E3S Web of Conferences **430**, 01092 (2023) https://doi.org/10.1051/e3sconf/202343001092
ICMPC 2023

Developing a Sustainable IoT-based Smart Weather Station for Real Time Weather Monitoring and Forecasting

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Abstract. Weather forecasting is an important aspect of many industries and activities, from agriculture to transportation. The main motive of this research is to design a sustainable smart weather station to track temperature, humidity, wind speed, and other weather parameters, and send the data to the IOTA network via a Wi-Fi module. The GISMO micro controller provides the necessary processing power to collect and store data, while the Wi-Fi module allows for real-time monitoring and remote access to the data. The data collected by the smart weather station can be used for weather forecasting, climate research, and disaster management. The proposed model is used to develop the accurate weather information in real-time, making it an ideal solution for individuals and organizations looking to monitor local weather conditions. By leveraging IoT technology, smart weather stations offer numerous advantages over traditional weather monitoring systems. The research mainly focuses to enable seamless data collection from multiple sensors placed strategically in various locations, providing a comprehensive view of weather conditions across different areas.

1 Introduction

Smart weather stations utilize a network of interconnected devices, sensors, and cloud-based platforms to collect, analyse, and share real-time weather information. Cloud computing is an effective IT infrastructure platform, but it still requires considerable security efforts, to reduce its flaws [9]. Because cloud data centre has a large quantity of personal and business information, security concerns and vulnerabilities related to cloud computing must be

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detected and mitigate. The station has the ability to monitor a wide range of meteorological parameters such as temperature, humidity, atmospheric pressure, wind speed, rainfall, and UV index, among others. By leveraging IoT technology, smart weather stations offer numerous sustainable advantages over traditional weather monitoring systems. They enable seamless data collection from multiple sensors placed strategically in various locations, providing a comprehensive view of weather conditions across different areas. The real-time nature of IoT allows for immediate updates and alerts, enhancing safety measures and decision-making for various sectors, including agriculture, aviation, transportation, and emergency services. Weather forecasting is an important aspect of many industries and activities, from agriculture to transportation. The system is designed to track temperature, humidity, wind speed, and other weather parameters, and send the data to the IOTA network via a Wi-Fi module. The GISMO micro controller provides the necessary processing power to collect and store data, while the Wi-Fi module allows for real-time monitoring and remote access to the data. The data collected by the smart weather station can be used for weather forecasting, climate research, and disaster management. This system is easy to set up and provides accurate weather information in real-time, making it an ideal sustainable solution for individuals and organizations looking to monitor local weather conditions.

2 Literature Survey

In this research paper, we present the development of a low-cost wireless weather station with Node MCU for sensor data collecting and transmission [1]. Accompanied by an IoT-based graphical application software. Our weather station is designed to provide users with easy access to accurate weather information, including Temperature, Pressure, Humidity, Rainfall, and Altitude measurements. Our experimental results demonstrate that our weather station exhibits good accuracy and stability compared to other affordable weather stations available in the market. The system features a user-friendly interface and requires minimal maintenance, resulting in cost-effectiveness. Furthermore, in future work, we aim to enhance the system by incorporating additional functionalities such as wind direction, solar radiation, and precipitation measurement. Further research efforts can be directed towards optimizing the system's cost to make it as affordable as possible.

The presence and placement of each module in the "IoT Weather Station using Arduino Uno" have been meticulously reasoned and carefully implemented [2]. This thoughtful approach contributes to the seamless functioning of the entire system. Moreover, the utilization of Wi-Fi technology to upload the weather sensor data to the Thing Speak web cloud further enhances the efficiency. As a result of thorough design and testing, it has been successfully executed, meeting its objectives effectively.

Monitoring the weather holds significant value in various practical Agriculture, archaeology, construction, tourism, and many other professions are examples of scenarios [3]. Weather monitoring can be carried out manually or automatically. With the increasing use of the internet, many areas have adopted IoT-based technologies for weather monitoring. Consequently, the traditional manual weather station has evolved into a Weather Station with

Intelligence. This research focuses on developing a Weather Station with Intelligence capable of accurately monitoring weather conditions and delivering real-time weather information to end-users. The primary goal is to create a modular and cost-effective system that uses renewable energy sources to monitor real-time weather conditions and improve local agriculture. The presence and placement of each module in the "IoT Weather Station using Arduino Uno" have been meticulously reasoned and carefully implemented. As a result of thorough design and testing, has been successfully executed, meeting its objectives effectively. Further research efforts can be directed towards optimizing the system's cost to make it as affordable as possible.

