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IoT Based Solar Monitoring and Time Series Forecasting System

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ABSTRACT
This research proposes the development and implementation of an IoT-based real-time weather monitoring and forecasting system using the ESP32 microcontroller. The primary goal of this system is to enable continuous environmental data acquisition and short-term forecasting to support applications in smart agriculture, climate research, and remote environmental monitoring. The system integrates a DHT22 sensor for temperature and humidity measurement, a BH1750 lux meter for solar irradiance detection, and a digital rain sensor. These sensors are interfaced with the ESP32, which reads the sensor data, displays it on an I2C LCD, and transmits it to the ThingSpeak IoT cloud platform via Wi-Fi.The uploaded data is stored and visualized on the cloud, where a machine learning-based time series forecasting model is implemented to predict environmental conditions for the next six hours. Data preprocessing techniques such as outlier filtering and interpolation are used to improve data quality. Forecasting is performed using polynomial regression, and visual results are generated in MATLAB to show actual vs. predicted trends.
Keywords: Node MCU, Temperature Sensor, Humidity Sensor, Lux Meter, Rain

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I. INTRODUCTION

The rapid advancement in Internet of Things (IoT) technologies has transformed how environmental data is collected, processed, and utilized for real-time decision-making. Weather monitoring systems are essential in various fields including agriculture, smart cities, disaster management, and climate research. Traditional systems often face challenges such as high cost, limited accessibility in remote areas, and lack of predictive capabilities. To address these limitations, this project presents a low-cost, energy-efficient, and intelligent IoT-based weather monitoring and forecasting system.

At the core of this system is the ESP32 microcontroller, known for its integrated Wi-Fi and low-power operation. It interfaces with a DHT22 sensor to capture temperature and humidity, a BH1750 sensor to measure solar irradiance (lux), and a digital rain sensor to detect rainfall presence. The collected environmental data is displayed locally on a 16x2 I2C LCD and simultaneously transmitted to the ThingSpeak IoT cloud platform for remote visualization and storage.

Beyond real-time monitoring, the project incorporates a machine learning-based time series forecasting model implemented in MATLAB. This model processes historical sensor data to predict temperature, humidity, and solar radiation for the next six hours. Data cleaning steps like outlier removal and interpolation ensure accurate model inputs. This predictive functionality enhances the system’s utility, especially in weather-sensitive domains like precision agriculture.

The proposed solution is scalable, solar-power compatible, and deployable in both urban and rural environments. It bridges the gap between real-time sensing and actionable forecasting, offering a complete weather intelligence solution for smart and sustainable development.

The integration of IoT with machine learning not only facilitates real-time data acquisition but also enables systems to become predictive and adaptive over time. This fusion is particularly valuable in agriculture, where timely weather insights can improve crop yield, reduce resource wastage, and mitigate risks from sudden weather changes. In developing regions where access to traditional meteorological infrastructure is limited, this system provides a practical alternative by utilizing affordable sensors and open-source

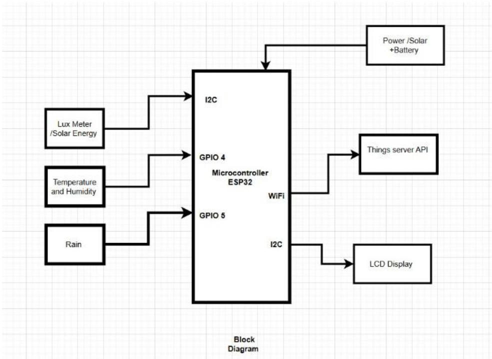

Fig: Block Diagram

Figure 1: Block Diagram

The block diagram illustrates the architecture of an IoT-based weather monitoring and forecasting system using the ESP32 microcontroller. The ESP32 serves as the central processing unit, interfacing with multiple environmental sensors. A DHT22 sensor is connected to GPIO 4 to measure temperature and humidity, while a digital rain sensor is connected to GPIO 5 to detect the presence of rainfall. A BH1750 lux meter, which measures ambient light or solar irradiance, is connected via the I2C communication interface, ensuring efficient digital data transfer. Additionally, an I2C-enabled 16x2 LCD display is used to present real-time sensor data to the user. The entire system is powered by a solar power unit with a battery backup, promoting energy efficiency and remote deployment. The ESP32 uses its inbuilt Wi-Fi capability to transmit sensor data to the ThingSpeak cloud platform, where it is logged, visualized, and further processed for time series forecasting using a machine learning model. This modular and compact architecture enables reliable, real-time weather tracking and prediction with minimal hardware components.

