https://doi.org/10.48048/tis.2022.4639

Development of Ultra Low-Cost Data Acquisition System (DAS) for Developing Countries

Muritala Osinowo[1,*], Alexander Willoughby[1], Oluropo Dairo[1], Theophilus Ewetumo[2] and Lawrence Kolawole[1]

[1]*Department of Physical Sciences, Redeemer's University, Ede, Osun State, Nigeria*
[2]*Department of Physics with Electronics, The Federal University of Technology, Akure, Nigeria*

([*]Corresponding author's e-mail: osinowom@run.edu.ng)

Received: 28 September 2020, Revised: 1 August 2021, Accepted: 8 August 2021

Abstract

The Data Acquisition System (DAS) is an important equipment in measurement systems especially in weather monitoring and also very crucial in many areas such as agricultural, communication, transportation, sport and industrial processes. This work proposes a weather monitoring system based on an Arduino Mega 2560 microcontroller board. The microcontroller has the ability to monitor, record and display the information of atmospheric sensor parameters connected to its analogue and digital pins. The outputs of analogue sensors are connected to the microcontroller through separate ADC for sampling. An LCD attached to the microcontroller displays the measured parameters. For analysis, the data is stored in excel format and can be copied directly from microSD card. The DAS was tested and examined through intensive experimental work. The tables and plots obtained from the experiment for standardizing the sensors, it is clear that there is a close conformity between the data collected by the developed system and the existing standard systems. The need for extra cost baud rate and expensive third-party computer software for interfacing to download data from the logger have been eliminated. There is no need of internet for any linking or configuration. It is evident that the DAS is of better choice in terms of cost and maintenance. The system will be helpful in monitoring and recording of atmospheric parameters.

Keywords: Data acquisition system, Microcontroller, Ultraviolet, Pressure, Weather monitoring

Introduction

In nearly all higher institutions and agencies in Nigeria that engage in data gathering for weather monitoring or other research purposes, most data logging equipment are purchased from renowned manufacturers abroad. The Davis weather pro is one that has gained popularity among institutions all over the country. The Nigerian Meteorological Agency (NIMET) and the Tropospheric Data Acquisition Network (TRODAN) are the foremost data repository agencies in the country, where almost all data analysts go to obtain data for any region of interest in the country. The TRODAN acquires atmospheric data using the Campbell Scientific automatic Weather Station equipment. Occasionally, a researcher may be faced with difficulty in obtaining data from these agencies because of the long distance of the repository from the researcher's station or inconveniences and cost of data purchase or requisition protocol. Usually, the servicing of these equipment is few and far between and as such some data retrieved are either missing with their dates skipped or unreliable, probably caused by natural or artificial noise interference. Also, a desired parameter may not even be in their inventory for logging.

Numerous data acquisition systems have been developed for the purpose of collecting and processing of meteorological data using different approaches. In literature as well as commercially, an abundance of the application of microprocessor/microcontroller-based data acquisition systems for solar energy and environmental monitoring can be sourced [1-6].

A few attractive software and development tool kits available commercially are: Waspmote (with more than 110 sensors with few data on each unit), MSP430 launch pad from Texas instruments and STML series ST Microelectronics, the Raspberry Pi, with other 'fruit' Pi and the Arduino, all with their attendant and unique flash memory, frequencies, RAM, data EPROM and power consumption ratings. Development kits are either microcontroller-based kits or multi-component single-board computer with a microprocessor.

Designs of data acquisition systems using Microchip's PIC16F877 microcontroller have been implemented: [7-14]. The PIC16F877 includes an onboard interface designs, analog-to-digital converter with an onboard DS18B20 temperature sensor at low cost and high reliability.

Also, some DAS have employed using the Arduino development kit which has the ATmega 328 or 2560 as the base microcontroller [3,4,8,15]. In those PIC-based systems, separate A/D converter was interfaced to the PIC16F877 unit to record a set of sensors' signals and the data stored in a local EPROM. This is not necessary in the Arduino as both the A/D converter and EPROM are embedded in the IDE.

Commercial type wind logging systems are the Wind Explorer [8] and the APRS World Wind Data Logger (www.aprsworld.com). The APRS wind logger provides solutions for wind site evaluation and windmill performance. It can record wind gust, speed and direction, as well as the date and time, battery voltage, temperature and other useful wind parameters. A PIC18F452 serves as the working microcontroller of the wind logger.

Going through their attributes, the authors deemed the Arduino a fitting choice as it is more user-friendly because it provides its hardware platform with software coding called a 'Sketch'. The sketch is the Arduino franchise free-to-download, proprietary integrated development environment (IDE) platform. The Arduino IDE offers an exceedingly cost-effective solution to a wide range of applications since it contains accessible software that can be found in the library. The popularity of the platform has increased markedly over the years because of the flexibility of the open-source IDE - easily obtainable example or tutorial sketches uploaded online by hobbyists, science and engineering contributors - that enable the development of complex electrical and engineering systems. These attributes are what attract hobbyists, researchers and system developers to apply the Arduino open-source IDE as a microcontroller-based data acquisition system. The board consists of general purpose I/O pins, USB programming and I^2C and SPI communication interfaces, its own voltage regulator and power input connections, Debugging, Rx and Tx LEDs and in-circuit serial programming connectors. More literature on Arduino is available from the developer's website [4].

There is a proliferation of Arduino-based data logger designs that are accessible online. Peripheral sensor modules or 'shields' are also readily available in the market that are compatible with the board. The board is a reasonably priced complete stand-alone microcontroller, e.g., the ATmega328 for the Uno/Nano or ATMega 2560 for the Mega. In this work, preference is the Arduino Mega 2560, which employs the ATMega 2560 as the main microcontroller. It has many more general input/outputs (54) and analog-to-digital converter (ADC) channels to allow for interfacing with input sensors than the Uno.

Materials and methods

Basic block diagram of DAS

Figure 1 is the building block diagram of the developed Data Acquisition System. This consists of sensors for air or atmospheric temperature, pressure, relative humidity, 3 soil temperature sensors, ultraviolet, rainfall and a wind speed sensor. It also consists of signal conditioning circuits, analog-to digital converters (ADC), real time clock module, SD card shield for data logging, LCD display unit, microcontroller and power supply unit using battery and solar panel.

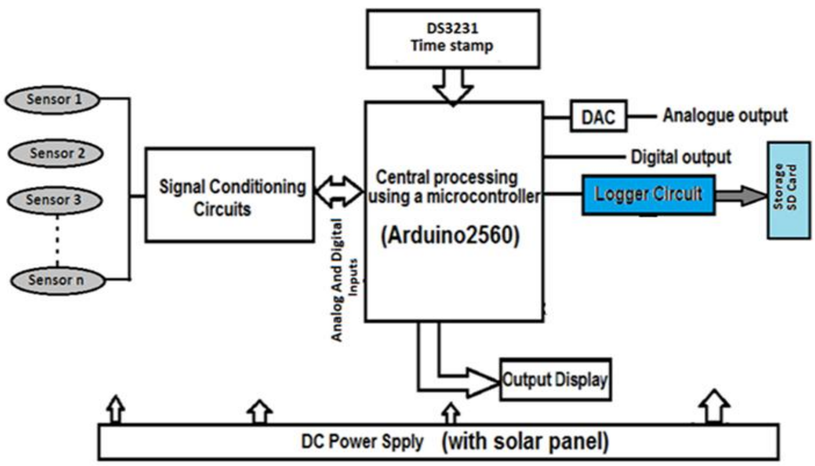


Figure 1 Block diagram of the developed DAS system.