The cloud technology has become increasingly popular in the IoT domain, offering numerous advantages for both organizations and individuals [9]. One of the primary objectives is to reduce data storage and infrastructure costs. In the current system, a cloud-based approach is employed instead of a traditional database management system. This shift significantly lowers the expenses associated with using and managing complex databases. The cloud service provides efficient storage and retrieval capabilities for data. Rather than relying on a local database, a global database is located worldwide and accessed through the internet, making it accessible from anywhere in the world. Users can access this data through various devices such as palmtops, desktops, or mobile phones, enhancing scalability and convenience. To ensure secure communication between the cloud and the consumer, a homomorphic encryption technique is utilized in the present work. This technique is chosen due to its ability to minimize limitations arising from communication overheads. Additionally, the implementation of lightweight homomorphic strategies further mitigates the drawbacks associated with existing security schemes.

This research paper presents a prototype system for a low-cost and effective weather station with a monitoring system [5]. The system utilizes Arduino Uno and ZigBee communication technique to transmit and receive weather data. The system demonstrates the capability to collect and record six different types of data, including rain state, wind level, air pressure, dust density, temperature, and humidity. The presence and placement of each module in the "IoT Weather Station using Arduino Uno" have been meticulously reasoned and carefully implemented. This thoughtful approach contributes to the seamless functioning of the entire system. The stored data can be retrieved at any given time and date. The results obtained from the proposed weather station are compared with data from www.weather.com, showing excellent accuracy across all readings. This comparison validates the reliability and performance of the proposed model, making it suitable for deployment without an internet connection in various regions of Iraq [11-25].

3 Methodology

The goal is to design and build a smart weather station that measures temperature, humidity, wind speed, and other meteorological parameters and communicates the data to the IOTA network via a Wi-Fi module. The ESP32 microcontroller-based smart weather station offers a practical and affordable way to keep track on local weather conditions. The ESP32 microcontroller and a number of weather sensors will be used in the design and construction of the weather station. Data from the sensors will be gathered and processed by the ESP32

https://doi.org/10.1051/e3sconf/202343001092

before being sent to the IOTA network through a Wi-Fi module. A web-based interface will make the data available, enabling real-time monitoring and analysis.

3.1 Automated Weather Monitoring System

The Internet of Things (IoT) is a revolutionary concept that entails connecting a wide range of devices, objects, and systems over the internet. Everything from everyday household goods and wearable devices to industrial gear and infrastructure is included. These devices in the IoT ecosystem are outfitted with sensors, actuators, and software that allow them to gather and transmit data. This information might range from basic environmental measures to detailed information about user behaviour and preferences. Various connectivity technologies, such as Wi-Fi, Bluetooth, cellular networks, and low-power wide-area networks (LPWANs), enable seamless communication and data sharing between IoT devices. These technologies offer real-time monitoring, control, and automation, which has a wide range of applications. IoT has ushered in the era of smart manufacturing and predictive maintenance in the industrial sector. Connected sensors and devices provide for real-time monitoring of machinery, allowing for better operations, less downtime, and lower maintenance costs. Thing Speak is a cloud based IoT analytics platform that enables users to gather, store, analyse, and visualize sensor data from connected devices. It has a simple interface and robust features for handling IoT data and developing apps. Thing Speak allows users to create channels to collect data from various sensors and devices. These channels serve as virtual containers for incoming data pieces and timestamps. The platform accepts a variety of data kinds, including numeric, textual, and geographic data. After gathering data, Thing Speak provides built-in visualization capabilities for creating custom charts, graphs, and gauges. Users can use these visualizations to acquire insights from their data, spot patterns, and track trends over time.