The ESP32 microcontroller acts as the hub, collecting data from environmental sensors and managing communication with external components. The lux meter (BH1750) and LCD display operate on the I2C bus, minimizing pin usage while ensuring synchronized data transfer. The DHT22 and rain sensor provide critical weather parameters like temperature, humidity, and precipitation status through dedicated GPIO pins. The system is powered by a solar energy source with battery backup, making it suitable for remote or off-grid installations. The processed data is sent via Wi-Fi to the ThingSpeak API, where it can be accessed for analysis and forecasting. This architecture supports scalability, allowing additional sensors to be integrated with minimal changes to the core structure.

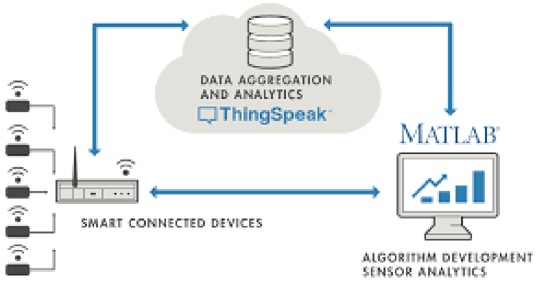

Figure 2: Things Speak Server Communication

The diagram illustrates the data flow architecture of an IoT system using ThingSpeak and MATLAB for sensor analytics and forecasting. Multiple smart connected devices (like ESP32 with sensors) collect environmental data and send it over a network (such as Wi-Fi) to a central gateway or router. From there, the data is uploaded to the ThingSpeak cloud, which performs data aggregation and analytics. ThingSpeak acts as the cloud-based data storage and visualization platform. The data can then be accessed by MATLAB, which enables algorithm development and sensor data analysis, such as time series forecasting or anomaly detection. This setup enables seamless integration of real-time sensor data with advanced analytics tools for intelligent decision-making.

II. METHODOLOGY

The proposed system is designed to monitor key environmental parameters in real time and forecast short-term weather conditions using machine learning techniques. The methodology is divided into four main stages: sensor data acquisition, data transmission, cloud-based processing and storage, and predictive analysis.

The hardware setup includes an ESP32 microcontroller interfaced with three key sensors: a DHT22 for temperature and humidity, a BH1750 for light intensity (solar irradiance), and a digital rain sensor. The DHT22 and rain sensor are connected to GPIO pins for digital input, while the BH1750 and I2C LCD display use the I2C bus for communication. The sensors continuously gather atmospheric data, which is periodically processed and displayed locally on the 16x2 LCD.

The ESP32 uses its built-in Wi-Fi capabilities to connect to a local wireless network. Sensor data is formatted into an HTTP GET request and transmitted to the ThingSpeak IoT platform using its API. ThingSpeak acts as a cloud-based service that stores, visualizes, and manages incoming data streams. The system is also designed to be solar-powered, making it suitable for deployment in off-grid or remote locations.

Data Processing and Forecasting:
On the ThingSpeak platform, collected data is linked with MATLAB analytics to perform time series forecasting. A MATLAB script fetches historical sensor data, cleans it using interpolation and thresholding methods, and applies polynomial regression to predict the next 6 hours of temperature, humidity, and solar lux values. These predictions are visualized using time plots, aiding users in weather-aware decision-making.

Figure 3 : Instrument

III. Flow Chart

The flowchart illustrates the step-by-step process used in the MATLAB script for weather forecasting using ThingSpeak data. It begins with **data acquisition** from the ThingSpeak cloud platform, where real-time sensor values for temperature, humidity, solar lux, and rain are fetched. The next step is **data preprocessing**, which includes handling missing values through interpolation and filtering out outliers based on defined thresholds. A decision block checks if there is **enough valid data** for meaningful forecasting. If valid data is available, the process proceeds to data preparation for forecasting. Then, **p**olynomial models are fitted individually for each parameter (temperature, humidity, and lux). Finally, the forecasted values are plotted along with historical data for visualization. This structured process ensures robust short-term weather prediction and analytics.