Design and fabrication of sensors

One of the simple and direct methods of measuring rainfall volume is to use a tipping bucket rain gauge. This type of rain gauge gives out a pulse signal for every unit of rain water collected.

Fabrication of tipping bucket

The tipping bucket consists of 2 right angled triangular boxes placed back to back as shown in **Figure 2**. Each right-angled triangle has 5 cm sides with height of 4 and 6 cm height. The tipping bucket was pivoted through an optical pin to a 1-inch pipe. At bottom of the bucket the tipping adjustment was mounted with 5 cm long screws as shown in **Figure 3**. At middle of the tipping bucket, a light aluminum (Al) flat sheet carries a small magnet that passes over a reed switch at every tip of the bucket. The tipping bucket switching system was housed inside a 25 cm diameter aluminum cylinder with the top collecting funnel, where rain drop is directed to the tipping bucket.

Mode of operation

The locally fabricated tipping bucket is as shown in **Figure 3**. Rain water collected from the funnel collector is made to drip through a small hole into one of the buckets such that when 1 bucket is filled with rain water, its centre of gravity is moved and therefore tips making the second bucket to take position while the first empties. The gauge is calibrated by a pair of adjustment screws beneath each bucket to tip at every 2 mm of rainfall. As long as the rain falls, the buckets tips back and forth and thus, the attached magnet at its centre of gravity is passed over a reed switch which closes briefly each time the bucket tips.

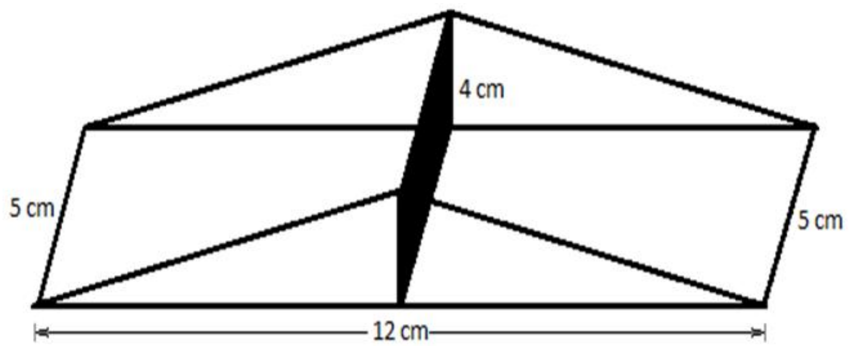


Figure 2 Schematic diagram of tipping bucket.

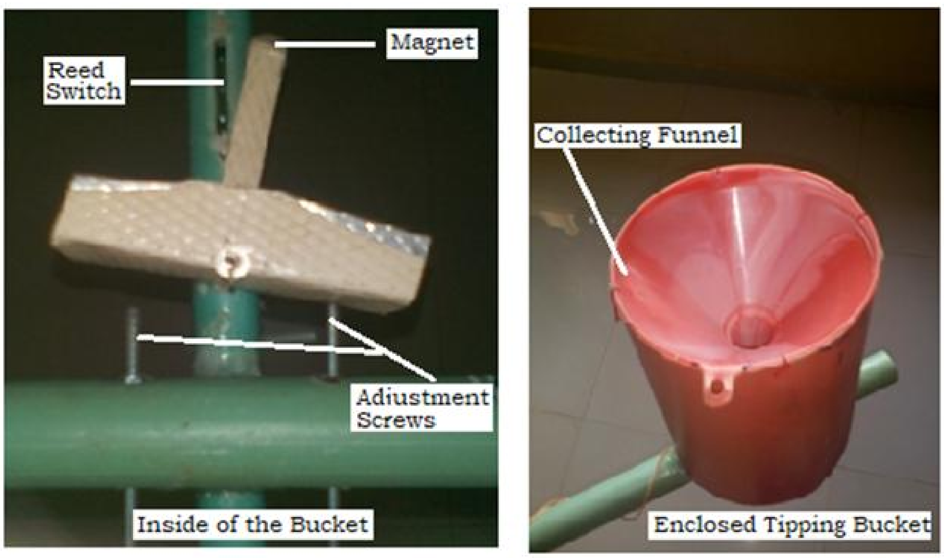


Figure 3 Fabricated tipping bucket.

The reed switch activates a monostable circuit of **Figure 4** that outputs a 30 ms pulse for each tip of 2 mm of rainfall. Every minute, the Arduino accumulates and stores the number of pulses. Thus, rain volume is 2 mm multiplied by number of pulses per time setting. Rain rate is then computed from the rain volume per minute which can also be converted to mm/h.

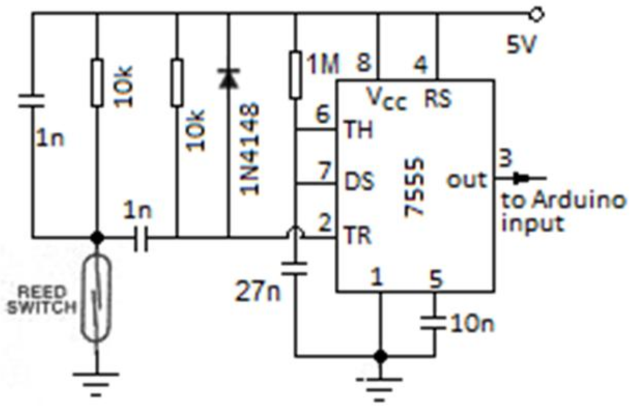


Figure 4 555 timer monostable used as a switching circuit.

Air and soil temperature

The DS18B20 is a digital temperature sensor. The resolution of this temperature sensor can be configured within the program from 9- bits to 12-bits in steps of 0.5 down to 0.0625 °C. At power-up, the resolution is 12-bits with low power and idle state. To start a temperature measurement with analog-to-digital conversion, the T (44 h) embedded in DS18B20 protocol master command must be issued. After this conversion, the obtained thermal data (or temperature value) is stored in a 2-byte temporary memory register and then the whole process returns to normal low power idle state. The DS18B20 can be powered externally with 5 V or with a parasitic power from the microcontroller's input. Here, the sensor is powered externally from 5 V source so that the data bus can be pulled high with a 4.7 kΩ resistor during the process of temperature conversion. **Figure 5** is the internal block diagram of the DS18B20 temperature sensor as obtained from its data sheet.

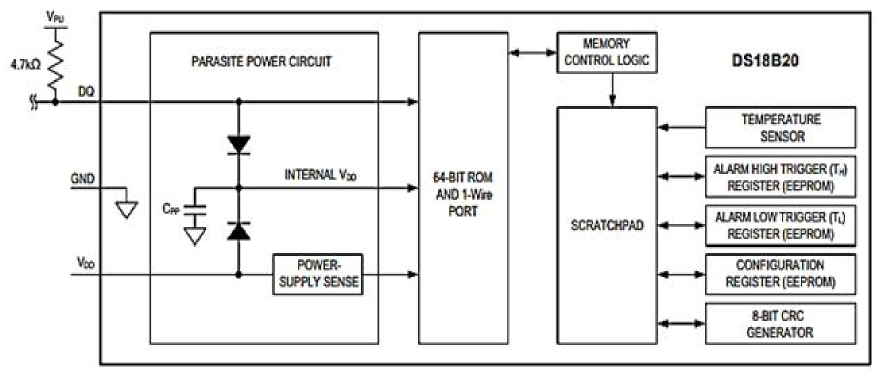


Figure 5 Block diagram of DS1820B temperature sensor.

