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Development of an Environment and Climate Data Acquisition System (EC-DAQS) for Radio Propagation Studies

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Most weather monitoring systems used for measuring meteorological parameters are imported. For many developing countries like Nigeria, importing measuring instruments is practically bedeviled with problems due to erratic exchange rates. This has hampered weather-related research especially in radio propagation studies where finite weather data are required. In the quest to develop a home-grown monitoring system, this paper presents an Environment and Climate data acquisition system (EC-DAQS). In the EC-DAQS, an Arduino Mega2560 microcontroller along with six environment and weather sensors were coded to measure, record and display atmospheric parameters. For digital signal processing and data logging, the sensors were interconnected to the microcontroller through an analogue-to-digital-converter (ADC). The measured data were displayed on a liquid crystal display (LCD) screen remotely connected to the controller. Temperature, Ultraviolet Violet (UV) rays, humidity and sound level were tested and calibrated with "off-the shelf" instruments. The mean bias error (MBE) and the root mean square error (RMSE) were used to validate the temperature readings from the EC-DAQS with readings from a standard infra-red thermometer. The low results of the MBE (0.16°C) and RMSE (0.51°C) – showed close proximity between the EC-DAQS and the standard infra-red digital thermometer measurements. Also, the equation obtained from modelling is a straight line of near unity slope (0.994) and a correlation of 99.98%. The EC-DAQS developed will be a useful meteorological instrument, and a suitable replacement for imported weather stations in terms of performance, cost and

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maintenance. It will also provide some invaluable data needed for radio-propagation research and applications.

Keywords: Microcontroller; sensors; data acquisition system; radio propagation data; climate meteorology.

1. INTRODUCTION

Acquisition of data of meteorological parameters is fundamental for effective research in radio meteorology and radio propagation. These parameters include air pressure, air temperature, air humidity, wind speed and direction, precipitation, haze, air contents, solar and terrestrial radiation. Effective measurement of these meteorological parameters is necessary for scientific research in Renewable energy, Solar radiation, Medical Physics, Geo-magnetics, Atmospheric and Space Physics, weather and environment forecasts and especially for telecommunications and radio propagation issues. Such meteorological parameters can be effectively collected using sensors.

A sensor is a module that measures or detects some parameters of the environment or changes of that parameter over time. The electronic sensor has two transducers, that is, primary and secondary transducers. The primary transducer converts real-world input parameters to an electrical signal, and the secondary transducer converts an electrical signal into analogue or digital results [1]. The data acquisition (DAQ) process requires the use of the sensor-transducer to collect and measure changes in the environment, transform it into electrical signals and interpret the information [2,3].

Most instruments and equipment used in developing countries like Nigeria are imported from technologically advanced countries such as USA, China, India and Japan. Sometimes these equipment are inferior, substandard and obsolete. Most of them are prone to damage by the fluctuating and erratic power supplies. When damaged, the devices need to be returned to their parent companies for repairs.

In meteorological research, the data acquisition systems (DAS) like the DAVIS weather station are very expensive to purchase. Moreso, a young researcher pays heavily to obtain meteorological data from government repository agencies like the Nigerian Meteorological Agency (NiMET) and the Tropospheric Data Acquisition Network (TRODAN) [4]. Other difficulties faced by a researcher accessing meteorological data from these agencies were highlighted by [5]. These problems spell the need to develop home-grown sensors that are low-cost, robust, accurate and may be readily maintained locally; and perform efficiently when compared with their counterparts around the globe.

Several DAQS have been designed to measure and process meteorological data using various methods such as a battery-powered microcontroller-based data acquisition system for remote measurements [6,7]; a computer-based system of sensors for meteorological and electrical parameters [8]; the Arduino open-source platform data logger [9]; the Arduino Mega board temperature sensor [10] for solar energy applications; the GIS-based system [11] for acquiring and analysing geographical and meteorological parameters, and for forecasting solar irradiation; a sensor-based wireless air quality monitoring network (SWAQMN) [12] to monitor real-time particulate matter concentration in India; a MATLAB-based microcontroller [13] connected to a microphone through software-installed systems to measure sound in different shape of nozzles. Each of these examples demonstrate the basic leverage required for the design of EC-DAQS with adequate electronics and necessary software.

Presented in this paper is the development of a low-cost Arduino-based climate data acquisition system (EC-DAQS) for radio meteorology. In this work, the Arduino Mega 2560 was used as the main controller because of its more general input/outputs [14] and analog-to-digital converter (ADC) channels, which allow for interfacing with input sensors.