3.2 Gismo VII(Esp32)

The GISMO VII is a flexible microcontroller development board known for its extensive feature set and connectivity options. It combines a dual-core processor, Wi-Fi, and Bluetooth into a tiny module and is powered by the ESP32 system-on-chip (SoC).
The board has:

- 2 Analog Grove ports
- 2 Digital Grove ports
- 2 I2C Grove ports
- 1 UART Grove port

3.3 Dht11 Sensor

The DHT11 digital temperature and humidity sensor module is widely used. It is commonly utilized in a variety of projects and applications that require temperature and humidity monitoring and management. The fundamental purpose, according to this response, is to develop a modular and cost-effective system that employs renewable energy sources to monitor real-time weather conditions and improve local agriculture. It can measure temperatures from 0°C to 50°C (32°F to 122°F) with a 2°C precision, and humidity from 20% to 90% with a 5% accuracy.

3.4 Rain Sensor

Raindrop detection sensors, also known as raindrop sensors or raindrop modules, are electronic devices used to detect the presence and intensity of raindrops. These sensors are commonly used in various applications, including automotive rain-sensing wipers, weather monitoring systems, and smart home automation. Raindrop detection sensors typically employ an optical-based approach to detect raindrops.

3.5 Bmp 180 Sensor

The Bosch Sensor BMP180 is a digital barometric pressure sensor. It is widely utilized in a wide range of applications that demand precise pressure and temperature readings, including weather monitoring, height sensing, and indoor navigation systems.

3.6 Thing Speak Cloud

Thing Speak is a cloud - based IoT analytics platform that enables users to gather, store, analyze, and visualize sensor data from connected devices. It has a simple interface and robust features for handling IoT data and developing apps. Thing Speak allows users to create channels to collect data from various sensors and devices. These channels serve as virtual containers for incoming data pieces and timestamps. The platform accepts a variety of data kinds, including numeric, textual, and geographic data. With integration to MATLAB, Thing Speak offers advanced data analysis and predictive modeling capabilities. The platform supports various IoT communication protocols, ensuring seamless connectivity with a wide range of devices. Additionally, users can set up alerts based on specific conditions and share data channels for collaborative efforts. Thing Speak empowers IoT enthusiasts, developers, and researchers to harness the potential of their data, enabling informed decision-making and insights for various applications.

3.7 Hardware Prototype

Building an IoT circuit for a smart weather station involves integrating various components to collect, process, and transmit weather data.

1. Microcontroller: Select a microcontroller board compatible with IoT, such as Arduino, Raspberry Pi, or ESP32. This will serve as the brain of the weather station and handle data processing and communication tasks.
2. Sensors: Choose weather sensors suitable for your requirements, such as temperature, humidity, pressure, rainfall, wind speed, and direction sensors. Connect these sensors to the appropriate pins of the microcontroller to collect weather data.
3. Power Supply: Provide a stable power source to the microcontroller and sensors. This can be achieved using batteries, solar panels, or a combination of both, depending on the availability and energy requirements of your weather station.
4. Data Storage and Transmission: Use appropriate protocols and libraries to store the collected weather data locally on the microcontroller or transmit it to a cloud platform for further analysis and visualization.

https://doi.org/10.1051/e3sconf/202343001092

5. Programming and Firmware: Develop the necessary firmware or software code to handle sensor data reading, processing, and communication tasks. Utilize suitable programming languages and frameworks supported by the chosen microcontroller board.

