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

Abstract

Most weather monitoring systems used for measuring meteorological parameters are imported. For most developing countries such as 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 parameters 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 was used to measure, record and display atmospheric parameters. The sensors for six environment and weather parameters were interfaced with the microcontroller through the ADC for digital signal conversion and data logging. Finally, the measured parameters were displayed on an LCD connected to the controller. Temperature, UV, humidity and sound level were tested and calibrated with "off-the shelf" instruments. Readings from the EC-DAQS were validated with readings from the digital thermometer and sound level meter using the mean bias error (MBE) and the root mean squared error (RMSE). The results of the MBE and RMSE were (0.21 ^{O}C and 1.03 ^{O}C) respectively for temperature – showing high proximity between the EC-DAQS and digital thermometer measurement. The EC-DAQS developed will be a useful meteorological instrument, and a good replacement for imported weather stations in terms of cost and maintenance. The EC-DAQS developed will give invaluable data needed for radio-meteorological applications and research.

Keywords: Radio meteorology, Climate, data acquisition system, microcontroller, Sensors

1. Introduction

Data acquisition of meteorological parameters such as air pressure, air temperature, air humidity, wind speed and direction, precipitation, haze and contents of the air, solar and terrestrial radiation etc is fundamental for effective research in radio meteorology and radio propagation. These meteorological parameters can be effectively collected using sensors. A sensor is a module that measures or detects some property of the environment or changes of that property 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 analog or digital results [1].

Processing and interpretation of information require sensor and transducer for data acquisition (DAQ), to collect and measure changes in the environment and transform it into electrical signals [2], [3]. Effective measurement of these meteorological parameters is necessary for scientific research in climatology, weather and environment forecasts and especially for telecommunications, space and radio propagation issues.

Most instruments and equipment used in developing countries like Nigeria are imported from technologically advanced countries like USA, China, India and Japan. When damaged, they need to be sent to the parent company for repairs. Moreso, some equipment are substandard, obsolete and inferior. They are easily damaged due to fluctuating and erratic power supplies. There is the need to develop home-grown sensors that are low-cost, robust, easy and cheap to maintain. Their accuracy must also compare favourably with their counterparts around the globe.

For most meteorological data acquired for research purposes, the data acquisition systems (DAS) like the DAVIS weather station are readily available for purchase at very high prices. Even the meteorological data obtained from the central repository agencies like the Nigerian Meteorological Agency (NiMET) and the Tropospheric Data Acquisition Network (TRODAN) come at a fairly high price for a juvenile researcher [4]. Numerous difficulties that a researcher may face in obtaining data from these agencies were highlighted by [5].

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, 8]; a computer-based system of sensors for meteorological and electrical parameters [7]; 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 Block Diagram of EC-DAQS

Figure 1a is the building block diagram of the developed Climate Data Acquisition System Transmitter. This block consists of microcontroller, temperature and humidity sensor, ultraviolet light sensor, air quality sensor, sound detector, transceivers to allow communication between the two signals and LCD display unit. Figure 1b is the building block diagram of the developed Climate Data Acquisition System Receiver. This block also consists of transceiver that receives all signal information, microcontroller and LCD display unit that displays the information in readable format.