2. MATERIALS AND METHODS

2.1 Schematic Diagram of EC-DAQS

Fig. 1a is the building block diagram of the developed Climate Data Acquisition System (EC-DAQS) Transmitter. It consists of microcontroller, temperature and humidity sensor, ultraviolet light sensor, air quality sensor, sound detector, transceivers to allow communication between the two devices. Fig. 1b is the Receiver section of the EC-DAQS, which also consists of a transceiver that receives all signal information; a microcontroller and a liquid crystal display (LCD) unit that displays the information in a readable format.

2.2 System Algorithm and Flowchart

The microcontrollers exchange the signals between the transmitter and receiver after which, they compare them as shown in the flowchart (Fig. 2). The transmitter takes both digital and analogue data from the sensors; process the data using Analogue to Digital Converter (ADC) or Digital to Analogue Converter (DAC), digitize the signal and decide in succession which one to forward to the receiver. The receiver receives all the data from the transmitter, interprets it and pass it to the LCD unit in a readable format. Two 3000mAh lithium ion 8650 batteries connected in series were used to supply 8.4 volts to each microcontroller. The microcontrollers have in-built power regulator circuits with input voltage of 12V and regulated output of 3.3V and 5V respectively. The system makes use of four sensors, two transceivers and one Liquid Crystal Display that are connected to microcontrollers and programmed. For this study, the microcontroller, data logger, power supply circuits and signal conditioning circuits are proper housed as shown in Fig. 2(b-c).

2.3 Complete Circuit Description of the Developed EC-DAQS

The EC-DAQS developed consists of the transmitter and receiver sections and their circuitry are shown in Fig. 3(a) and 3(b). The microcontroller has various input and output (I/O) pins that communicate with each other. DSM Pin 2 and Pin 4 were connected to microcontroller Pin 3 and Pin 6. DHT22 Pin 2 was connected to Arduino Pin 4. TSL2561 and RTC used I2C communication protocol of microcontroller while nRF240L and microSD Card CE, CSN and CS connected to Arduino digital Pins 9, 8 and 10. The Microphone was connected to Analog Pin A0 of the microcontroller.

The complete circuit of EC-DAQS Receiver in Fig. 3b shows the nRF240L receiver on Pin 10 connected to Pin 11 of Atmega2560. The EC-DAQS was designed to collect data from sensors, log data into the SD Card for storage; and also transmit it wirelessly to a remote receiver for display in a readable format. The microcontrollers sample the data received from sensors, process and send for individual task.

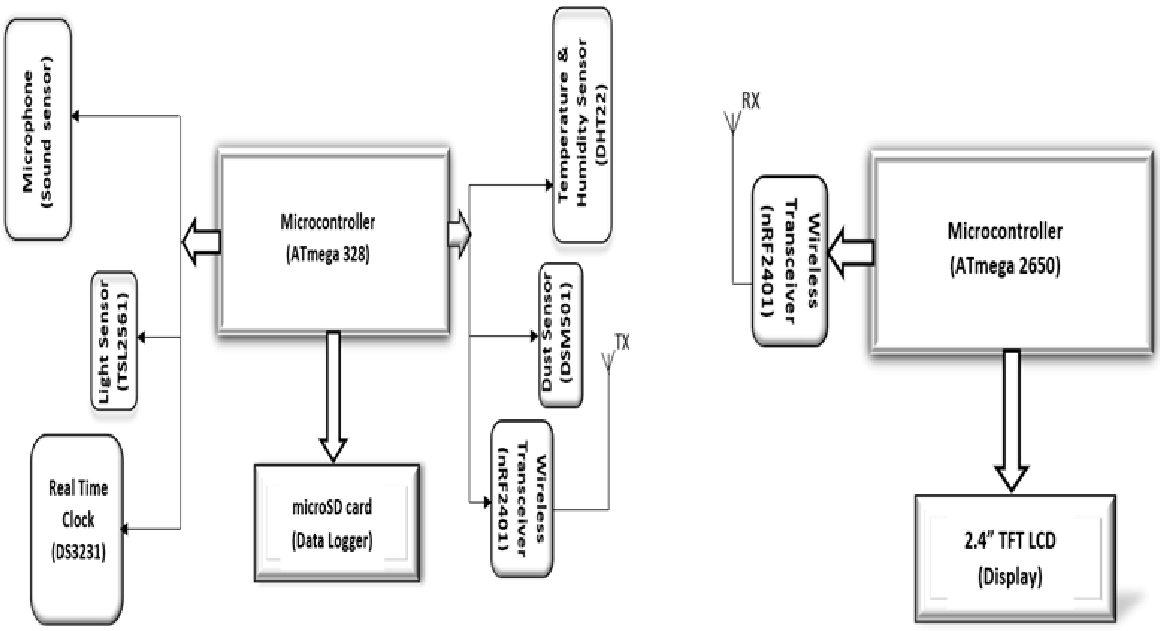

Fig. 1. Schematic diagram of the developed EC-DAQS (a) Transmitter and (b) Receiver

