

Literature Survey on Compact Real-Time Weather Sensing System

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Abstract-- Accurate weather sensing is essential for understanding local atmospheric conditions and supporting applications such as agriculture, environmental assessment, transportation, and outdoor operations. Conventional weather stations often involve relatively large installations and may not be suitable for compact, portable applications. This paper presents a literature-based study of a Compact Real-Time Weather Sensing System designed to integrate multiple meteorological sensors within a portable and low-cost architecture. The proposed system uses an ESP32 microcontroller to acquire and process data from sensors measuring temperature, relative humidity, atmospheric pressure, wind speed, and wind direction. Wi-Fi and Bluetooth connectivity are considered for wireless data transmission, while an OLED display provides local access to the sensed parameters. The study reviews existing weather-sensing approaches, compares their sensing capabilities, controller technologies, communication methods, and portability, and identifies opportunities for improved sensor integration and compact design. The proposed architecture aims to provide real-time acquisition of essential weather parameters in a battery-operated unit. As hardware development and experimental validation are ongoing, the system's measurement accuracy, power consumption, and outdoor performance require further evaluation. This study establishes a foundation for developing an integrated, portable, and practical weather-sensing solution.

Keywords— Weather sensing, ESP32, wind speed, wind direction, temperature, humidity, atmospheric pressure, IoT, portable weather station.

I. INTRODUCTION

Weather sensing plays an important role in understanding atmospheric conditions by measuring essential meteorological parameters such as temperature, humidity, atmospheric pressure, wind speed, and wind direction. Accurate and timely acquisition of these parameters is useful in applications such as agriculture, aviation, environmental studies, disaster management, and local weather assessment. Recent advancements in sensors and embedded systems have enabled the development of compact, portable, and low-cost weather-sensing devices capable of collecting atmospheric data in real time.

The Compact Real-Time Weather Sensing System focuses on acquiring and processing weather-related parameters using suitable sensors and a microcontroller. The proposed system uses an ESP32 as the central processing unit, integrated with sensors for measuring temperature, humidity, atmospheric pressure, wind speed, and wind direction. The sensed parameters are processed to obtain meaningful meteorological information, which can be displayed on an OLED screen and transmitted wirelessly through Wi-Fi or Bluetooth. Its compact design and battery-powered operation support portability and flexible deployment in different environments.

Unlike systems primarily designed for continuous weather monitoring and long-term data visualization, weather sensing emphasizes the direct acquisition, measurement, and processing of atmospheric parameters. Integrating multiple sensors into a single compact unit can reduce system complexity and provide localized weather measurements. This study examines existing weather-sensing approaches, their underlying technologies, advantages, and limitations to identify opportunities for developing an efficient, portable, and cost-effective real-time weather-sensing system.

II. LITERATURE SURVEY

The literature survey examines existing research on weather-sensing technologies, sensor integration, embedded controllers, and wireless data acquisition. The selected studies provide a foundation for understanding the capabilities and limitations of compact real-time weather-sensing systems, particularly those measuring temperature, humidity, atmospheric pressure, wind speed, and wind direction.

Review of Existing Research:

Paper 1: Low-Cost IoT-Based Weather Station for Real-Time Data Acquisition

Alam et al. [1] proposed a low-cost IoT-based weather station using NodeMCU and Arduino UNO controllers. The system incorporated a three-cup anemometer for wind-speed measurement, a wind vane for wind-direction measurement, a DHT22 sensor for temperature and humidity, and a rain gauge for rainfall measurement.

The collected data were processed and transmitted to the ThingSpeak cloud platform. The study demonstrated the feasibility of integrating multiple meteorological sensors into an affordable system. However, its emphasis on cloud-based data access leaves opportunities for improving compactness, local data presentation, and integrated atmospheric sensing.