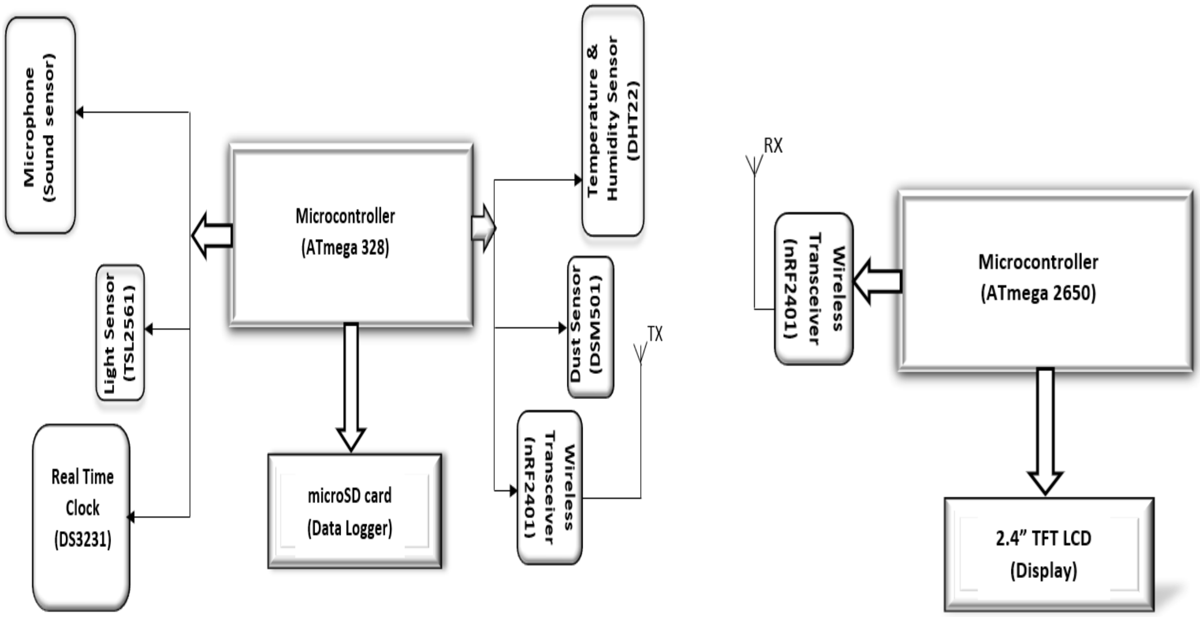

Figure 1: Block diagram of the developed EC-DAQS (a) transmitter and (b) Receiver

2.2 System Algorithm

The microcontrollers exchange the signals between the transmitter and receiver after which, they compare them. The transmitter takes both digital and analogue data from the sensors. The transmitter then processes the data using Analogue to Digital Converter (ADC) or Digital to Analogue Converter (DAC), digitized it and decides 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 display in a readable format. The cycle is continuous in a repeated process. Two 3000mAh lithium ion 8650 batteries connected in series were used to supply eight plus (8.4) volts power to each microcontroller. Each of the microcontrollers has built in power regulator circuits for input voltage of up to 12V and regulated output of 3.3V and 5V respectively.

2.3 Complete Circuit Description of the Developed EC-DAQS

The EC-DAQS developed consists of the transmitter and receiver section. The complete circuit of the EC-DAQS is shown in figure 2(a). The microcontroller has various input and output (I/O) pin to 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. Microphone was connected to Analog pin A0 of the microcontroller. Figure 2b showed complete circuit of EC-DAQS Receiver. The nRF240L receiver was connected to Pin 10 and 11 of Atmega2560. Figure 3(a) showed the flowchart of the EC-DAQS. The EC-DAQS is developed to collect data from sensors, log it to SD Card for scientific purpose and transmit this data wirelessly to a remote receiver which displays it in a readable format. The system makes use of four sensors, two transceivers and one Liquid Crystal Display that are connected to microcontrollers and programmed. The microcontrollers sample the data received from sensors, process and send for individual task. For this study, the microcontroller, data logger, power supply circuits and signal conditioning circuits are proper housed as shown in figure 3 (b-c).