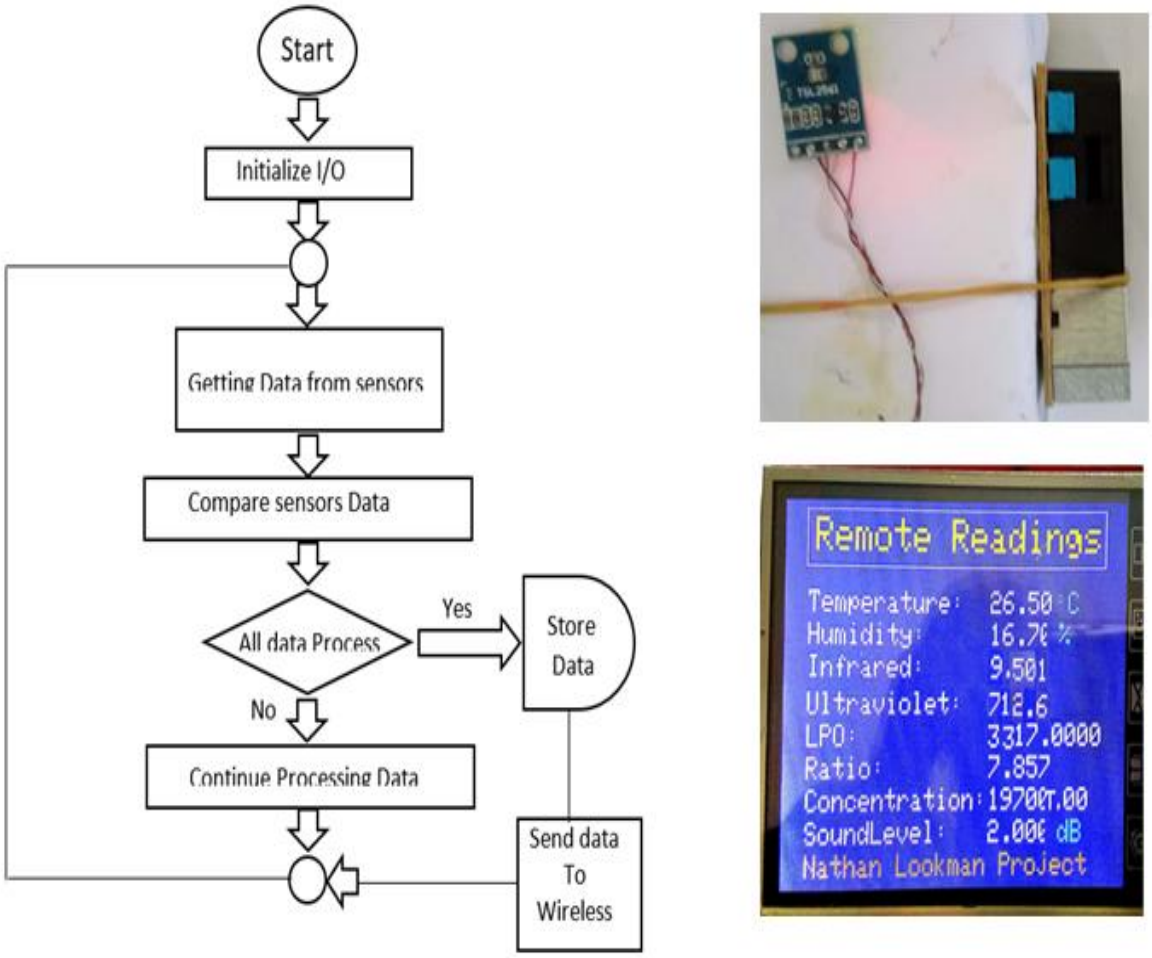

Fig. 2. (a) Flow Chart of the EC-DAQS, (b) EC-DAQS Transmitter, (c) EC-DAQS Receiver display