Paper 2: Efficient IoT-Based Weather Station

The study Efficient IoT Based Weather Station 2 presented a weather station developed using a NodeMCU controller and Blynk IoT technology. The system measured temperature, humidity, atmospheric pressure, and rainfall, allowing users to access weather information through an application. The approach demonstrated the usefulness of embedded processing and wireless communication in collecting environmental data. However, the reported system's parameter selection does not establish a complete integrated solution for wind-speed and wind-direction sensing, which are important requirements for the proposed system.

Paper 3: Low-Cost Automatic Weather Stations in the Internet of Things

In 2021, Dombrowski et al. 3 investigated the performance of the ATMOS41 all-in-one weather station, while the broader research on low-cost automatic weather stations examined the integration of IoT, edge computing, and low-power communication technologies. These approaches support the collection of multiple meteorological parameters using integrated sensing platforms. However, practical implementation still requires consideration of sensor accuracy, power consumption, calibration, and suitability for the intended application. This research highlights the importance of evaluating the reliability of compact sensing hardware rather than focusing only on data connectivity.

Paper 4: IoT-Based Weather Station Using NB-IoT Communication

Wang et al. 4 proposed a low-power weather station based on Narrowband Internet of Things (NB-IoT) communication. The design used an STM32L051C8T6 microcontroller, environmental sensors, a wireless communication module, and an energy-harvesting arrangement using a solar panel and supercapacitors. The system was designed to acquire environmental parameters and transmit the collected information to a cloud platform while reducing power consumption.

Although the approach is suitable for long-duration remote deployment, its communication and energy-management architecture differs from a compact battery-powered system intended to provide immediate local readings.

Paper 5: IoT-Based Weather Monitoring Station for Smart City

Azmira and Kian Sek 5 developed a weather station for smart-city applications using Arduino Uno R3, an ESP32-based Wi-Fi module, multiple environmental sensors, and LoRa-based communication between client and master units. The system collected parameters including temperature, humidity, wind speed, air quality, ultraviolet radiation, and rainfall, with information transmitted to the Arduino Cloud IoT platform. The study demonstrated the potential of combining multiple sensors with wireless communication for localized atmospheric data acquisition. However, its distributed architecture and cloud-oriented presentation leave scope for a simpler, portable sensing unit that integrates local display and essential meteorological measurements.

Paper 6: An IoT-Based Real-Time Weather Sensing System Using ESP32

Bestari and Wibowo 6 presented an ESP32-based weather-data acquisition system using an SHTC3 sensor, BMP180 pressure sensor, wind-speed and wind-direction anemometers, and a tipping-bucket rain gauge. The system collected temperature, humidity, atmospheric pressure, wind speed, wind direction, and precipitation data. MQTT, WebSocket, and HTTP-based communication supported data presentation through ThingsBoard and a Telegram bot. The study is particularly relevant because it integrates several parameters required for a comprehensive weather-sensing platform. Nevertheless, further investigation into compact hardware integration, power efficiency, and direct local data access can help address the requirements of a portable, cost-effective sensing device.

III. COMPARATIVE ANALYSIS OF EXISTING SYSTEMS

The literature indicates that existing weather-monitoring solutions can generally be grouped into three categories: conventional weather stations, microcontroller-based systems and IoT-enabled portable systems.

Conventional weather stations provide comprehensive measurements but generally require dedicated infrastructure and fixed installation.

Microcontroller-based weather stations reduce cost and complexity but may require separate modules for wireless communication and data processing. IoT-based systems provide remote accessibility but often depend on internet connectivity and focus on a limited set of environmental parameters.

The reviewed systems show that the integration of temperature, humidity, atmospheric pressure, wind speed and wind direction into a single compact portable platform is an area that can be further developed.

