



Development of a Low-cost IoT-based Remote Sensing Device for Real-time Atmospheric Data Acquisition and Weather Monitoring

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Authors' contributions

This work was carried out in collaboration among all authors. Authors AJU and PMA managed the Literature searches and wrote the first draft of the manuscript. Authors PMA and ACS managed the analyses of the study. Authors BA and IE managed the final compilation of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

The knowledge of basic meteorological parameters is needful in terms of understanding the atmospheric behavior for a given period and consequently also for creating the weather forecast. In this study, an IOT based atmospheric weather data acquisition device is designed to ease and improve on the current measuring technique of acquiring Temperature, Pressure, and Relative Humidity measurement at different altitude levels. This design aims at solving the problem of inadequate atmospheric data by monitoring atmospheric weather conditions using sensors while

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the microcontroller processes the data collected and relays it to the user. This research was carried out at the University of Uyo, between September 2021 and January, 2023. Taking cognizance of the fact that weather forecasting is of great relevance in our world, this system has been designed using a BME280 module for the atmospheric parameters capturing, an ESP8266 as the microcontroller for Data processing, and a wireless module for processing and transfer of the data from the BME module, a NEO6M GPS module for longitude and latitude, a Li-ion cell to power the components and then a TP4056 circuit to recharge the Li-ion cell. A web server application known as Thingspeak.com was incorporated to help the user interact and access the acquired data to make for ease of understanding and real-time logging of the data obtained. The device successfully transmitted real-time weather data of the target atmospheric parameters captured by it to its users remotely. The results prove that this device is optimally effective and viable for capturing atmospheric parameters for real-time monitoring purposes. This work is relevant in the weather forecasting sector, agricultural sector, as well as to individuals who may have need of gathering information about the atmosphere for proactive planning of daily activities.

Keywords: Remote sensing; IoT; weather; atmospheric parameters; temperature.

1. INTRODUCTION

Accurate weather predictions are of high importance for humankind, from agriculture via air traffic, warning of severe weather events like storm and heavy rain to the personal activities of individuals. With increasing computational power, there have been significant improvements in operational weather models [1]. However, these global and mesoscale models require measurement data as input to tie the short-term forecast towards observations [2]. In this computing intensive process, data can be assimilated continuously, with high flexibility regarding spatial and temporal resolution and trajectory [3]. The data to be assimilated originates from the World Meteorological Organisation (WMO) Global Observing System [4], consisting of measurements using both in-situ and remote sensing techniques. Atmospheric measurements of pressure, temperature, humidity, wind speed and wind direction are crucial to Numerical Weather Prediction (NWP). These measurements can partially be provided by ground based remote sensing techniques [5]; [6], satellite based remote sensing techniques [7]; [8], radiosondes [9], aircraft [10] and dropsondes-meteorological sensor packets dropped from high altitude platforms [11] Each of these observing system types has its own peculiarities which have to be considered for implementing in weather models, and has a different impact on the forecast quality. Ground based remote sensing instruments need significant financial effort to be deployed and operated.

Apparently, rising sea levels and precipitation patterns, temperature, and more extreme

weather changes threaten food and water security, human health, security, and socioeconomic development on the continent. For this reason, accurate and up-to-date data is needed for adaptation planning that will help to curb these natural occurrences and seek to proffer a positive prediction of the weather.

This paper, development of a low-cost IOT based remote sensing device for real-time atmospheric data acquisition and weather monitoring device comprises of Section 1 covering the introduction and related works, Section 2 highlighting the materials and methods used for the design of the IOT based weather capturing device, Section 3 underscoring the observed findings and discussions, and section 4 provides the conclusion.

2. REVIEW OF RELATED WORKS

Several weather monitoring systems and stations have been proposed and implemented worldwide; some of these proposed devices have one or more improvements in terms of design, cost, and accuracy.