Construction of soil temperature sensor

The DS18B20 was inserted into a copper pipe of 4 mm welded and then sealed at one end using gas welding with brass soldering material. A silicone gum was used to seal it to prevent water from seeping into the sensor.

Air temperature sensor

DS18B20 is wired and placed inside the constructed Stevenson screen.

Humidity sensor

Humidity is measured using an analog-output integrated circuit; the HIH-4030 which is manufactured by Honeywell International Inc. (Honeywell). It is a laser trimmed, thermoset polymer capacitive sensing element with an on chip integrated signal conditioner. Therefore, to get the right code for this sensor in C-language, the following subsequent steps are utilized.

Reference voltage of the ADC = 2.4 V = 2,400 mV

Microcontroller bit (10-bits) = 210 = 210 −1= 1,023

To change from the ADC value to Voltage in mV,

$$V_{out} = V_{out}\left(\frac{2,400}{1,023}\right)$$

Calculating the RH in 100 %

$$RH = (V_{out} - 528)(10,000)$$

$$RH = \frac{V_{out}}{2,046}\ \% \qquad (1)$$

A code for the relative humidity sensor written in C-language was used to program the microcontroller. The calculated relative humidity (RH) needs to be temperature compensated, thus;

$$RH_{corrected} = \frac{RH}{1.0546 - 0.00216T} \qquad (2)$$

T is the surrounding temperature in degrees centigrade measured by DS1820b.

UV sensor ML8511

The ML8511 is an ultraviolet radiation sensor sensitive to UV-A and UV-B range, and is suitable for measurements of ultraviolet intensity both indoors and outdoors. The ML8511 comes with an internal amplifier that transforms photo current generated by the photodiode into analog voltage proportional to the ultraviolet intensity. This feature makes it easy to interface its output to an external circuit or a microcontroller through an ADC circuit. In a standby mode and operating with a 3.3 V, it consumes about 0.1 µA making it suitable for battery operation. The internal circuit of ML8511 is shown in **Figure 6**.

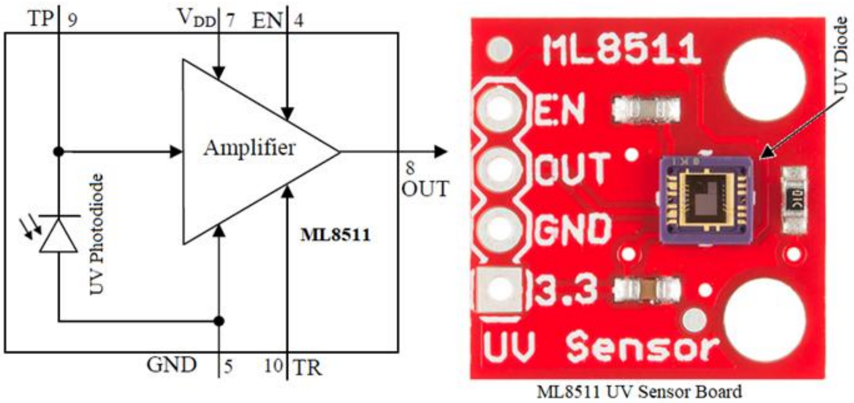


Figure 6 Internal circuit of ML8511 and its board.

Atmospheric pressure

The MPXA6115A sensor is a piezo-resistive transducer for pressure measurements. It incorporates thin film and bipolar semiconductor processing technology to provide a high precision analog voltage output signal that is proportional to external applied pressure. A thin silicone gel layer as a protection from the environment is placed over a die with ratiometric wire bonds that are encapsulated in a basic chip carrier package as in **Figure 7**. The force or pressure is transmitted via the gel to the transducer (ratiometric wires) on the die. The MPXA6115A series air pressure sensors' operating characteristics, their reliability and all quality tests are practically designed for use in dry air environments. They are not suitable for other media such as fluid medium that can have negative effects on the sensor's behavior and its reliability. The implementation schematic of the atmospheric pressure sensor is given in **Figure 7**.

This integrated circuit, MPXA6115A, is manufactured by Motorola and it requires a power supply of 5 V with an output voltage range between 0 and 5 V for pressure values between 15 to 115 kPa (150 to 1,150 mbar).

$Nominal\ transfer\ value: V_{out}$

$$V_{out} = V_s(0.009 \times P - 0.095) \pm (Pressure\ Error \times Temp.Factor \times 0.009 \times V_s \quad (3)$$

where Vs is 5 ± 0.25 Vdc.

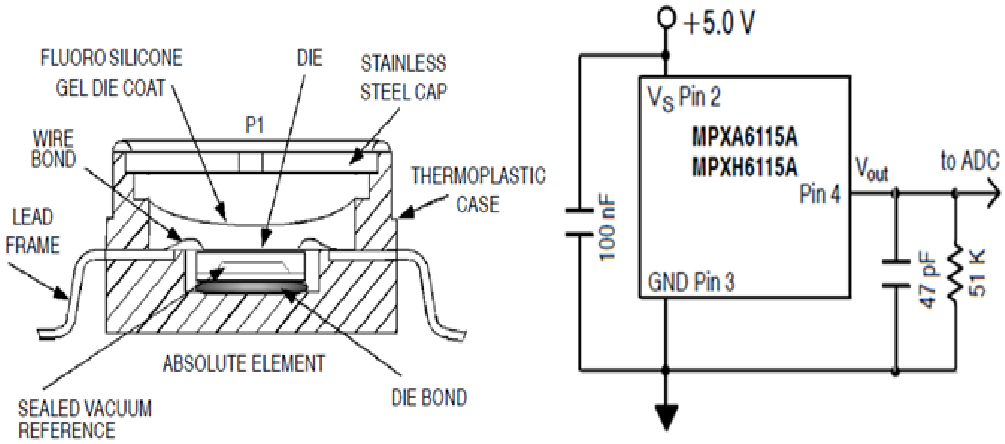


Figure 7 Block diagram of MPXA6115 and its application circuit.