Ref.	System / Technology	Parameters sensed	Limitation / Research scope
[1]	NodeMCU, Arduino, ThingSpeak (2020)	Temp., humidity, wind speed/direction, rainfall	Cloud-dependent data access
[2]	NodeMCU, Blynk (2020)	Temp., humidity, pressure, rainfall	Wind sensing not included
[3]	ATMOS41 integrated station (2021)	Temp., humidity, pressure, wind, rainfall, radiation	Cost and measurement uncertainty
[4]	STM32, NB-IoT, energy harvesting (2022)	Environmental parameters	Requires specialized communication hardware
[5]	Arduino, LoRa, cloud platform (2022)	Temp., humidity, wind speed, air quality, UV, rainfall	Increased system complexity
[6]	ESP32, MQTT, ThingsBoard (2023)	Temp., humidity, pressure, wind speed/direction, rainfall	Focuses on data presentation
Proposed	ESP32, BME280/BMP280, wind sensors, OLED	Temp., humidity*, pressure, wind speed/direction	Compact, portable design with local display and optional wireless access

Table 1. General Comparison of Existing Approaches

IV. RESEARCH GAP

The reviewed studies demonstrate that embedded controllers, meteorological sensors, and wireless communication can support real-time weather-data acquisition. However, several opportunities remain for improvement:

- *Compact integration:* Combining essential atmospheric and wind sensors in a single portable unit.
- *Local data accessibility:* Providing immediate readings through an onboard display without depending entirely on cloud connectivity.
- *Power efficiency:* Supporting battery-powered operation for flexible deployment.
- *Integrated sensing:* Acquiring temperature, humidity, atmospheric pressure, wind speed, and wind direction within one system.
- *Cost and simplicity:* Reducing hardware complexity while maintaining useful measurement capabilities.

Based on these observations, the proposed Compact Real-Time Weather Sensing System focuses on integrating essential meteorological sensors with an ESP32 controller, OLED display, and wireless communication in a portable design.

Its performance and measurement accuracy will require experimental validation after hardware implementation.

V. PROPOSED SYSTEM

The proposed system is a Compact Real-Time Weather Sensing System designed to acquire and process essential meteorological parameters using an ESP32 microcontroller and integrated sensors. The system measures temperature, humidity, atmospheric pressure, wind speed, and wind direction to provide localized weather information in real time.

The ESP32 acts as the central processing unit, collecting sensor outputs and processing the measured data. A BME280 sensor is used to measure temperature, humidity, and atmospheric pressure, while dedicated wind sensors measure wind speed and direction. An OLED display provides immediate access to the sensed readings, and the ESP32's Wi-Fi and Bluetooth capabilities enable optional wireless data transmission.

The system is designed to be compact, portable, and battery-powered, making it suitable for localized weather-data acquisition in outdoor environments. Unlike approaches that primarily emphasize cloud-based visualization, the proposed design prioritizes direct sensing, local processing, and immediate presentation of atmospheric parameters.

VI. SYSTEM ARCHITECTURE

The overall architecture consists of five major functional blocks:

Sensing Unit → ESP32 Processing Unit → Data Processing
 → Display Unit → Wireless Communication

The sensing unit contains the BME280, wind-speed sensor and wind-direction sensor. The ESP32 collects the sensor outputs and performs data processing. The processed information is displayed on an OLED display and can be transmitted wirelessly through Wi-Fi or Bluetooth.