However, this proposed method employs Internet of Things (IoT) technology in which microcontrollers and sensors linked wirelessly to a web server are used to monitoring atmospheric variations and predict the weather. Hence, this section underscores existing studies and their limitations in monitoring climate change. Akhilesh Chawla et al. [12] proposed a Bluetooth Based Weather Station that uses DHT11 sensor and HC-05 Bluetooth module to measure temperature and humidity. Ukhurebor, K. E et al. [13] proposed a low-cost weather-monitoring

device that uses Arduino Mega 2560 and other devices to monitor temperature, pressure, humidity, and light intensity. Dushyant Pande et al. [14] in their study proposed the Measurement and transmission of atmospheric parameters using radio frequency communication. Deeksha Srivastava et al. [15] also proposed the Measurement of Temperature and Humidity that uses Using Arduino Tool And DHT11 to measure temperature and humidity. Nisha G et al. [16] also made use of ZigBee wireless technology and other sensors to monitor temperature, humidity, light intensity, and raindrop. Zahra Ghattan et al. [17] designed and fabricated an Atmospheric Parameter Monitoring System for Weather Forecast using *radiosonde attached to a weather balloon* that measures various atmospheric parameters such as pressure, temperature, relative humidity, wind (both wind speed and wind direction), then transmits them by radio to a ground receiver. Wanogho et al. [18] make use of an ESP32 microcontroller and other sensors to monitor weather conditions like humidity, temperature, and light intensity. An IoT-based weather station with embedded system was developed by Olanrele et al. [19] using ESP8266/Nodemcu to monitor temperature, humidity, and light intensity. Rajesh Singh et al. [20] designed a temperature monitoring device in a wireless sensor network using ZigBee transceiver communication module with IC-CC2500 and 2.4GHz as RF transceiver to monitor temperature. A wireless mobile microcontroller-based weather monitoring device was designed by Devaraju et al. [21] using a PIC16f887 microcontroller and other sensors to measure. N. V. Gowtham et al. [22] proposed the Design, Development and Implementation of Real Time Canal and Weather Monitoring Devices using an ultrasonic sensor (HC-SR04) used for measurement of canal depth and a water flow Sensor YF-S403 $\frac{3}{4}$, for measuring Velocity of water flow in Canal. Both sensors were interfaced with the arduino UNO microcontroller board and results were displayed on LCD I2C display. The weather monitoring device was made up of DHT11 sensor (for measuring Temperature and Humidity), and an IR sensor (active type) to sense certain characteristics of its surroundings by either emitting and/or detecting infrared radiation all of which were interfaced with the arduino UNO microcontroller. Jayashree T. R. et al. [23] also proposed a Li-Fi & Wi-Fi Based Drone for Weather Monitoring with Data Storage in Cloud Using IoT. Mohamed Abdelkader et al. [24]

designed a UAV based system for real time flash flood monitoring in desert environments using Lagrangian microsensors. Kirankumar Sutar [25] designed a cost-effective weather monitoring system that uses a ZigBee radio communication module and other sensors to monitor temperature, humidity, and light intensity. [26] designed and implemented a microcontroller-based weather acquisition device that measures temperature, pressure and relative humidity. Accordingly, Lopez et al. [27] published a tool to store IoT-based data in cloud. In view of the foregoing reviewed works, this IoT based weather capturing device has significant advantages compared to most existing technologies in terms of its low cost of development, portability, simplicity in its operation and real-time logging of the target atmospheric weather parameters namely; temperature, relative humidity and pressure.

3. MATERIALS AND METHODS

Choosing the best method is vital when building and implementing a system of this strength. For this research, this weather data-gathering and monitoring gadget was constructed using embedded system technology. This low cost IOT based weather capturing device is made up of a BME280 module for the atmospheric parameters acquisition, an ESP8266 as the microcontroller for Data processing, and a wireless module for processing and transfer of the data from the BME module, a NEO6M GPS module for longitude and latitude, a Li-ion cell to power the components and a TP4056 circuit to recharge the Li-ion cell. A web application Thingspeak.com is incorporated to help the user interact and access the data to enable ease of understanding and real-time logging of the data collected.