Wind speed sensor

The output voltage range of 3-cup type wind speed sensor (**Figure 8**) ranges from 0 - 5 V. The external power requirement is 9 - 24 V and its wiring to the Arduino device shares the same ground connection with external power's GND. Arduino Program to estimate the wind speed according to output voltage is as follows:

```
int sensorValue = analogRead(A0);
float outvoltage = sensorValue * (5.0 /1023);
Serial.print("outvoltage = ");
Serial.print(outvoltage);
Serial.println("V");
int Level = 6*out voltage; //The level of wind speed is proportional to VOUT.
Serial.print("wind speed is ");
Serial.print(Level);
Serial.println(" level now");
Serial.println();
delay(500);
```

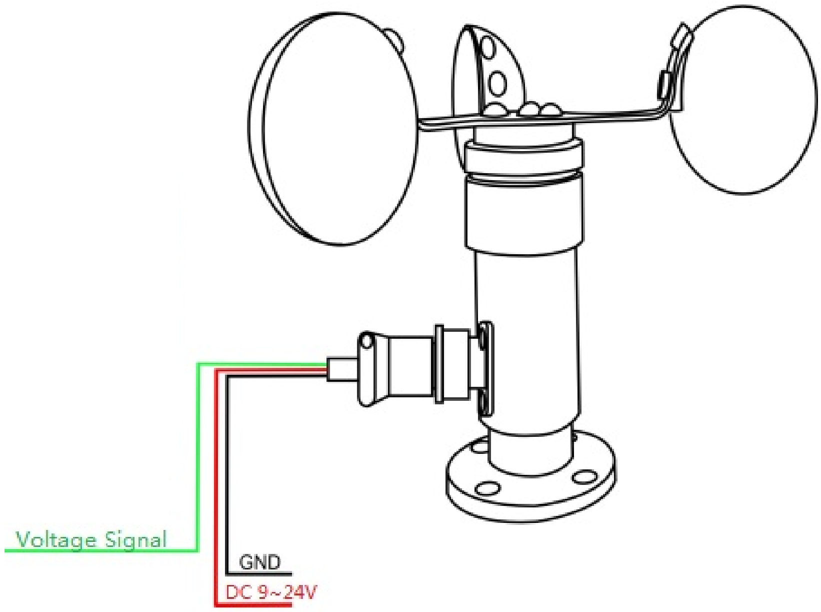


Figure 8 The wind speed device.

Complete circuit description of the developed DAS

The developed DAS system consists of a main microcontroller, Arduino Mega 2560 that controls all the activities within the system. The complete circuit of the DAS system is shown in **Figure 9**. The sensors for solar irradiance and soil heat flux were connected to an analog-to digital-converter, ADS1115 which was then linked to Arduino Mega 2560 via an inter - integrated circuit (I^2C) with SDA and SCL address for communication link.

Wind speed and ultraviolet radiation sensors were also connected to the Arduino's adc input with address of A0 and A1 pins. The atmospheric temperature and soil temperature sensors' outputs use serial 1-wire communication with the Arduino. The air temperature and 3 soil temperatures at 3 levels below the soil surface were connected to digital input and output pins D22, D24, D26 and D28, respectively. The data storage medium is connected to ISCP communication link on the arduino. The SD card memory point MOSI, MISO, CS and SCK was connected to digital pins D50, D51, D52 and D53, respectively.

LCD display is driven using serial communication link to the microcontroller using data pins of the lcd PD7, PD6, PD5, PD4 including pins E and R/W and other data pins. The tipping bucket was connected to external interrupt pin of the Arduino Mega 2560 to count numbers of tipping of the bucket per logging time setting. Analog input A2 was assigned and used for the purpose of interrupt, where the output of the 555 timer monostable circuit from the tipping bucket is being connected to on the Arduino.