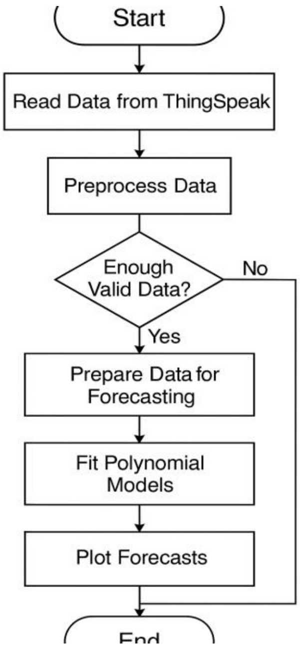

Figure 4:FlowChart

IV. Results and Conclusion:

The flowchart illustrates the step-by-step process used in the MATLAB script for weather forecasting using ThingSpeak data. It begins with **data acquisition** from the ThingSpeak cloud platform, where real-time sensor values for temperature, humidity, solar lux, and rain are fetched. The next step is **data preprocessing**, which includes handling missing values through interpolation and filtering out outliers based on defined thresholds. A decision block checks if there is **enough valid data** for meaningful forecasting. If valid data is available, the process proceeds

Figure 5: Model output

3.1.1 Results

The proposed IoT system successfully captured real-time environmental parameters including temperature, humidity, solar irradiance (lux), and rainfall using low-cost sensors connected to an ESP32 microcontroller. The data was transmitted to the ThingSpeak cloud in a structured and timely manner using Wi-Fi connectivity. The real-time readings were also displayed locally on a 16x2 I2C LCD, ensuring immediate visibility of current weather conditions. the predicted value with the received value

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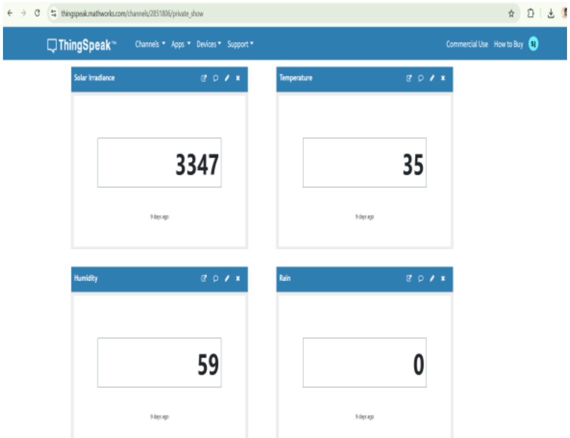

Figure: Real Time Observation

Once the data reached the cloud, it was retrieved using MATLAB for analysis and forecasting. The MATLAB code implemented preprocessing techniques such as interpolation for missing values and threshold-based outlier removal. After cleaning the dataset, polynomial regression was applied to predict the values for the next six hours. The forecasted temperature, humidity, and solar lux were plotted alongside the actual historical data, allowing for a clear visual comparison.

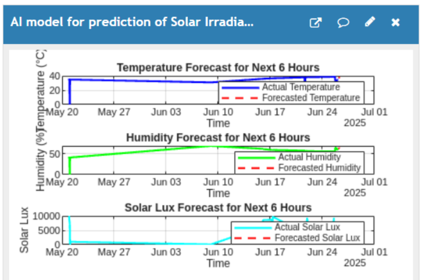

Figure: Time series forecasting result with MATLAB

The model demonstrated good accuracy for short-term predictions over a six-hour horizon. Temperature and humidity trends followed realistic seasonal and diurnal variations, while solar irradiance showed smooth transitions appropriate for daylight data. The rain sensor, while binary in nature, helped indicate weather condition changes. The system proved to be robust, energy-efficient, and reliable for real-time and predictive weather data monitoring.

V. CONCLUSION

Th This project successfully integrated IoT-based sensing and cloud-based forecasting to develop a smart weather monitoring system. Using ESP32, DHT22, BH1750, and a rain sensor, the system gathered reliable weather data and uploaded it to ThingSpeak for storage and analysis. The MATLAB-based time series forecasting algorithm enabled accurate short-term predictions, which are useful for applications like smart farming, environmental research, and disaster preparedness. The system's low power consumption, cost-effectiveness, and solar compatibility make it suitable for deployment in remote or off-grid locations. Future improvements may include the use of deep learning models for more accurate forecasting and the addition of more sensor types such as wind speed, barometric pressure, and soil moisture to enhance system capabilities.

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