The intervals between meteorological measurements might range from 1 to 6 seconds, depending on the type and maker of the weather station. The suggested model creates a weather-acquisition device to capture atmospheric parameters using sensors. The sensors are used to measure atmospheric changes every minute and the information sent to the web server for immediate access by users, providing a precise forecast of the weather by using Thing Speak IoT platform as a display.

Every five (5) minutes, the weather capturing device will submit weather-related data to the database, including data on temperature, humidity, and pressure. The weather data will be

saved in the database and provided to the application. Through the program, the user will ask for weather information. The application will then ask the database for the information and deliver it back to the user. Fig.1 displays the block diagram of the weather capturing device and under listed are the components that make up the weather capturing device:

- BME280 Sensor: for measuring Temperature, Humidity and Pressure
- Noe6M GPS module: GPS for longitude and latitude
- Power Supply (TP4056): Power supply with 1500mAh lithium polymer battery
- ESP8266 Devkit: Microcontroller that connects the sensor data to your Wi-Fi, and sends data to the web server.
- Jumper wires: for connection of the components.
- 3D printed enclosure for the protection of the entire device

3.1 BME280- Data capturing or acquisition module

The BME280 is an integrated environmental sensor for pressure, humidity and temperature, combining high linearity, high accuracy and low power consumption [28]. The humidity sensor features an extremely fast response time which

supports performance requirements for emerging applications such as context awareness, and high accuracy over a wide temperature range. The pressure sensor is an absolute barometric pressure sensor with features exceptionally high accuracy and resolution at very low noise. The integrated temperature sensor has been optimized for very low noise and high resolution. It is primarily used for temperature compensation of the pressure and humidity sensors, and can also be used for estimating ambient temperature. Fig. 2 displays the picture of the BME280 module.

Features of BME280

- High accuracy
- Easy-to-use Grove Compatible Interface
- Supports both I2C and SPI communication
- Can be used as an altimeter with an accuracy of ± 1 meter and low altitude noise of 0.25m

Pressure and temperature range

- Pressure range: 300hPa to 1100 hPa with an absolute accuracy of ± 1 hPa.
- Temperature range: -40 to 85°C with an accuracy of ± 1 hPa
- Humidity Range: 0 to 100% RH ($\pm 3\%$ accuracy)

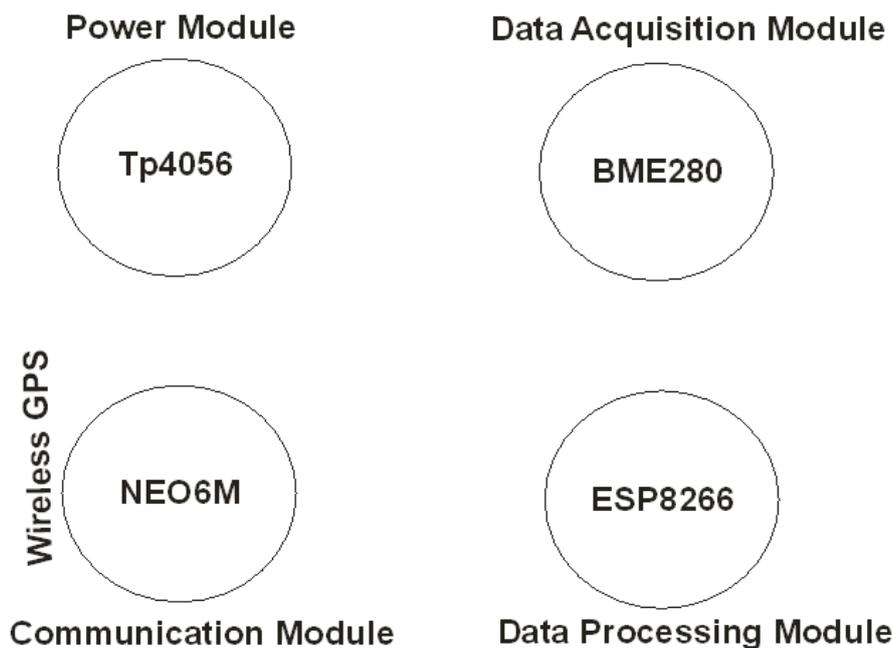


Fig. 1. Block Diagram of the Weather Capturing Device

- Power consumption: 1mA (typ.) and 5 μ A (idle)
- Sensor Size: 15mm x 12mm x 5mm



