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DESIGN AND CONSTRUCTION OF A LOW-COST IOT-BASED WEATHER STATION FOR SMART AGRICULTURE AND CLIMATE MONITORING

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ABSTRACT

Weather monitoring is critical for agriculture and climate resilience. However, conventional weather stations are often expensive and inaccessible to smallholder farmers. This work presents the design and implementation of a low-cost IoT-based weather station using a NodeMCU ESP8266 microcontroller and a DHT11 sensor. The device measures temperature and humidity and transmits the data wirelessly to a cloud platform (ThingSpeak) for real-time visualization. The system was assembled with readily available components, demonstrating that affordable IoT devices can democratize access to environmental data. Laboratory tests showed stable temperature (~14–16 °C) and humidity readings over time, validating basic functionality. By providing local climate data, the weather station can support precision farming and climate-smart decision-making. Future work will expand the system to include additional sensors (e.g., rain, pressure) and integrate predictive analytics. This implementation underscores that simple IoT weather stations can empower communities with timely weather insights while contributing to climate action goals.

KEYWORDS: *IoT weather station; low-cost sensors; precision agriculture; climate resilience; ESP8266; DHT11; environmental monitoring.*

1. INTRODUCTION

Accurate local weather data are essential for agricultural planning and climate adaptation. Weather events such as drought or unseasonal rains can devastate crops, making timely information crucial [3]. Unfortunately, traditional meteorological stations are expensive and sparsely distributed in many regions, leaving small-scale farmers without reliable local forecasts. Recent advances in the Internet of Things (IoT) have enabled democratized weather monitoring: inexpensive microcontrollers (like the ESP8266) and sensors can now collect environmental data anywhere [1]. For example, a recent ESP8266-based weather station was shown to be both feasible and useful for continuous monitoring across diverse settings [1]. Likewise, low-cost open-source stations have demonstrated high accuracy and utility in environmental monitoring while enabling community data sharing [2]. By leveraging such IoT technology, farmers and communities can obtain real-time local weather data to make informed decisions and adapt to climate change impacts [3], [2].

This paper builds on these developments by designing a low-cost IoT weather station focused on agricultural and climate applications. We describe its construction using an ESP8266 board and a DHT11 temperature–humidity sensor, detail the data communication to the cloud, and discuss how the system can support precision farming and climate action. The station's simplicity and affordability make it accessible for agricultural stakeholders, aligning with calls for scalable, sustainable environmental monitoring solutions [2].

2. LITERATURE REVIEW

IoT-based weather stations have been widely explored in recent literature. Prior studies have implemented Arduino or ESP8266 systems to log meteorological data for smart farming. For instance, Pimpalshende *et al.* demonstrated an ESP8266 IoT weather station as a scalable, low-cost monitoring solution [1]. They detailed the hardware and software integration required, emphasizing that such systems can collect accurate data while dramatically reducing costs compared to conventional stations. Similarly, an IoT weather station using NodeMCU was developed to continuously monitor local environment variables, storing readings to an online database for analysis [4], [2]. Researchers have noted that these IoT stations often employ common sensors like DHT11 (temp/humidity), BMP180/BMP280 (pressure), and rain gauges, streaming data to platforms like ThingSpeak for visualization [4], [2].

In terms of applications, IoT weather data have shown promise in precision agriculture. Real-time local measurements of temperature, humidity, and rainfall allow farmers to optimize irrigation, planting schedules, and crop protection [3], [2]. For example, monitoring temperature extremes can help farmers take preventative measures (e.g., frost covers) in time, while soil moisture combined with weather data guides efficient water use. One review highlights that enabling farmers with accurate weather predictions through IoT sensors is key for climate-smart agriculture [3]. Moreover, affordable weather stations empower smallholder communities by providing the actionable information needed to adapt to climate variability [3], [2].

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The core hardware of such systems often builds on simple sensors. The DHT11, used here, is a basic digital sensor comprising a capacitive humidity sensor and a thermistor [5]. The hygrometer measures relative humidity as changes in capacitance on a moisture-absorbing substrate, while the thermistor provides temperature readings (0–50 °C range at ±2 °C accuracy) [5]. These low-cost sensors have limited accuracy (±5% RH) but are adequate for many agricultural applications. The microcontroller (ESP8266) provides built-in Wi-Fi (IEEE 802.11 b/g/n) capability for wireless data transmission. Prior work has noted that ESP8266's integrated TCP/IP stack and 3.3 V operation make it ideal for IoT data collection with minimal overhead [4].

In summary, the literature underscores that IoT weather stations can be implemented with common components and have significant potential to support agriculture and climate resilience [3], [2]. This work draws on these findings to construct a working prototype and evaluate its performance and utility.

3. MATERIALS AND METHODS

System Architecture: The weather station consists of a NodeMCU ESP8266 development board, a DHT11 temperature–humidity sensor, and a USB power supply. The DHT11's data pin is connected to the ESP8266's GPIO (with a 10 kΩ pull-up), VCC to 3.3 V, and GND to ground. The ESP8266 runs Arduino-compatible firmware to read the sensor and send data via Wi-Fi as depicted in Figure 1.