2.4 Validating the EC-DAQS

In order to validate the EC-DAQS, observation from the digital thermometer were compared with the result of EC-DAQS using mean bias error (MBE) and root mean squared error (RMSE) given in equations 1 and 2. That is

$$MBE = \frac{1}{n}\sum_{i=1}^{n}(P_i - Q_i) \quad (1)$$

where Q_i is the observation value and P_i is the forecast value. Root Mean Square Error is given as

$$RMSE = \sqrt{1/n\,\{\sum_{i=1}^{n}(Observation - Measured)^2\}}$$

$$= \sqrt{\frac{\sum_{i=1}^{n}(P_i - Q_i)^2}{n}} \quad (2)$$

Equations (1) and (2) were solved on Microsoft Spreadsheet (EXCEL).

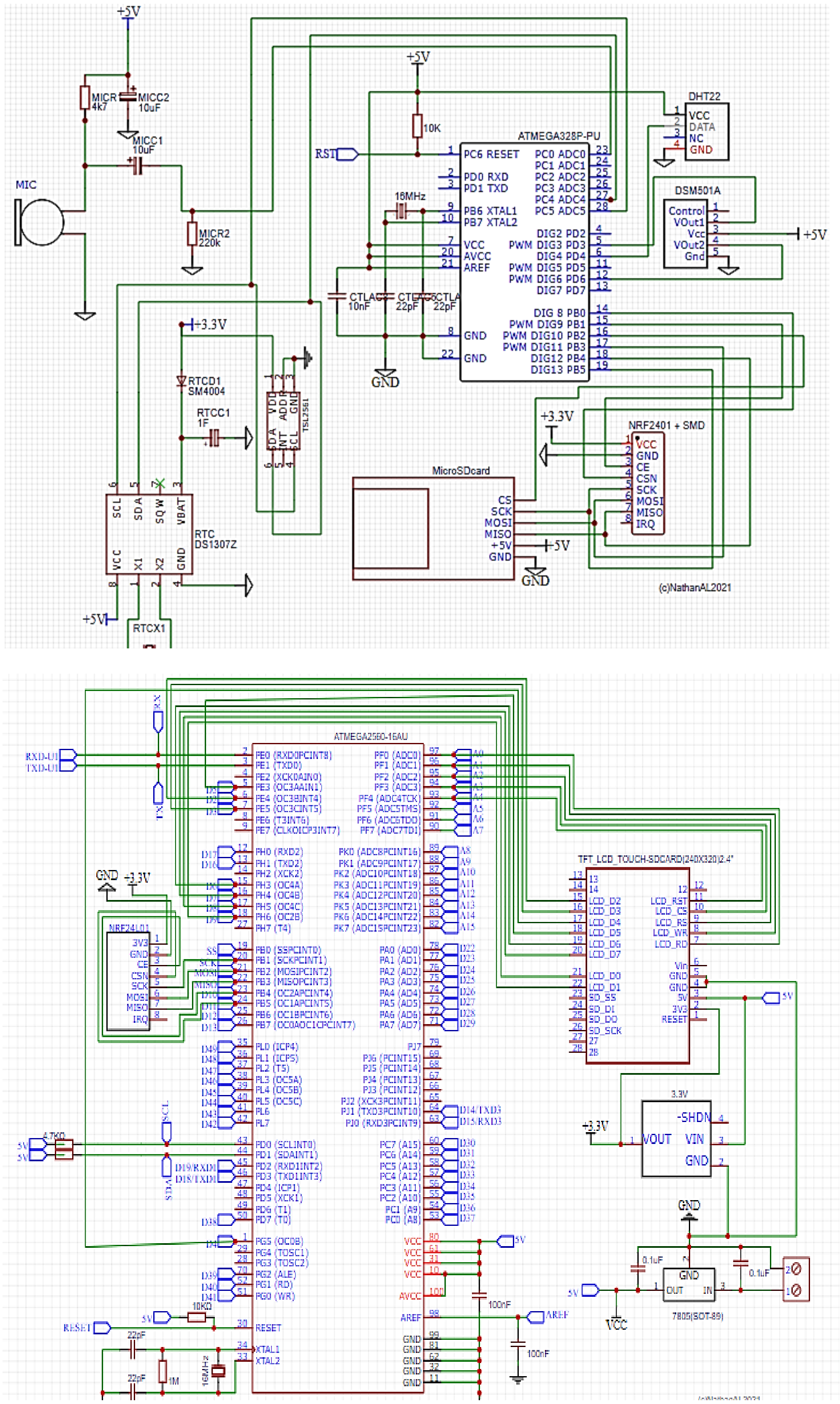

Fig. 3. The Pin-Configuration of the developed EC-DAQS (a) Transmitter, (b) Receiver