Fig. 2. BME280 Module

3.2 ESP8266 – Data Processing Module

As shown in Fig. 3, the ESP8266 is a low-cost Wi-Fi microchip, with built-in TCP/IP networking software, and microcontroller capability. Espressif Systems created a low-cost Wi-Fi chip called the ESP8266. To enable other microcontrollers to connect to a Wi-Fi network, it can be used as a standalone device or as a UART to Wi-Fi adaptor [29]. For instance, to add Wi-Fi functionality to an Arduino board, an ESP8266 can be attached. Utilizing it as a standalone device is its most useful use. Similar to how inputs and outputs with an Arduino could be controlled, the ESP8266 also have Wi-Fi capabilities.

Features of ESP8266

- The CPU is based around ESP8266 at 240MHz dual-core
- Wi-Fi is up to 150Mbps 802.11 b/g/n/e/h, direct P2P soft app
- Has a flash size of 4MB (32Mbit)
- Uses CP2102 as the USB-Serial converter
- It uses Semtech SX1276 Radio module
- It uses an external antenna connector: IPX (UFL)
- Integrated TCP/IP protocol stack
- Built-in low-power 32-bit CPU



Fig. 3. ESP8266 Module

3.3 NEO-6M - Data Communication Module

The NEO-6M module is a powerful full-featured GPS receiver with a ceramic antenna built-in 25 x 25 x 4mm that provides a powerful satellite search function. NEO-6M GPS chip is the heart of the module from u-blox [30]. The chip packs a surprising number of functions into its small frame and measures less than a postage stamp. Unlike other GPS modules, it has a horizontal position precision of 2.5m and can update its location up to 5 times per second. The Time-To-First-Fix of the u-blox 6 positioning engine is also sub-one second (TTFF). The image of the NEO-6M Module is shown in Fig. 4.



Fig. 4. NEO-6M GPS Module

Features of NEO-6M GPS module

- High sensitivity for tracking
- Low supply current (~45mA)
- Operating temperature range: -40 TO 85°C UART TTL socket
- Is able to track 5 locations per second with an accuracy of 2.5m (horizontal).
- Comes equipped with PSM also known as Power Saving Mode. This mode causes very less power consumption by turning the module ON/OFF according to the need.
- Rechargeable battery for Backup
- The cold start time of 38 s and Hot start time of 1s
- Supply voltage: 3.3 V

3.4 TP4056-POWER SUPPLY

The TP4056 is a complete constant-current/constant-voltage linear charger for single cell lithium-ion batteries. Its SOP package and low external component count make the TP4056 ideally suited for portable applications. Furthermore, the TP4056 can work within USB

and wall adapter. TP4056 automatically terminates the charge cycle when the charge current drops to 1/10th the programmed value after the final float voltage is reached. TP4056 Other features include current monitor, under voltage lockout, automatic recharge and two status pin to indicate charge termination and the presence of an input voltage [31, 32].

A compact lithium-ion battery charger module is the TP4056 charging module. One IC and a few discrete components are used to create a high-quality charging module that can provide the necessary charging procedures for li-ion batteries, extending their useful lives and enabling them to supply their full backup. The images of the Power Supply module and lithium Battery is displayed in Fig. 5.