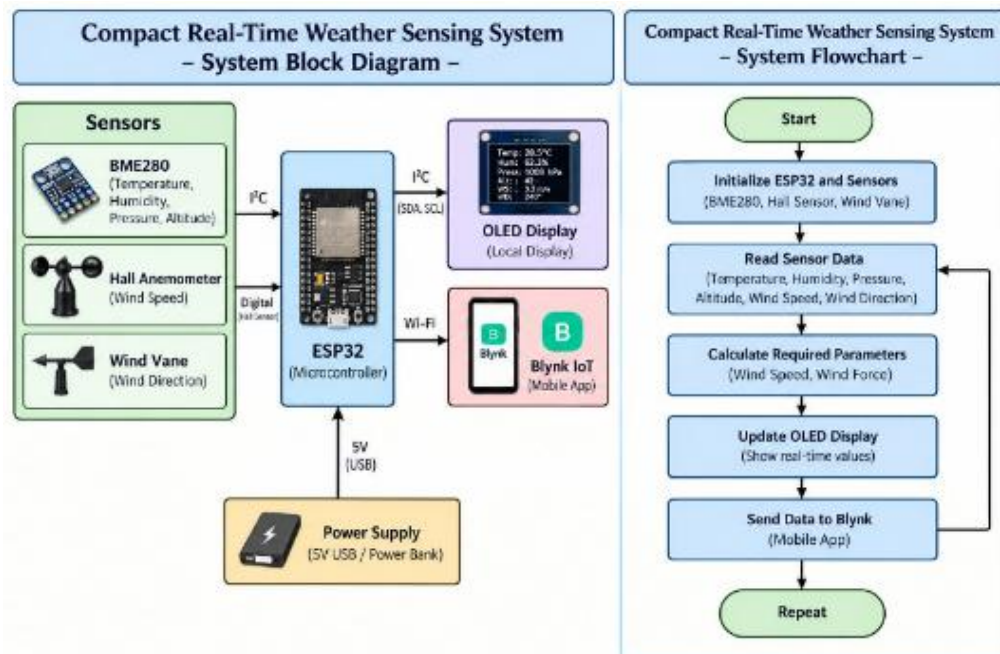


Figure 1. Proposed system architecture & Flowchart

VII. HARDWARE REQUIREMENTS

The proposed system consists of the following major components:

ESP32: Main controller responsible for sensor interfacing, data processing and wireless communication.

BME280: Environmental sensor used to measure temperature, relative humidity and atmospheric pressure.

Anemometer: Sensor used to determine wind speed.

Wind Direction Sensor: Determines the direction from which the wind is blowing.

OLED Display: Provides local real-time visualization of measured parameters.

3.7 V Li-ion Battery: Provides portable power to the system.

TP4056 Charging Module: Provides battery charging functionality.

Outdoor Enclosure: Protects the electronics from the external environment while allowing appropriate sensor exposure.

VIII. WORKING PRINCIPLE

The system begins by initializing the ESP32 and connected sensors. The BME280 continuously measures temperature, humidity and atmospheric pressure, while the wind sensors provide wind-speed and wind-direction information.

The ESP32 reads the sensor outputs at regular intervals and processes the acquired data. The measured values are then formatted for display on the OLED screen. Depending on the communication requirement, the data can also be transmitted wirelessly using Wi-Fi or Bluetooth.

The complete sequence can be represented as:

Start → Initialize ESP32 and Sensors → Acquire Wind Speed and Direction → Acquire Temperature, Humidity and Pressure → Process Data → Display Results → Wireless Transmission → Continuous Monitoring

IX. APPLICATIONS

The proposed Compact Real-Time Weather Sensing System can be used in the following applications:

1. *Agriculture*: Sensing local temperature, humidity, atmospheric pressure, and wind conditions to support agricultural planning and field activities.
2. *Environmental Studies*: Collecting localized atmospheric data for environmental assessment and microclimate studies.
3. *Aviation*: Providing supplementary local wind measurements for educational and experimental applications.
4. *Disaster Preparedness*: Identifying changes in local wind conditions that may support preliminary weather-risk assessment.
5. *Smart Cities*: Integrating localized weather-sensing data into smart-city and environmental data-acquisition networks.
6. *Industrial Safety*: Assessing local wind conditions in suitable outdoor industrial environments.
7. *Educational and Research Purposes*: Demonstrating sensor interfacing, embedded systems, IoT communication, and real-time meteorological data acquisition.
8. *Remote and Outdoor Locations*: Enabling portable weather-data collection at locations where fixed weather stations may be unavailable.