3. RESULTS AND DISCUSSION

3.1 Measurements of Environmental and Weather Parameters

A sample of data logged in by the designed EC-DAQ device is presented in Fig. 4. The device was able to log in the Date and Time on minute-by-minute time basis, as well as measure and log in six environment and climate parameters namely:- Temperature, Humidity, Infra-Red, Ultra-Violet, Air-Concentration, Sound Level. These are major parameters required for studies in various fields of Physics such as radio-propagation, Atmospheric and Space, Acoustics, Aerodynamics and Solar Irradiation to name a few.

3.2 Comparison of Reading between the EC-DAQS and Off-the-Shelf Sensor

Temperature, UV, humidity and sound level were tested, compared with the off-the-shelf sensors. The process of Temperature testing is presented in Fig. 5 showing the comparison between the standard infrared thermometer and the designed temperature reading; while Table 1 provides the comparison averaged over a 2-hour basis for the purpose of result validation.

3.3 Validating the EC-DAQS

The results Microsoft Spreadsheet to obtain the Mean Bias Error (MBE) and the Root Mean Squared Error (RMSE) respectively. = 0.16°C (Using Excel to solve equation 5) and = 0.51°C (Using excel to solve equation 6). The very low MBE result of 0.16°C and RMSE of 0.51°C indicates high accuracy of EC-DAQS as compared with the standard laboratory digital thermometer. Also, the hourly variation of the temperature measured for both Infra-red (IR) thermometer and the EC-DAQS are shown in Fig. 6. The modelling equation obtained is a straight line of near unity slope (0.994) and a correlation coefficient of 99.98%.

*Log.txt3 - Notepad

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DATE	TIME	Temp	Hum	IR	UV	LPO	Ratio	Conc	Soundlevel
(17-02-2021)	(22:16:00)	23.80	24.20	2.00	22.00	172521.00	74.95	385540.00	50.01
(17-02-2021)	(22:17:00)	24.20	23.50	2.00	22.00	230963.00	56.71	497925.00	50.01
(17-02-2021)	(22:18:00)	24.10	23.20	2.00	22.00	6277.00	67.92	460890.00	50.00
(17-02-2021)	(22:19:00)	24.10	23.20	2.00	22.00	186437.00	75.49	445048.00	50.01
(17-02-2021)	(22:20:00)	24.10	23.30	2.00	22.00	9174.00	66.29	549069.00	50.01
(17-02-2021)	(22:21:00)	24.10	23.40	2.00	22.00	11823.00	72.30	381657.00	50.00
(17-02-2021)	(22:22:00)	24.00	23.30	2.00	22.00	350841.00	71.34	348209.00	50.01
(17-02-2021)	(22:23:00)	24.00	23.30	10.00	115.00	344040.00	69.50	350649.00	50.03
(17-02-2021)	(22:24:00)	24.00	23.40	13.00	110.00	5006.00	65.40	509822.00	50.01
(17-02-2021)	(22:25:00)	24.00	23.50	2.00	22.00	213310.00	64.20	466827.00	50.01
(17-02-2021)	(22:26:00)	24.00	23.50	2.00	22.00	72318.00	74.01	511251.00	50.00
(17-02-2021)	(22:27:00)	23.90	23.60	5.00	20.00	86274.00	68.15	489437.00	50.01
(17-02-2021)	(22:28:00)	24.00	23.60	2.00	22.00	311617.00	69.50	393189.00	50.01
(17-02-2021)	(22:29:00)	23.90	24.00	2.00	22.00	78502.00	69.97	368915.00	50.02
(17-02-2021)	(22:30:00)	23.90	23.90	2.00	22.00	6188.00	69.39	324940.00	50.01
(17-02-2021)	(22:31:00)	23.90	23.80	2.00	22.00	254892.00	78.31	596957.00	50.01
(17-02-2021)	(22:32:00)	23.90	23.80	2.00	22.00	111145.00	70.42	556357.00	50.00
(17-02-2021)	(22:33:00)	23.90	23.90	2.00	22.00	11317.00	70.12	387276.00	50.00
(17-02-2021)	(22:34:00)	23.80	24.00	2.00	22.00	10427.00	62.35	538862.00	50.01
(17-02-2021)	(22:35:00)	23.80	23.90	2.00	22.00	30220.00	60.70	55608.00	50.00
(17-02-2021)	(22:36:00)	23.80	23.90	2.00	22.00	202052.00	75.43	413945.00	50.01
(17-02-2021)	(22:37:00)	23.80	23.70	2.00	22.00	97524.00	66.97	411203.00	50.01
(17-02-2021)	(22:38:00)	23.80	23.80	2.00	22.00	32337.00	73.68	332560.00	50.00
(17-02-2021)	(22:39:00)	23.70	23.90	2.00	21.00	129982.00	39.11	81052.00	50.01
(17-02-2021)	(22:40:00)	23.70	23.90	2.00	22.00	5840.00	33.31	46714.00	50.00