Features of Power Module TP4056

- Low weight
- Higher energy density for a given weight (WH/kg)

- Slightly higher top usage temperature.
- It can charge any size of 3.7V Li-ion cell
- Low-cost and reliable Li-ion battery charger
- Battery temperature measurement inside (Disconnect charging when the temperature of the battery goes high than normal)
- Can connect to any USB port with a USB cable
- Power: 4.2W.
- Charging accuracy: 1.5%
- Operating Temperature: -10 to +85°C.
- Input voltage: 4.5V ~ 5.5V.
- A full charge voltage: 4.2V.

3.5 Jumper Wire

As shown in Fig. 6, jumper wires are electrical wires with connector pins at each end. They are used to connect two points in a circuit without soldering [33]. Jumper wires are used to modify a circuit or diagnose problems in a circuit.

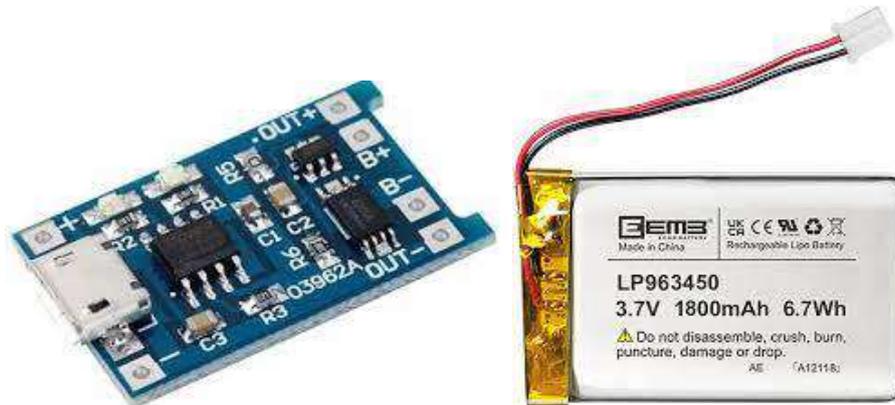


Fig. 5. Power Supply module and lithium Battery



Fig. 6. Jumper Wires

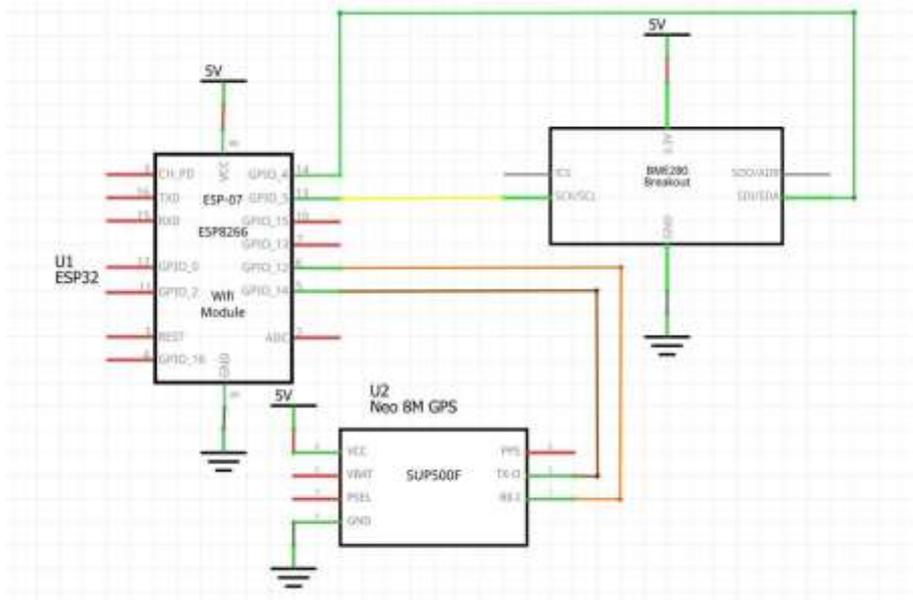


Fig. 7. Schematic Diagram of the weather Capturing Device



Fig. 8: The Weather Capturing Device

3.6 Device Schematic

A schematic is a straightforward, symbol-based representation of a topic. a diagram that shows all important components, tasks, or parts of the circuitry, device, flow process, or project, together with their relationships and connections to one another. The schematic diagram and the images of the weather capturing device are shown in Fig. 7 and Fig. 8 respectively.

