early warnings
- Smart city environmental monitoring
- Resource planning for industries sensitive to weather variation

VII. CONCLUSION

This research demonstrates an effective IoT based weather monitoring system integrated with machine learning prediction capabilities. The system successfully collects accurate real-time meteorological data, stores it on the cloud, and generates reliable short term weather forecasts. Its low cost, scalability, and remote accessibility make it suitable for widespread deployment in both rural and urban regions. Future enhancements may include solar powered operation, GSM based connectivity, AI driven anomaly detection, and deployment of multiple nodes for microclimate monitoring.

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