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"DESIGN AND IMPLEMENTATION OF AN IOT-BASED WEATHER MONITORING SYSTEM USING ESP32 AND E-PAPER DISPLAY"

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ABSTRACT

Weather monitoring is essential for agricultural decision-making, environmental analysis, and disaster management. Conventional systems are costly, location-specific, and depend heavily on manual data collection. This research presents an IoT-Based Weather Monitoring System using an ESP32 microcontroller and a 2.9-inch Waveshare E-Paper Display to deliver real-time environmental observations. The system continuously captures atmospheric parameters using a DHT11 sensor (temperature and humidity), a rain sensor, a BMP180 sensor (pressure and altitude), and an IR sensor configured as an anemometer (wind speed). Data is processed locally by the ESP32, rendered on an ultra-low-power E-Paper display, and transmitted via Wi-Fi to the Blynk cloud platform for remote access via mobile application. Experimental validation demonstrates that the system achieves high reliability, low energy consumption, and scalable multi-sensor monitoring suitable for precision farming and remote environmental observation.

Keywords: *Weather Monitoring, Internet of Things (IoT), ESP32, E-Paper Display, Blynk, Environmental Sensors.*

I. INTRODUCTION

Weather monitoring plays a vital role in agriculture, environmental studies, disaster management, and day-to-day human activities. Traditional systems are expensive and require manual reading, limiting localized accessibility. With advances in Internet of Things (IoT) technology, automated smart monitoring systems provide accurate, real-time data from remote locations without manual intervention.

The proposed system addresses localized data scarcity by integrating smart sensors with an ESP32 development board. ESP32 serves as the core processor, leveraging built-in Wi-Fi to stream data to cloud platforms. To maintain continuous local visibility under direct sunlight with minimal power consumption, a 2.9-inch E-Paper display is utilized. This combination allows users to track localized temperature, humidity, atmospheric pressure, rainfall, and wind speed in real time via an intuitive dashboard or mobile app.

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II. Review of Literature

- R. Kavin et al. (2020) proposed an IoT-based weather monitoring system to collect real-time environmental parameters. While effective for remote data acquisition, their setup relied on standard display modules with high standby power draw.
- H. Ali et al. (2024) introduced an IoT weather monitoring system tailored for smart agriculture. Their study demonstrated the value of real-time parameter collection for crop management, but noted challenges regarding continuous power management in field deployments.
- K. Acharya (2025) presented an IoT-based monitoring framework focusing on sensor integration and data processing. The work emphasized the necessity of low-cost, scalable architectures to replace manual weather reporting.

The system proposed here builds on these foundations by pairing multi-sensor sensing with an ultra-low-power E-Paper display and Blynk cloud integration, providing both low power operation and dual-mode (local and cloud) visibility.

III. PROBLEM IDENTIFICATION

Conventional weather monitoring solutions present several key operational challenges:

- **High Cost and Fixed Installation:** Traditional stations are expensive and sparsely distributed, leaving rural areas without localized data.
- **High Power Consumption:** Standard LCD or LED screens consume continuous power, making off-grid deployment difficult.
- **Lack of Real-Time Cloud Visibility:** Older data logging setups require manual sample retrieval.

IV. Proposed Methodology

The system architecture consists of sensor modules, an ESP32 processing unit, an E-Paper display, and cloud connectivity.

Parameter	Sensor	Interface / Protocol
Temperature & Humidity	DHT11	Digital Input (GPIO 27)
Rainfall Detection	Rain Sensor	Analog Input (GPIO 34)
Atmospheric Pressure & Altitude	BMP180	I2C (SDA: GPIO 21, SCL: GPIO 22)
Wind Speed	IR Sensor (Anemometer)	Digital Interrupt (GPIO 14)
Local Display	Waveshare 2.9" E-Paper	SPI (CS: 5, DC: 17, RST: 16, BUSY: 4)

System Flow & Processing:

1. **Data Acquisition:** The ESP32 reads environmental values sequentially. Wind speed is calculated via pulse counting over 3-second intervals using an external interrupt handler.

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2. **Local Output:** Sensory data and time fetched via Network Time Protocol (NTP) are updated on the E-Paper screen using the `GxEPD2` and `Adafruit_GFX` libraries.
3. **Cloud Transmission:** Sensor metrics are transmitted over Wi-Fi to the Blynk IoT platform via virtual pins (V0–V4) every 15 seconds.

V. RESULT & DISCUSSION

Experimental evaluation was performed under real-time field operating conditions. Recorded measurements show steady execution and consistent display output:

Environmental Parameter	Observed Sensor Reading	Blynk Virtual Pin
Temperature	37.4 °C	V0
Humidity	22.0 %	V1
Rain Status	DRY (Analog > 2000)	V2
Wind Speed	Calculated via IR pulses (m/s)	V3
Atmospheric Pressure	Measured in hPa (BMP180)	V4

The E-Paper display successfully retained readable weather metrics without drawing power between screen refresh cycles. Remote monitoring via the Blynk application confirmed real-time data synchronization.

VI. Conclusion

The IoT-Based Weather Monitoring System provides a practical, automated, and energy-efficient solution for local environmental tracking. Combining the ESP32 microcontroller with an E-Paper display allows for low-power operation and clear sunlight readability. The integration of Blynk cloud connectivity ensures remote access for agricultural planning, smart city infrastructure, and disaster warnings.

VII. FUTURE SCOPE

- **Machine Learning Integration:** Implement predictive algorithms for localized weather forecasting.
- **Solar Energy Integration:** Add a solar-powered harvesting circuit to enable off-grid operation.
- **Long-Range Connectivity:** Incorporate LPWAN technologies like LoRa for remote agricultural environments

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