3.7 Webserver

A web server is where the resources of a website live, it could be a local host or remote, the local host can sometimes suffer proper maintenance and live data feed. The remote type is more reliable since they are mostly paid services and

will be properly maintained such that data can be sent or retrieved at any time without complications. The Thingspeak web server is a host to a lot of could data that relates to data logging being that it has some analysis tools to help in processing the data logged in the web server. Thingspeak web server is owned by Mathworks, you will need an active account before you can publish sensor data to their web server.

4. RESULTS AND DISCUSSION

Unit testing, integration testing, and system testing are the tests that were performed to ensure that this system achieved its goals. Usually, a weather monitoring device consists of

sensors that take the atmospheric measurements at different levels of the atmosphere and transmit them by radio to a base station on land or water and use the result for weather forecasting or to predict natural disasters such as hurricanes, tornadoes and the like that can destroy lives and property. For this system, a microcontroller is connected to sensors that can read temperature, humidity, pressure and altitude is then programmed to take such readings in the fastest possible time, typically between one hundred milliseconds and five seconds, as a physical quantity and these faint signals then amplified using a cascaded amplifier configuration and then later convert these amplified readings of physical quantities into electrical impulses which in most cases appear in analog form since their readings vary over time. The electrical pulses are then converted into a digital signal that can be read by a microcontroller using an analog-to-digital converter built into the microcontroller's circuitry for this function. The signal is then processed by the microcontroller's arithmetic and logic unit (ALU) to perform calculations and return a result of the measured physical quantity. Often times, the results are compared to some standard to determine if the result is correct before its answer is validated as correct, or if it needs to be corrected by the error amplifier. The result is now ready to be sent. Before connecting the sensor to the microcontroller, a boot loader must first be loaded onto the microcontroller, the first time it is used, the chip is then ready to be programmed thousands of times depending on the read and write cycles.

The booted microcontroller is then connected to a network capable of transmitting data over long distances, one such network is the Lora gateway, which allows long-distance radio communication with constant connectivity. An example sketch is uploaded to the microcontroller to test its functionality before the firmware is uploaded to it. The uploaded firmware took care of the data transfer and internet connection between the microcontroller and the remote server used to publish or log the weather data. The device is encased in an inexpensive 3D-printed case so it can shield the weather-capturing device's components while leaving the sensors outside to read the atmospheric data. In order for the weather station to take the vertical profile measurements, it can either be attached to a drone or a glider. The basic atmospheric

elements in Atmospheric Boundary Layer detection include Pressure, humidity, and temperature. In this project, an atmospheric parameter capturing device was developed based on the actual need for atmospheric weather parameters Pressure, humidity, and temperature as well as altitude, latitude, and longitude.

More so, the hardware circuit is the foundation of the whole detection platform, and its design needs to consider many aspects, such as working environment and component model selection, and only reasonable development of the entire hardware circuit can finish the work of the hardware system of this weather-acquisition device. NEO-6M GPS module has an LED that shows the status of the positioning. When there is no blinking, it is searching for satellites, when it blinks for 1 second: the position is found. The design involves the weather-capturing device made up of ESP8266 that connects the sensors and sends data to your browser. It also processes the weather data collected such as temperature, humidity, pressure, altitude, longitude and latitude using the BME280 sensor. TP4056 and lithium polymer battery serve as the main power to the device, and NEO-6M captures the longitude and latitude. The Microcontroller processes the information captured, the Wi-Fi router, and the 4G cellular and network modem convey the processed information to the Thingspeak web server. The schematic diagram in Fig. 7 shows how the components were soldered.