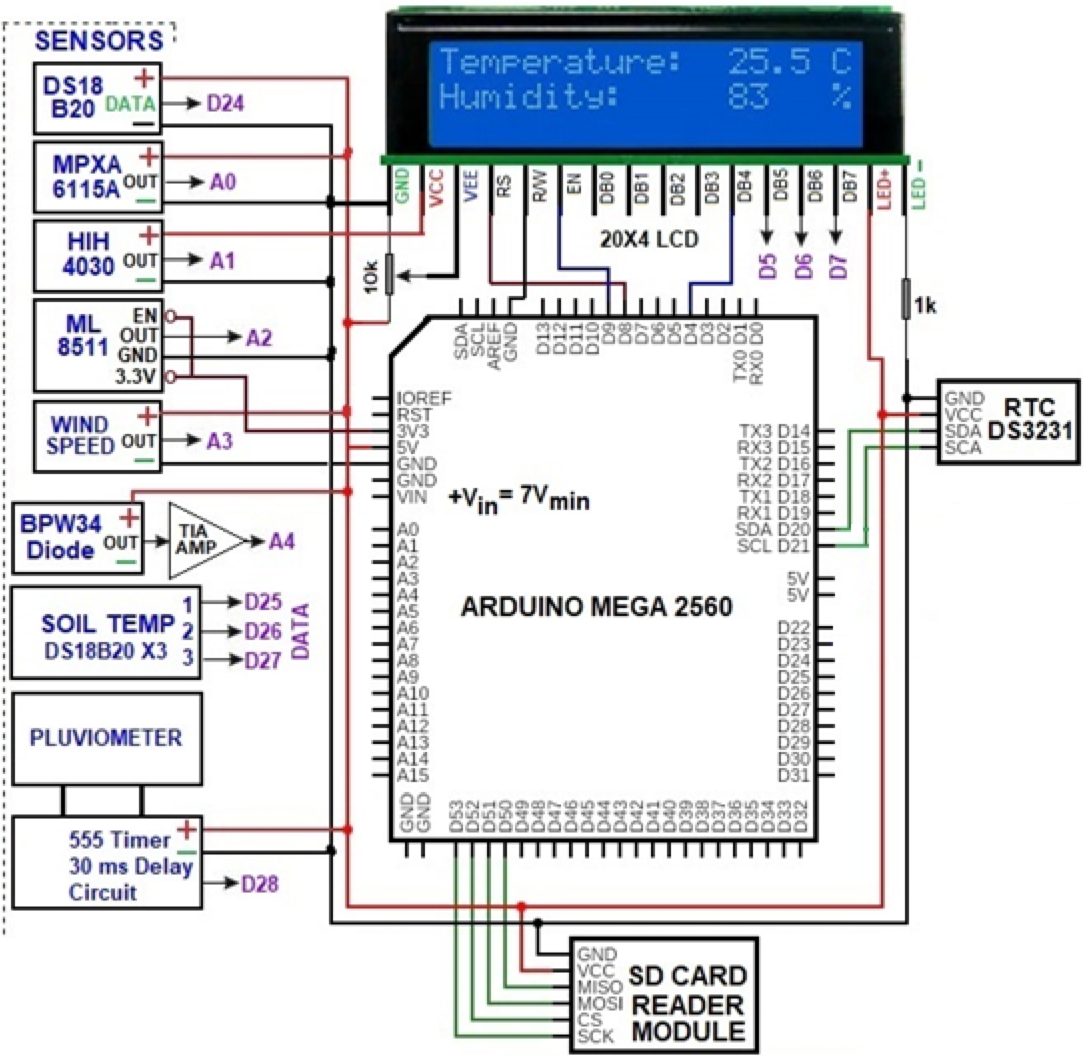


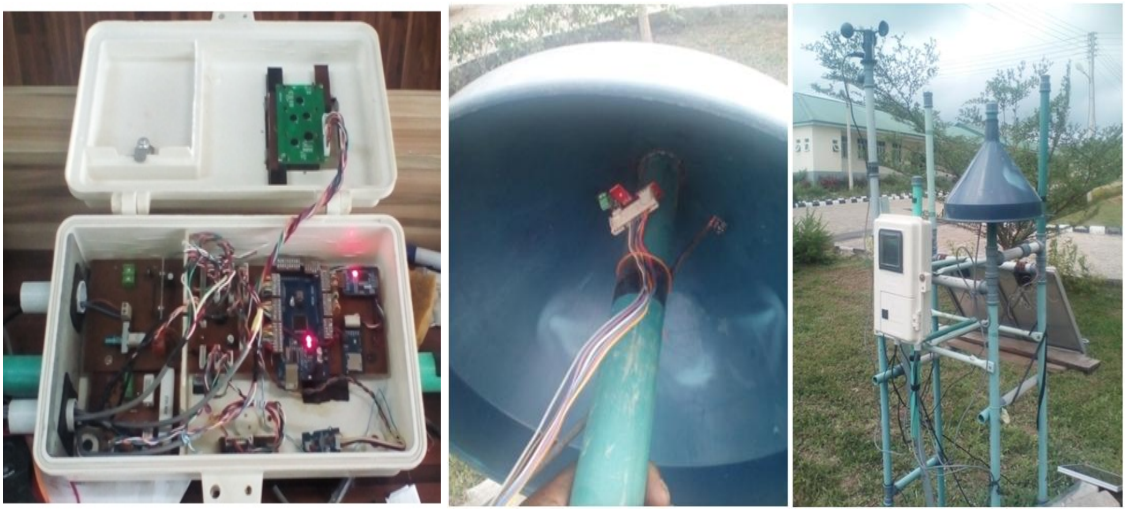
Figure 9 The complete schematic diagram of the developed DAS system.

Weather instrument shelter

A weather instrument shelter is also known as Stevenson Screen. It is a big box painted white to reflect sun's rays and is usually made of wood with a louvered side that allows proper air circulation within the box. A Stevenson Screen houses and protects weather instruments and sensors from direct solar radiation, precipitation and intrusions.

It is usually placed at least 1 m above the ground level to prevent heat conduction from the ground to avoid erroneous readings by instruments and thermometers. Modern instrument shelters are either made of metals or plastic enclosures that are properly sealed to house the electronic parts, amplifiers, signal conditioning circuits and the data logger while the sensors are placed outside the box with covers. For this research purpose, the microcontroller, signal conditioning circuits, data logger and power supply circuits are properly placed inside a white box measuring 30×18×40 cm^3 with half-front transparent plastic as shown in **Figure 10(a)**. The white box was bored at the bottom to hold 2 pipes for passage of sensor wires and for aeration to prevent heat buildup within the box during the day. Soft rubber bands were placed at the 4 edges of the box to prevent water sipping into the box. Also, plenty silica gels are placed inside the box to absorb moistures.

Atmospheric sensors placed outside the box were covered with a 30 cm diameter plastic cone (a funnel) sealed with rubber at one end as shown in **Figure 10(b)**. The completed installation the weather is shown in **Figure 10(c)**.



(a) (b) (c)

Figure 10 (a) Housing of the DAS system, (b) atmospheric sensors shield and (c) the final installation.

Testing, calibration and performance evaluation

Testing

Testing is necessary after the completion of any developed meteorological equipment to confirm if the attached sensors are responding and at the same time giving proper signals at the output when they are exposed to the atmosphere. This is very easy to confirm if the output of the sensors are analog signals. Below are the sensors used and how they performed when exposed during the test.

1) Humidity sensor

The HIH4030 humidity sensor operates on 5 Vdc and its output can vary from 0 V in very low humidity environment to about 4.5 V in high humidity. If its output is connected to a voltmeter and moisture is blown against the sensor, its output voltage rises rapidly in response to continuous blowing of moisture against the sensor. When a source of heat like a soldering iron is suddenly brought near it, its output reduces to almost 0.

2) Wind speed

A voltmeter was connected to the output of the wind speed device which was powered with a 5 V supply. The 3 cups were rotated manually, its output dc voltage increases as it rotates depending on the speed of rotation. It gives out almost 0 voltage when it is not rotating.

3) Ultraviolet sensor

During testing, the UV sensor was powered with 5 V and a voltmeter connected across its output. When exposed to sunlight, it responds by increasing in output voltage according to sun's intensity and an output voltage of about 7 mV when covered with hand.

4) Temperature sensor (DS18B20)

A sketch was written and uploaded to the Arduino Mega 2560 connected to an LCD to view the temperature sensor's output. When a hot soldering iron was brought very close to it, the output immediately indicated 71 °C and then decreased to the environmental temperature when the source of heat was removed.

5) Tipping bucket

The setup for testing the tipping bucket is as shown in **Figure 11**. Also, an Arduino program was written for the counter values to be displayed on the LCD. Manually tipping the bucket, the value displayed on the LCD equals the number of tips per specified time in the program and equivalent volume per sampling time. In the settings of **Figure 11**, a burette tap filled with water was opened steadily into the collecting funnel which is approximately 20 cm in diameter. The number of tips per minute and the volume of water collected were then used to calibrate the amount of rainfall volume per min in mm.

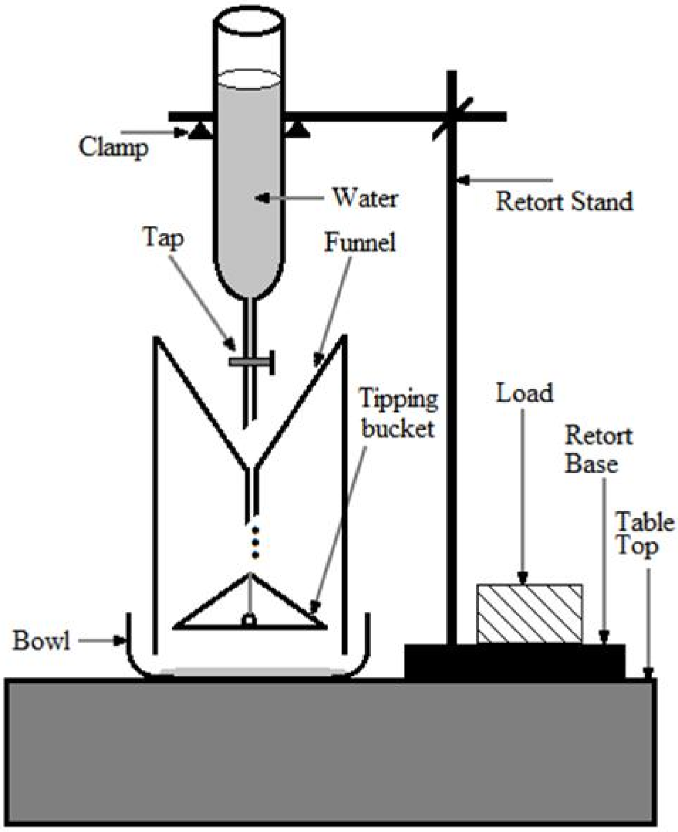


Figure 11 The setup for testing the tipping bucket.

Calibration of tipping bucket

1) Water of 2 mm was measured using a standard measuring syringe and poured on the tipping bucket. The screw under the bucket was adjusted until the bucket tipped. The same adjustment was done on both arms of the bucket.

2) Number of tips that is obtainable per second depends on the reed switch switching time for both closed and open. When magnet passes over it, the closed response time is 0.1 and 0.4 ms for open when magnet left the distance of response. A monostable of 30 ms response time remained in HIGH state after trigger. The monostable is used to trigger external interrupt of Arduino Mega 2560 microcontroller with a delay of 0.5 ms for switch to open and wait for next count.