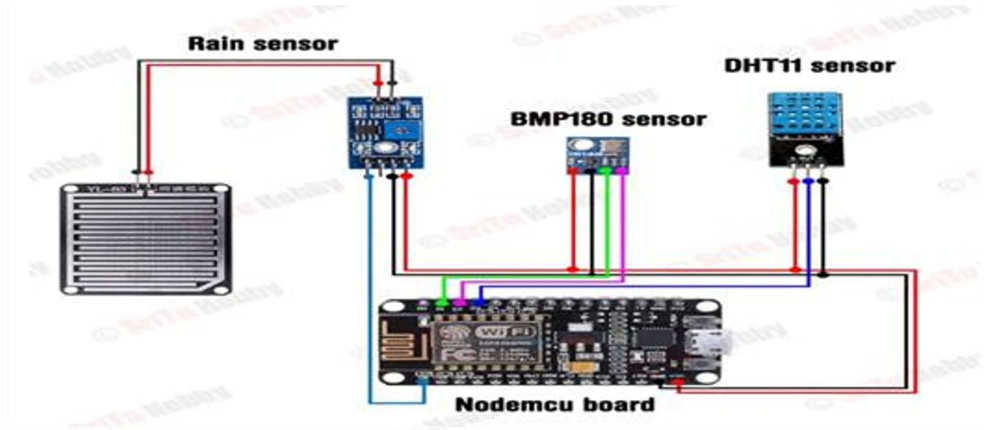

Fig. 1. IoT Circuit Diagram

3.8 Stepwise Procedure

The proposed system follows the following step to complete the tasks.
Step 1: Sensors collect data on temperature, humidity, pressure, wind, rainfall, UV, and solar radiation.
Step 2: The ESP32 module processes the data and prepares it for transmission.
Step 3: The ESP32 sends the processed data to Thing speak, the cloud-based platform.
Step 4: Thing speak stores and organizes the data for easy access.
Step 5: Users visualize and analyse the data through Thing speak's user-friendly interface.
The system has some features that make the system unique.
1. Affordable Cost: The full system is cost-effective, with reasonably priced components, making it accessible to a wide range of users.
2. Portable Size: The weather station's compact and lightweight design allows for easy portability, enabling users to carry it from one location to another effortlessly.
3. User-Friendly Interface: The model comes with an intuitive and user-friendly interface, ensuring that even non-technical users can quickly grasp the mechanism of the weather station.
4. Fast Response Time: The smart weather station exhibits a rapid response time, providing real-time weather data and updates promptly.
5. Wide Coverage Area: Being connected to the internet, the weather station can reach a large coverage area, allowing users to access weather information remotely from various locations.

3.10. Applications

The applications where this proposed system used are:
1. Precision Agriculture: Smart weather stations provide real-time weather data to farmers, helping them make informed decisions about irrigation schedules, pest control, and crop

management. Weather forecasts aid in planning planting and harvesting activities, optimizing crop yields, and conserving resources.
2. Disaster Management: Smart weather stations play a crucial role in disaster management by monitoring and providing early warnings for extreme weather events. Governments and emergency response teams use the data to plan evacuations, allocate resources, and mitigate the impact of natural disasters such as hurricanes, floods, and wildfires.
3. Environmental Monitoring: Smart weather stations assist in environmental monitoring efforts by collecting data on air quality, pollution levels, and climate conditions. Researchers and organizations can use this data to assess local climate trends, study pollution patterns, and implement sustainable practices.

4 Result Analysis

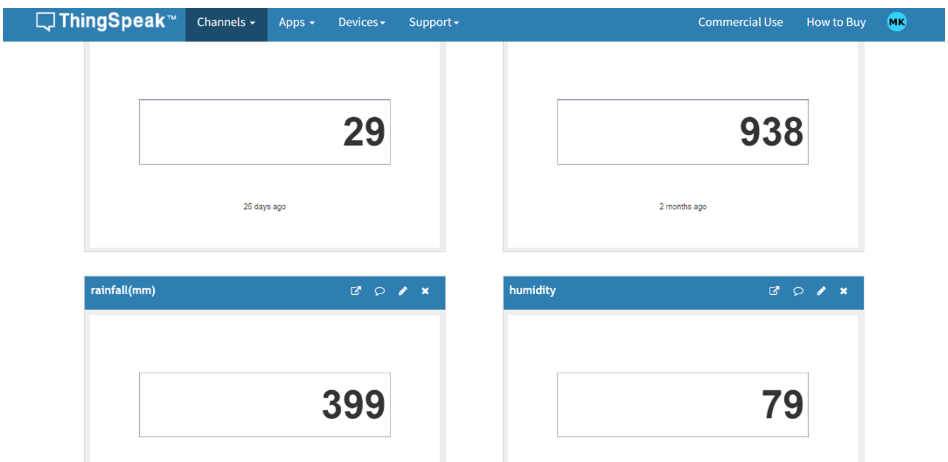

Fig. 2. Weather forecast on thing speak cloud

The collected weather data from sensors can be visually presented to users through a graphical representation. This graphical representation, accessible through a cloud interface, provides users with a clear and intuitive display of various weather parameters, such as temperature, humidity, pressure, and rainfall values. Users can easily interpret and analyze the data, allowing them to gain insights into current weather conditions and trends. By leveraging the cloud interface, the weather information is readily available and easily accessible to users, enabling them to make informed decisions based on the displayed data.