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Fig. 4. Sample of minute-by-minute data logged by EC-DAQS

Fig. 5. Temperature reading of Infra-red thermometer compared with designed EC-DAQS

Table 1. Validation of temperature readings of EC-DAQS with IR thermometer (Observed)

Time	IR Thermo (Observed)	EC-DAQS (Measured)	MBE = d/n d= (P-Q)	RMSE, x = ((d^2)/n)^0.5
06:00	15.4	14.7	0.7	0.490
08:00	16.0	16.2	-0.2	0.040
10:00	24.6	25.7	-1.1	1.210
12:00	27.1	27.0	0.1	0.010
14:00	28.5	28.3	0.2	0.040
16:00	30.3	29.8	0.5	0.250
18:00	29.8	29.3	0.5	0.250
20:00	26.6	26.4	0.2	0.040
22:00	24.2	24.0	0.2	0.040
00:00	23.4	22.9	0.5	0.250
			0.16	**0.51**

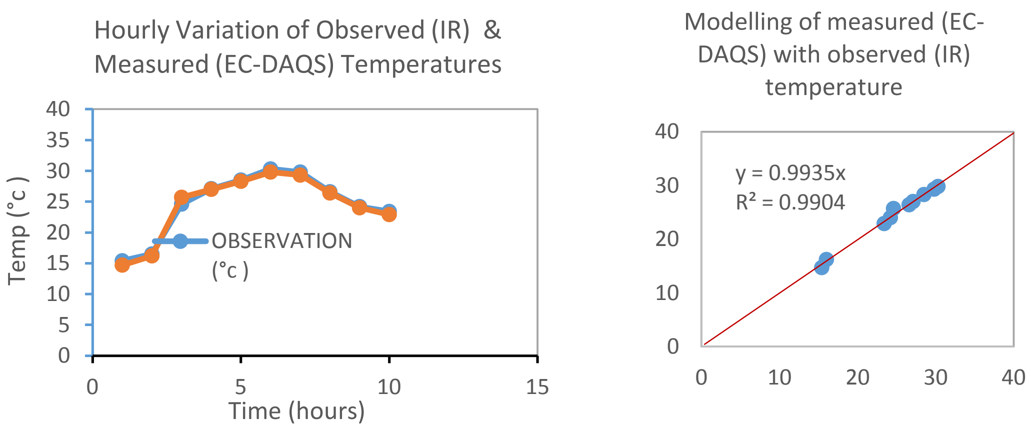

Fig. 6. a) Comparison of observed (IR) and measured (DAQS) Temperatures b) Linear relationship between observed (IR) and measured (DAQS) readings

4. CONCLUSION

This paper has addressed the dearth of meteorological equipment for acquiring radio-propagation research data in Nigeria by designing the Environment and Climate Data Acquisition System (EC-DAQS). The home-grown EC-DAQS designed is low cost and easy to repair; with electronic sensors capable of detecting, recording, storing and displaying the values of temperature, humidity, infrared and ultraviolet rays, dust particles and acoustic sound. The EC-DAQS was designed and constructed using Arduino IDE, C++ programming codes, sensors and other peripheral modules. The experimental test results of the MBE and RMSE were very low (0.16 °C, 0.51 °C respectively) showing close proximity between measurements by EC-DAQS and digital thermometer. Also, the equation obtained from the model is a straight line of near unity slope (0.994) and a correlation of 99.98%. The EC-DAQS device will serve as an important tool for estimating daily, diurnal, monthly and seasonal variations of meteorological parameters with high accuracy. It will also provide invaluable data required for meteorological applications and enhance scientific research especially in. radio-communication.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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