Comparing off-shelf sensors with known standards

Temperature sensor

The readings of the temperature sensor DS18B20, was compared with that of a mercury-in-glass thermometer. The following apparatus were used: Copper calorimeter, thermometer with a scale of −10 to 120 °C, small stove and a small quantity of water. Water was poured inside the copper calorimeter and tip of DS18B20 temperature sensor and thermometer were inserted into calorimeter via a non-conducting led, including the stirrer for stirring water uniformly for even distribution of temperature. The calorimeter was placed on the lighted stove and temperatures recorded every 10 min until the water was boiled. **Table 1** and **Figure 12** show the response of the temperature sensor when compared with mercury-in-glass thermometer.

Table 1 Comparison of sensors with available in FUTA, meteorological garden.

Time (10 min)	Temperature		Humidity		Wind speed	
	$T_{(DS18B20)}$ (°C)	T_{Hg} (°C)	$RH_{(HIH4030)}$ (%)	$RH_{(Dry\ \&\ wet)}$ (%)	$WS_{(Off\text{-}shelf)}$ (m/s)	WS_{Std} (m/s)
1	27.40	27.4	75.41	73	7.50	6.9
2	27.74	27.6	73.84	75	7.24	7.2
3	29.63	29.6	67.25	65	6.60	6.1
4	29.69	29.8	66.44	65	6.20	6.2
5	30.06	30.0	64.77	65	5.06	5.1
6	28.47	28.4	69.50	71	6.33	6.3
7	29.21	29.0	68.26	68	4.45	4.5
8	28.62	28.6	70.90	72	4.37	4.1
9	28.62	28.6	70.90	72	4.07	4.1
10	27.90	30.0	73.91	74	3.98	3.9
11	26.65	26.6	78.69	80	5.78	5.8
12	25.96	26.0	81.76	82	3.71	3.7
13	25.54	25.5	83.76	86	5.35	5.4
14	25.02	25.0	85.40	85	4.32	4.1
15	24.46	24.6	87.96	90	4.98	4.9
16	24.14	24.0	90.61	91	3.40	3.1
17	24.05	24.0	92.28	96	2.60	2.3
18	23.82	23.6	94.18	92	1.98	1.9
19	23.80	23.8	94.97	97	2.99	2.8
20	23.74	23.8	95.70	93	4.54	4.7
Correlation	0.98		0.99		0.99	

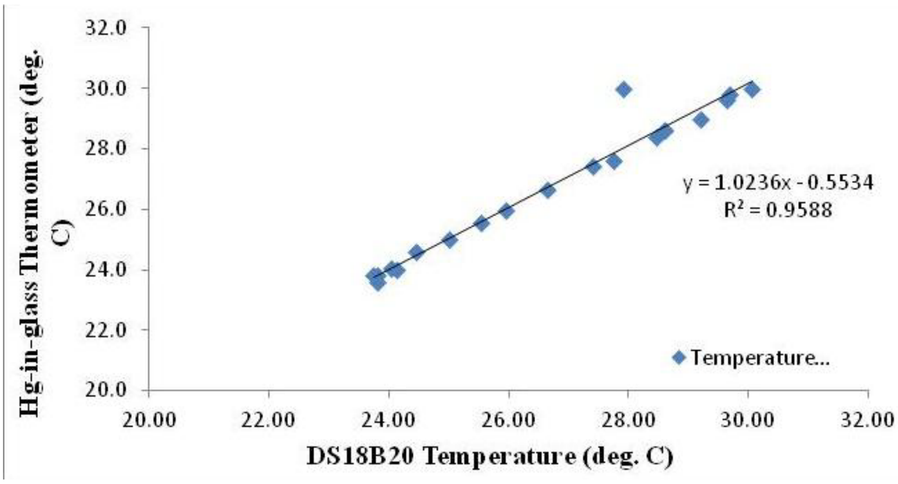


Figure 12 Comparison of performance of DS18B20 with Hg-in-glass thermometer.

Humidity sensor

Humidity sensor HIH4030 was compared with dry and wet thermometer. Humidity sensor HIH4030 developed with Arduino uno for test measurement. This was done to determine the accuracy of HIH4030 sensor. On 17th of September 2017, the developed test instrument was placed inside a Stevenson screen at the meteorological garden FUT, Akure that contained dry and wet thermometers. The displayed value of the developed test instrument and dry and wet thermometer were recorded every 10 min for 2 h. From **Table 1**, graph of the collected data is plotted in **Figure 13**.

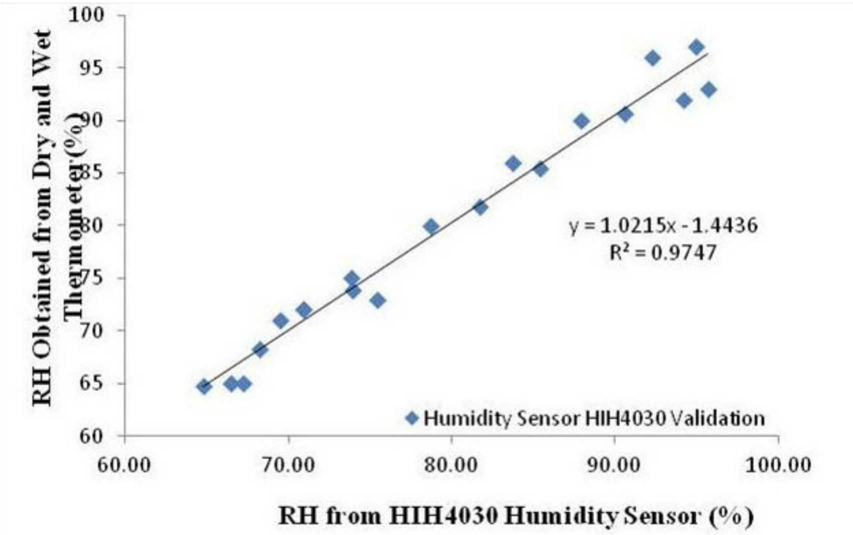


Figure 13 Comparison of performance of HIH4030 with RH obtained from dry and wet thermometer.

Wind speed sensor

Wind speed sensor (MYR150) was compared with another Cup Anemometer by placing them at the same place and height at meteorological garden FUT, Akure. The values were recorded every 2 min for 2 h. **Table 1** shows the data collected and **Figure 14** shows the response graphically.

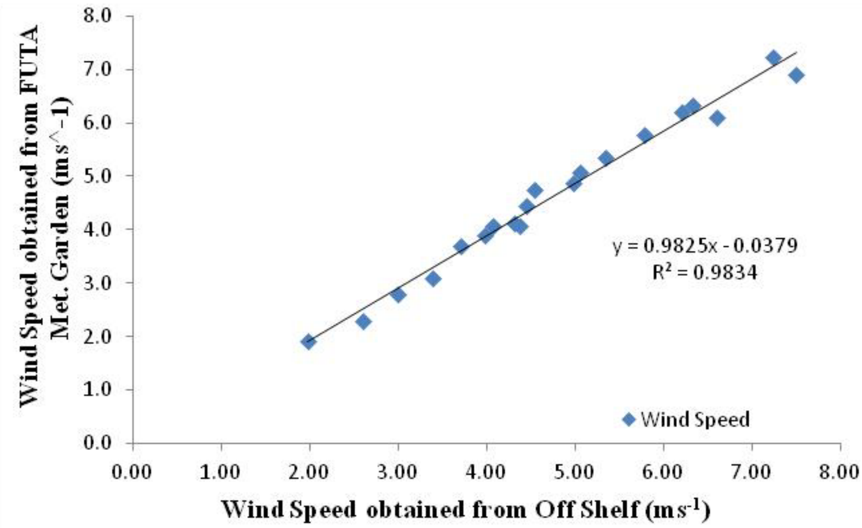


Figure 14 Comparison of performance of off-shelf wind speed device with Campbell wind speed device.