1. Real-Time Weather Monitoring: A smart weather station using IoT can provide real-time weather data, allowing users to monitor and access current weather conditions instantly. This data includes temperature, humidity, atmospheric pressure, wind speed, wind direction, rainfall, UV index, and solar radiation.
2. Weather Forecasting: By analysing historical and real-time data, the smart weather station can generate accurate short-term and long-term weather forecasts. These forecasts are valuable for planning outdoor activities, agricultural operations, and disaster preparedness.

3. Data Visualization: The weather data collected by the smart weather station can be visualized through graphs, charts, and dashboards, making it easy for users to interpret and understand weather trends and patterns over time.
4. Alerts and Notifications: The smart weather station can be programmed to send alerts and notifications to users' devices when specific weather conditions or thresholds are met, enabling timely response to extreme weather events.

TABLE 1. DATA COMPARISION OF NATIONAL INFORMATION AND EXPERIMENTAL INFORMATION OF HYDERABAD CITY

Weather Component	National Information	Measured Information	Percentage Error
Temperature	32 degrees Celsius	30 degrees Celsius	6.6%
Humidity	78%	75%	2.56%
Pressure	80kpa	85kpa	6.06%
Rainfall	0	0	0%

From the comparison we can conclude that the results are produced accurately by the weather station and smart weather station is efficient in the following way:

1. Energy Efficiency: Smart weather station is designed to be energy-efficient, using low-power sensors and communication modules to minimize power consumption. This allows the station to operate for extended periods on battery or renewable energy sources.
2. Connectivity: The IoT connectivity enables seamless data transmission to the cloud or central server, ensuring data accessibility from any internet-connected device. Reliable and stable connectivity is essential for the station's efficiency.
3. Data Processing: Efficient data processing algorithms enable the weather station to analyse and process large volumes of data quickly, leading to faster weather updates and forecasts.
4. Scalability: Smart weather station using IoT can is scaled up to cover larger geographical areas, providing a more extensive network for weather monitoring and forecasting.
5. User-Friendly Interface: It has a user-friendly interface that enhances the efficiency of the weather station by making it easy for users to set up, configure, and access weather data and forecasts.

5 Conclusion

In conclusion, the integration of IoT and machine learning in smart weather stations has revolutionized weather monitoring and forecasting capabilities. By collecting real-time data from various sensors, such as temperature, humidity, wind speed, and rainfall, these stations provide accurate and up-to-date weather information. Machine learning algorithms analyze the collected data to identify patterns and make accurate predictions, improving the accuracy of weather forecasts. Smart weather stations enhance the efficiency of weather monitoring, allowing for timely warnings and better preparation for severe weather events. The IoT connectivity enables remote access to weather data, facilitating its availability for various applications and sectors. The combination of IoT and machine learning has the potential to transform industries like agriculture, transportation, and energy by optimizing resource management and decision-making based on weather conditions. Smart weather stations contribute to environmental sustainability by aiding in climate change research and supporting the development of climate-adaptive strategies. Overall, the integration of IoT and machine learning in weather stations offers a powerful tool for understanding, predicting, and adapting to weather patterns, fostering safety, efficiency, and resilience in various domains.

6 FUTURE ENHANCEMENTS

In the future, several enhancements can further revolutionize smart weather stations utilizing IoT and machine learning. Advanced sensor technology will allow for more precise and comprehensive data collection, enabling the monitoring of additional weather parameters like air quality and atmospheric composition. Integration of diverse data sources such as satellite imagery and social media feeds will provide a more holistic understanding of weather patterns. The development of advanced machine learning algorithms will lead to more accurate and localized weather predictions. Edge computing capabilities within weather stations will enable real-time analysis and decision-making without relying solely on cloud infrastructure. Predictive maintenance algorithms can ensure uninterrupted data collection by monitoring the health of weather station components. Integrating smart weather stations into smart city infrastructure will enhance urban planning and emergency response. AI-driven alerts and notifications will provide timely and personalized weather information. Weather stations will contribute to climate change analysis by analyzing historical data and supporting mitigation strategies. Integration with the IoT ecosystem will enable cross-domain data analysis and personalized weather information. Citizen science participation will expand data coverage and foster community involvement in weather observations. These enhancements will further advance the capabilities of smart weather stations, providing valuable insights for various industries and contributing to a safer and more sustainable future and sustainable environment for upcoming generations.

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