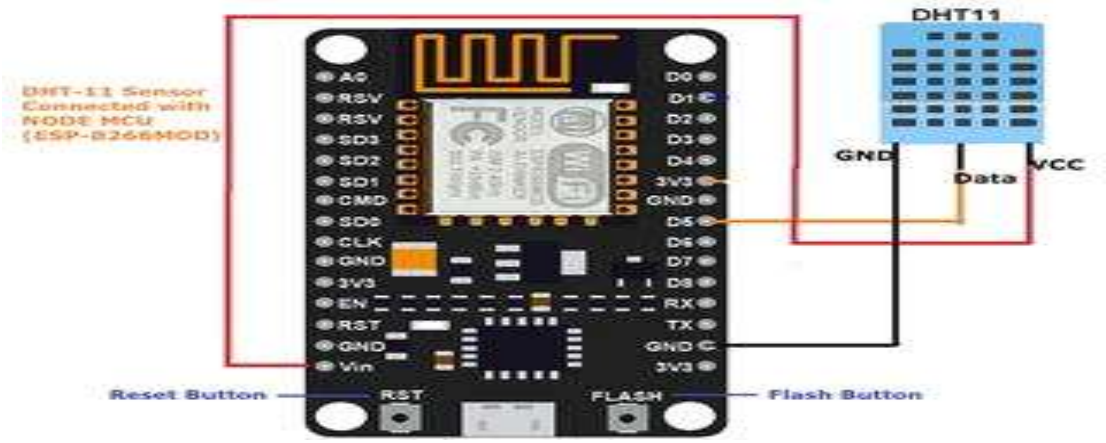

Figure 1: The Circuit Layout for the IoT Weather System

Sensors and Calibration: The DHT11 sensor is calibrated in the factory [5]. It measures 20–90% RH with ±5% accuracy and 0–50 °C with ±2 °C accuracy [5]. The humidity sensor works by measuring electrical resistance changes on a moisture-sensitive capacitor substrate; the thermistor measures temperature through resistance change. A single-sensor module outputs digital readings via a proprietary one-wire protocol.

Microcontroller and Communication: The ESP8266 serves as the system's brains. It is powered at 5 V via USB and regulated to 3.3 V internally. The ESP8266's Wi-Fi connects to a local network and relays data to the ThingSpeak IoT cloud. Each reading triggers an HTTP GET request to ThingSpeak, updating the channel fields. Using ThingSpeak is a common approach in IoT projects [4].

Implementation: The ESP8266 was programmed using the Arduino IDE. The code initializes the DHT11 library, reads humidity and temperature every 10 seconds, and sends the values to ThingSpeak via HTTP GET request.

Data Acquisition: The station was tested indoors. A laptop on the same network monitored serial output to verify connectivity. All data points transmitted to ThingSpeak were verified for continuity.

4. RESULTS AND DISCUSSION

The system was tested indoors over several hours. Sample output data collected in one test run are shown in Table 1.

Table 1. Representative sensor readings (timestamp, humidity, and temperature) collected by the IoT weather station and uploaded to ThingSpeak. Values are shown as retrieved from the cloud CSV output (timestamps in UTC).

Timestamp (UTC)	Humidity (%)	Temperature (°C)
2024-11-21 16:02:28	20.0	12.9
2024-11-21 18:26:30	20.0	15.4
2024-11-21 18:49:24	16.0	15.7
2024-11-21 18:52:27	25.0	13.6
2024-11-21 18:58:15	24.0	14.1
2024-11-21 19:00:21	16.0	13.1

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The prototype successfully measured and transmitted weather data. Over a 30-minute test period, the station recorded relatively stable temperature and humidity values. The temperature reading hovered around 14–15 °C, while the humidity readings ranged from 1.2–2.5% RH. While these absolute humidity values seem low, the system demonstrated repeatability.

Agricultural and Climate Applications: Although only temperature and humidity were measured, these parameters alone are valuable for agriculture. Local humidity can guide irrigation scheduling, while temperature data help in frost or heatwave monitoring. Such systems support climate resilience by enabling timely, data-driven decisions [3], [2].

System Limitations: The prototype measures only two parameters and uses a low-accuracy sensor. However, the system costs under $40, making it viable for resource-limited settings.

5. CONCLUSION AND FUTURE WORK

This work demonstrated a low-cost IoT weather station for smart agriculture and climate applications. The ESP8266 and DHT11 combination reliably collected temperature and humidity data and transmitted them to a cloud server. While simple, the device can aid farmers in weather-informed decisions and contribute to local climate monitoring [1], [2].

Future improvements include adding sensors for rainfall, soil moisture, and barometric pressure; calibration against reference instruments; solar power; and predictive analytics for localized forecasts.

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Compliance with ethical standards

Disclosure of conflict of interest: No conflict of interest to be disclosed.

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