Results and discussion

A more cost-effective DAS for meteorological observations was designed and built. **Figure 10(c)** is a completed installation of the developed DAS on the field with power supply. Selection of suitable sensors were considered so as to ensure good compromise between measurement accuracy and measurable range. Modular implementation of sensors allows upgrading and addition of sensors according to user needs. The DAS can read and record values from more than 20 analog and digital sensors. This due to the capability of the Arduino microcontroller board. Data logged can be easily opened in an excel sheet for analysis. The samples of logged data in excel format is shown in **Figure 15**.

Development of Ultra Low-Cost DAS for Developing Countries
Department of Physical Sciences (RUN), Ede
Refresh Rate (ms) = 60000

Date	Time	Air T (°C)	Pressure (mbar)	RH (%)	SolarRad (w/m^2)	WindSpd (m/s)	UV Rad (mW/m^	Rain (mm)	Rrate (mm/hr)	ST 1(°C)	ST 2(°C)	ST 3(°C)
1/1/2020	8:04	19.19	976.72	80.51	6.46	3.35	0.32	0	0	22.31	25.31	26.81
1/1/2020	8:05	19.25	976.7	80.73	99.14	3.51	0.32	0	0	22.31	25.19	26.81
1/1/2020	8:06	19.31	976.82	79.92	47.03	4.57	0.32	0	0	22.31	25.25	26.81
1/1/2020	8:07	19.31	976.82	79.7	2.77	3.05	0.32	0	0	22.31	25.25	26.81
1/1/2020	8:08	19.33	976.91	80.61	7.84	7.47	0.36	0	0	22.31	25.31	26.81
1/1/2020	8:09	19.41	976.87	78.53	38.73	2.44	0.36	0	0	22.37	25.12	26.81
1/1/2020	8:10	19.47	976.85	78.89	11.99	4.73	0.36	0	0	22.37	25.31	26.75
1/1/2020	8:11	19.51	976.9	79.62	5.07	2.29	0.4	0	0	22.37	25.19	26.81
1/1/2020	8:12	19.6	976.89	79.27	21.21	0.3	0.4	0	0	22.44	25.12	26.75
1/1/2020	8:13	19.65	976.91	78.77	105.13	3.05	0.4	0	0	22.44	25.12	26.75
1/1/2020	8:14	19.74	976.96	77.92	8.76	2.9	0.36	0	0	22.44	25.31	26.75
1/1/2020	8:15	19.72	977.04	78.58	64.55	1.68	0.4	0	0	22.44	25.12	26.75
1/1/2020	8:16	19.84	977.01	78.14	108.82	3.35	0.4	0	0	22.5	25.19	26.75
1/1/2020	8:17	19.93	977.03	77.14	8.76	2.44	0.44	0	0	22.5	25.31	26.75
1/1/2020	8:18	19.99	977	77.83	5.07	2.29	0.44	0	0	22.5	25.19	26.75
1/1/2020	8:19	20.05	977.06	77.8	47.95	4.88	0.44	0	0	22.5	25.31	26.75
1/1/2020	8:20	20.05	977.09	76.22	16.14	7.47	0.44	0	0	22.56	25.25	26.75
1/1/2020	8:21	20.01	976.97	74.96	42.88	5.18	0.44	0	0	22.56	25.19	26.75
1/1/2020	8:22	19.97	977.07	75.31	92.68	3.51	0.52	0	0	22.56	25.25	26.75
1/1/2020	8:23	20.06	977.13	75.32	82.08	3.05	0.48	0	0	22.56	25.19	26.75
1/1/2020	8:24	20.13	977.18	76.01	43.34	1.83	0.52	0	0	22.62	25.25	26.75
1/1/2020	8:25	20.15	977.16	76.52	13.37	1.22	0.52	0	0	22.62	25.25	26.75
1/1/2020	8:26	20.32	977.11	76.47	92.22	1.83	0.52	0	0	22.62	25.31	26.75
1/1/2020	8:27	20.36	977.11	75.62	72.39	4.57	0.56	0	0	22.69	25.12	26.75

Figure 15 Samples of logged data for Jan 2020 in excel format.

To validate the accuracy of the developed system, data collected were examined and compared with that of a nearby station. The 3 soil temperatures sensors were placed in the same level inside soil at 10 cm above the surface for 2 h to examine their responses from 21 to 23 h of local time. The data obtained for the period were plotted in **Figure 16**, which shows similar behaviour in their responses.

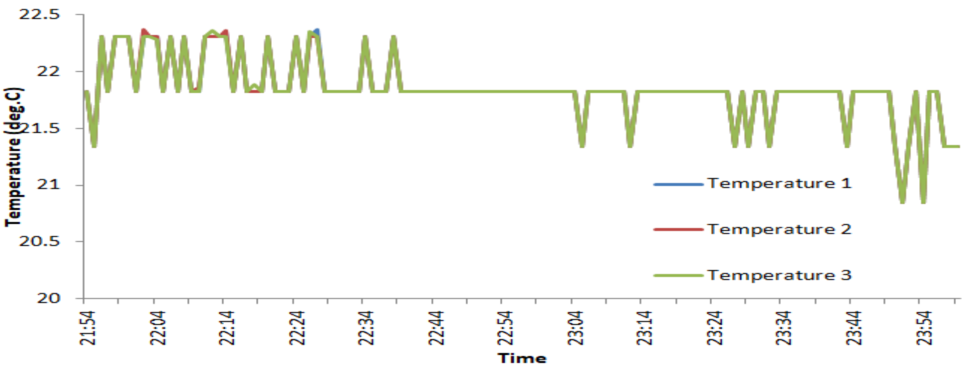


Figure 16 Three soil temperature sensors measurement at same level in the soil.

Data set for the year 2017 were obtained from Davies Instrument at Fountain University, Osogbo at latitude 7.7667°N and longitude 4.5667°E, and January data of the year 2017 was compared with that of January 2020 obtained from the developed DAS system at Ede latitude 7.733°N and longitude 4.433°E. Air temperature data and ultraviolet radiations from the 2 stations were plotted, the trend were similar as shown in **Figures 17** and **18**. This confirms that developed DAS is working to expectation. **Figure 19** shows the diurnal variation of air temperature, pressure, relative humidity and wind speed on the 2nd of January 2020. This shows the functionality of the developed DAS, and it logs the data every 1 m which is the minimum integration time of the DAS. Higher integration times up to 24 h can be configured if desired.