The atmospheric parameter weather-acquisition device includes temperature and humidity sensing, pressure sensing, and geographic coordinate sensing. The communication mode of the atmospheric element detection sensor was as follows: Temperature and humidity were sent over one bus, pressure was sent through his I2C in an ESP8266 microcontroller, and altitude, latitude, longitude and west African time were sent through a serial port.

The screenshots in Fig. 9, Fig. 10 and Fig. 11 were taken by the Thingspeak web server and they display the data collected by the weather collection device. Also, the data captured in Thingspeak was converted to Excel format as shown in Fig. 12 for easy export and usage.



Fig. 9. Temperature screenshot from Thingspeak



Fig. 10. Humidity screenshot from Thingspeak



Fig. 11. Pressure screenshot from Thingspeak

	A	B	C	D	E
1	created_at	entry_id	field1	field2	field3
2	2021-10-21T07:01:37+02:00	58	30.44	100	1005.44
3	2021-10-21T07:01:58+02:00	59	30.48	100	1005.46
4	2021-10-21T07:02:19+02:00	60	30.57	100	1005.47
5	2021-10-21T07:02:41+02:00	61	30.66	100	1005.48
6	2021-10-21T07:03:02+02:00	62	30.73	100	1005.49
7	2021-10-21T07:03:23+02:00	63	30.82	100	1005.48
8	2021-10-21T07:03:44+02:00	64	30.87	100	1005.51
9	2021-10-21T07:04:05+02:00	65	30.92	100	1005.49
10	2021-10-21T07:04:26+02:00	66	30.98	100	1005.49
11	2021-10-21T07:04:47+02:00	67	31.03	100	1005.5
12	2021-10-21T07:05:08+02:00	68	31.1	100	1005.49
13	2021-10-21T07:05:30+02:00	69	31.17	100	1005.51
14	2021-10-21T07:05:51+02:00	70	31.25	100	1005.49
15	2021-10-21T07:06:12+02:00	71	31.31	98.89	1005.51
16	2021-10-21T07:06:33+02:00	72	31.36	97.64	1005.51
17	2021-10-21T07:06:55+02:00	73	31.42	96.48	1005.53
18	2021-10-21T07:07:16+02:00	74	31.49	95.3	1005.5
19	2021-10-21T07:07:37+02:00	75	31.57	94.15	1005.51
20	2021-10-21T07:07:58+02:00	76	31.62	93.06	1005.53
21	2021-10-21T07:08:19+02:00	77	31.67	92.02	1005.48
22	2021-10-21T07:08:40+02:00	78	31.7	91.17	1005.48
23	2021-10-21T07:09:01+02:00	79	31.73	90.39	1005.49
24	2021-10-21T07:09:23+02:00	80	31.8	89.61	1005.49
25	2021-10-21T07:09:43+02:00	81	31.74	88.97	1005.49

Fig. 12. Excel Presentation of the data captured by the device

The IOT based-weather-capturing device was tested by continuously monitoring the atmospheric parameter changes with sensors. The output of the monitored atmospheric parameters weather changes is reported from the 4G networks to the Thingspeak web server, verifying the accuracy of the developed model. The results are shown above present the data monitored and reported via Thingspeak.

5. CONCLUSION

The design of this low cost IoT based weather capturing device is a project ostensibly geared towards enabling individual users access real-time atmospheric weather data from any location. This research demonstrates the construction of an inexpensive weather monitoring device that makes for flexibility, portability, scalability and user friendly operations which can provide data of some weather variables. Using a real-time data logger, this paper shows how to develop and implement a weather-acquisition device that can capture data on certain weather variables, including pressure, temperature, humidity,

altitude, latitude, and longitude. The data can be used to examine weather trends and forecast upcoming weather conditions.

6. RECOMMENDATIONS

The following are the recommendations for this paper:

- This IoT based weather capturing device is suitable for atmospheric weather data acquisition and monitoring when considering its low cost of development and robustness, more sensors can be added to the device.
- This device can be used with an unmanned aerial vehicle (UAV) for effective vertical profiling of atmospheric parameters at different altitude levels within the altitude limit of the UAV.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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