X. ADVANTAGES

1. *Compact Design*: Integrates multiple weather sensors into a single portable unit.
2. *Real-Time Sensing*: Acquires essential atmospheric parameters continuously during operation.
3. *Multi-Parameter Measurement*: Measures temperature, humidity, atmospheric pressure, wind speed, and wind direction.
4. *Low-Cost Implementation*: Uses commonly available sensors and an ESP32 microcontroller.
5. *Wireless Connectivity*: Supports optional data transmission through built-in Wi-Fi and Bluetooth.
6. *Local Data Display*: Provides immediate access to weather readings through an OLED display.
7. *Portable Operation*: Battery-powered design enables deployment at different locations.

8. *Low Power Potential*: Can be optimized for reduced energy consumption during field operation.
9. *Expandable Architecture*: Additional sensors and data-processing features can be incorporated when required.
10. *Simple Operation*: Provides a practical and user-friendly approach to localized weather-data acquisition.

XI. LIMITATIONS

1. *Sensor Accuracy*: Measurement accuracy depends on sensor specifications, calibration, and operating conditions.
2. *Weather Exposure*: Sensors and electronic components require suitable protection against rain, dust, and extreme environmental conditions.
3. *Limited Battery Life*: Continuous sensing and wireless transmission can increase power consumption.
4. *Wind Measurement Constraints*: Mechanical anemometers and wind-direction sensors may be affected by friction, installation, and obstruction.
5. *Limited Communication Range*: Wi-Fi and Bluetooth communication depend on distance, obstacles, and environmental conditions.
6. *No Independent Weather Forecasting*: The system primarily measures current atmospheric conditions and does not independently predict future weather.
7. *Maintenance Requirements*: Periodic sensor inspection, calibration, and cleaning may be necessary.
8. *Environmental Interference*: Improper sensor placement, direct sunlight, and nearby structures can affect measurement reliability.
9. *Limited Spatial Coverage*: A single unit provides localized readings that may not represent weather conditions across a wider region.
10. *Prototype Validation*: Measurement accuracy, durability, and long-term performance must be evaluated through practical testing before deployment.

XII. FUTURE SCOPE

1. *Advanced Sensor Integration*: Incorporate rainfall, solar radiation, and air-quality sensors to measure additional environmental parameters.
2. *AI-Based Weather Prediction*: Integrate machine-learning algorithms to analyze historical and real-time sensor data for localized weather prediction.
3. *Cloud-Based Data Storage*: Enable cloud connectivity for long-term data logging, visualization, and remote access.

4. *Solar-Powered Operation:* Integrate a solar panel and efficient power-management circuit to extend operating time in outdoor environments.
5. *Improved Measurement Accuracy:* Implement sensor calibration, filtering, and compensation techniques to improve the reliability of measurements.
6. *Mobile Application Development:* Develop a mobile application to display real-time readings, historical trends, and weather alerts.
7. *Advanced Wireless Communication:* Integrate LoRa or cellular communication for data transmission over longer distances.
8. *Rugged Outdoor Design:* Develop a weather-resistant enclosure and improve sensor placement for reliable operation under different environmental conditions.
9. *Multiple Station Integration:* Connect several sensing units to create a localized weather-data network for comparing conditions across different locations.
10. *Automated Weather Alerts:* Introduce threshold-based alerts for strong winds and other significant atmospheric changes to support early awareness of potentially hazardous conditions.

XIII. CONCLUSION

The proposed Compact Real-Time Weather Sensing System aims to provide an efficient, portable, and cost-effective solution for acquiring essential meteorological parameters, including temperature, humidity, atmospheric pressure, wind speed, and wind direction. By integrating an ESP32 microcontroller with suitable sensors, an OLED display, and wireless communication, the system is designed to support real-time data acquisition, processing, and local presentation of weather information.

Its compact architecture and battery-powered operation offer flexibility for deployment in different environments. The proposed system provides a foundation for further improvements in measurement accuracy, energy efficiency, and intelligent data processing. Future development may include cloud integration, advanced analytics, and automated weather alerts. Practical implementation and experimental validation will be essential to evaluate its performance and establish its suitability for real-world weather-sensing applications.

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