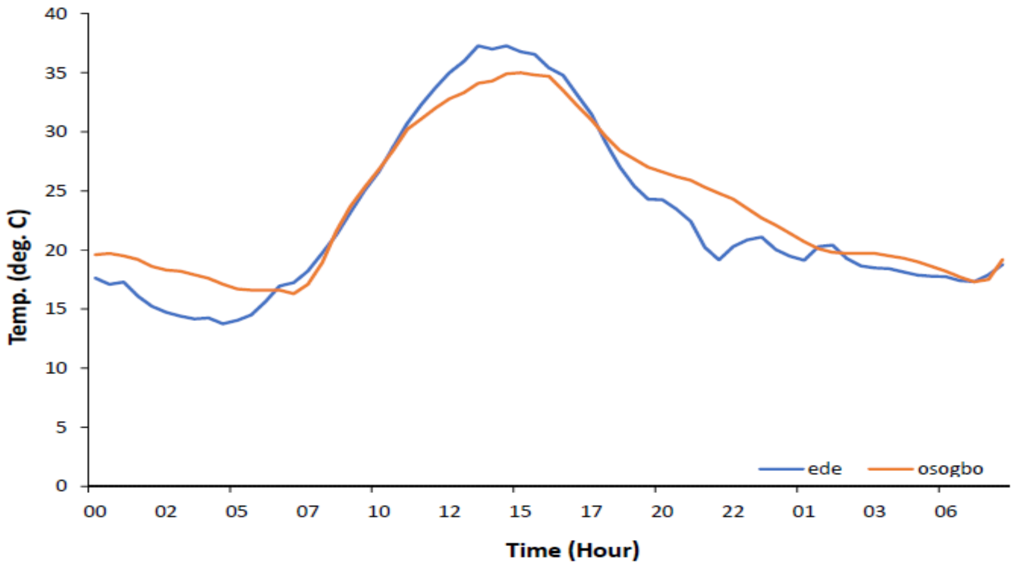


Figure 17 Comparison of daily variation of air temperature between Jan 1 2020, Ede and Jan 1 2017, Osogbo.

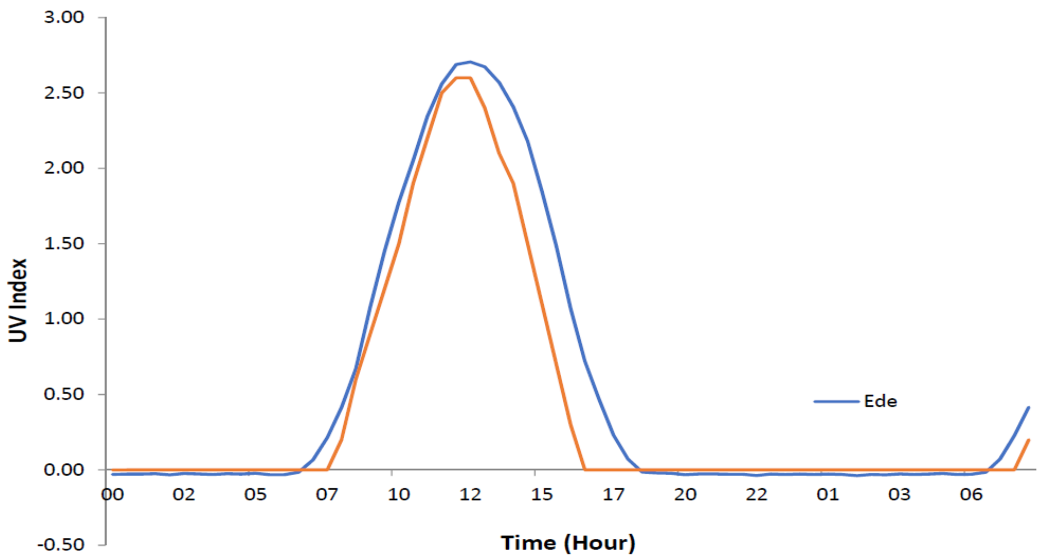


Figure 18 Comparing diurnal variation of UV index between Jan 1 2020, Ede and January 1 2017, Osogbo.

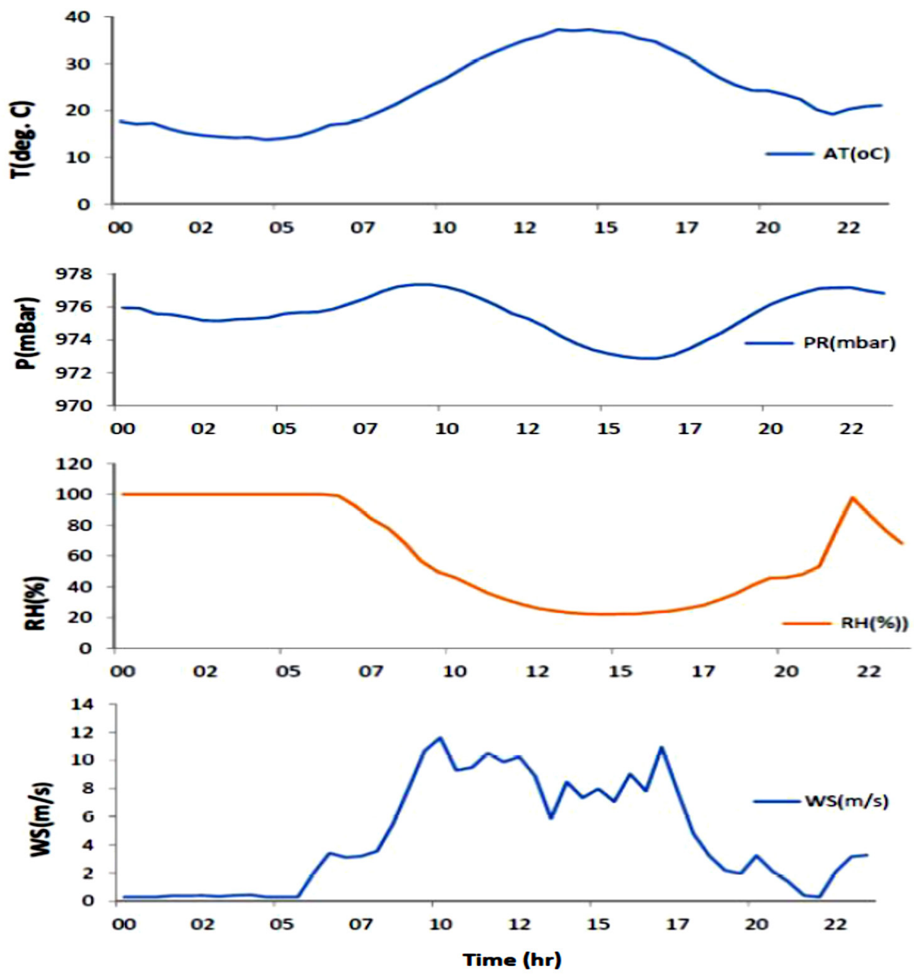


Figure 19 Daily variation of air temperature, pressure, humidity and wind speed for 2nd January 2020.

Conclusions

This work has successfully developed a low-cost DAS for meteorological observations. Logged data are stored as comma separated values which can be opened in an excel sheet for analysis. The tables and plots obtained from experiments for standardizing the sensors, it is clear that there is a close conformity between the data collected by the developed system and the existing calibrated systems when compared. The need for extra cost baud rate and expensive third-party computer software for interfacing to download data from the logger have been eliminated. When compared with imported datalogger including all the sensor on the developed DAS, it is about 65 % less in cost. The performance proved to be reliable and flexible with ease of maintenance when compared to other commercially available data acquisition systems. It is thereby evident that the DAS is of better choice in terms of cost and maintenance. The developed system can also be used for other personal, scientific and industrial applications that require long term measurements and recordings from various atmospheric sensors.

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