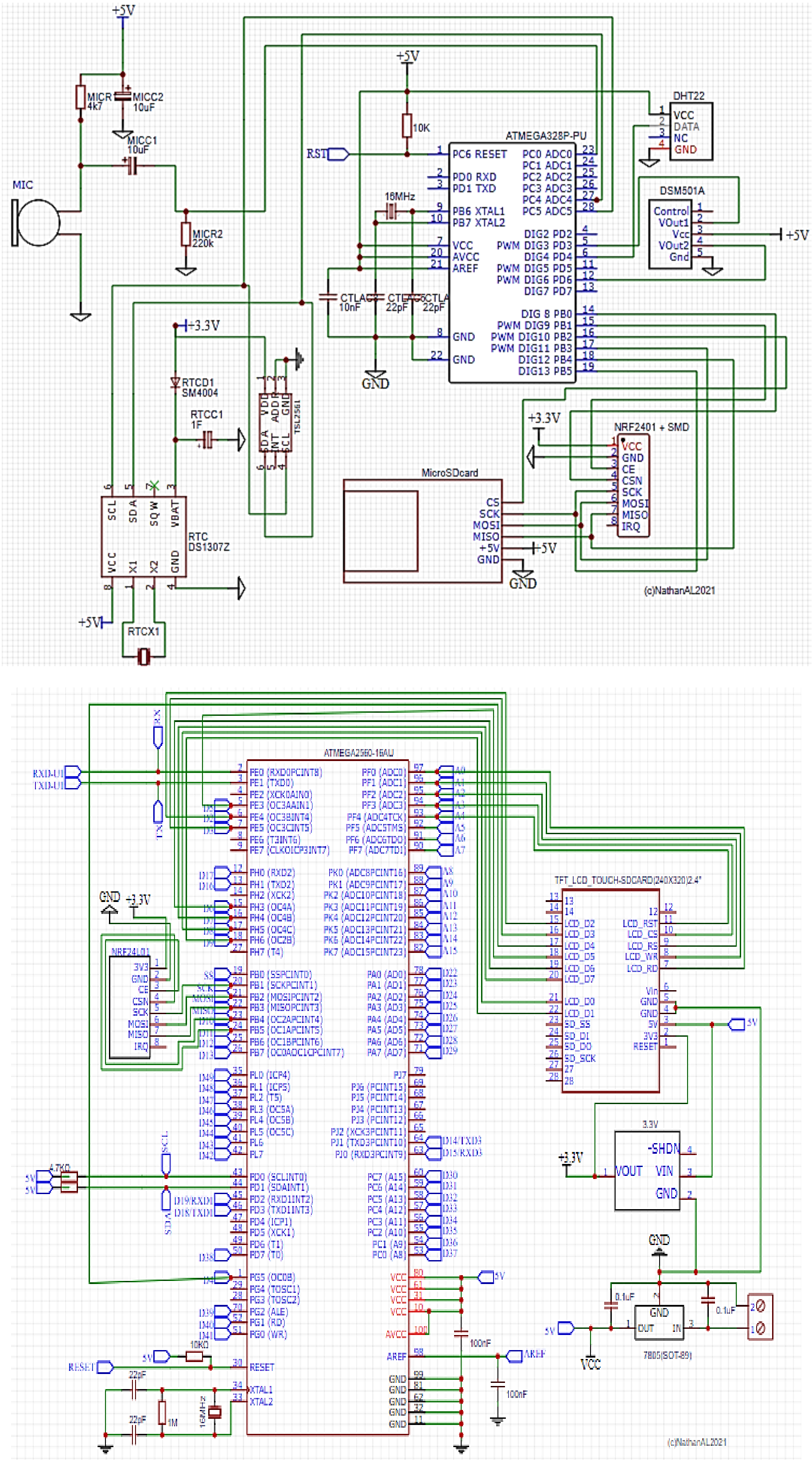

Figure 2: The Pin-Configuration of the developed EC-DAQS (a) Transmitter, (b) Receiver

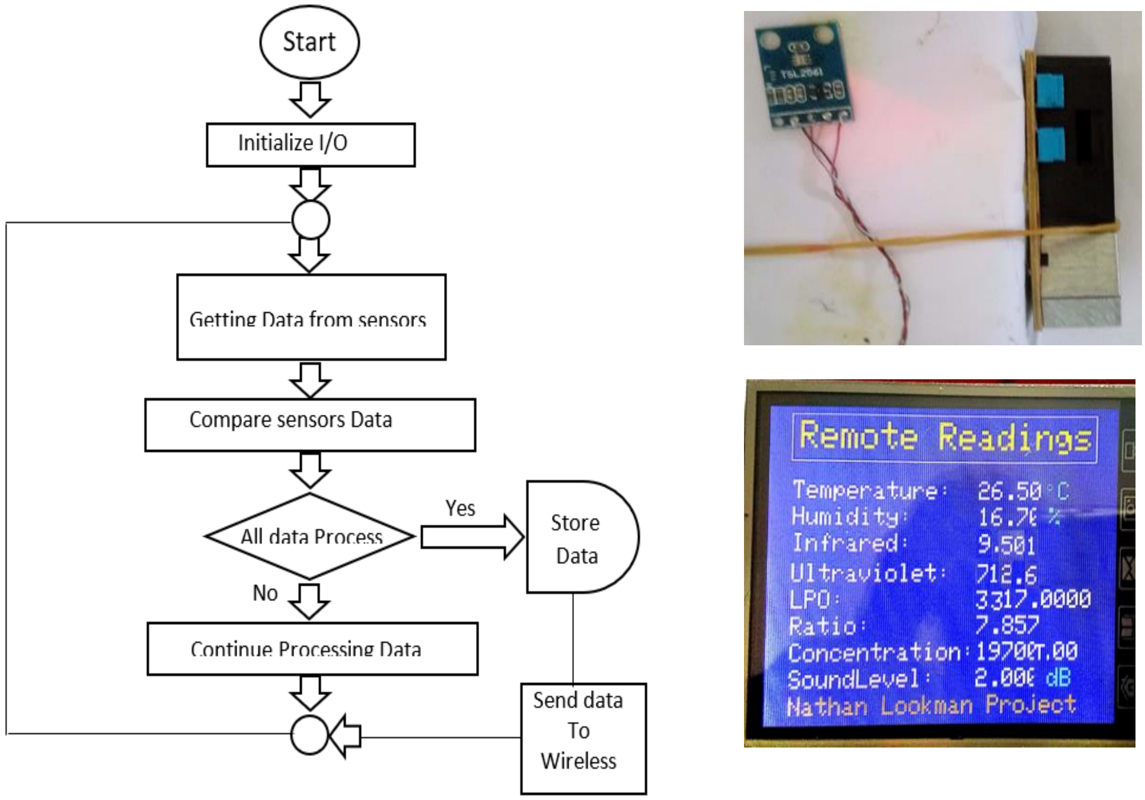

Figure 3: (a) Flow Chart of the EC-DAQS, (b) EC-DAQS Transmitter, (c) EC-DAQS Receiver display

3. Results and Discussion

3.1 Comparison of Reading between the EC-DAQS and Off-the-Shelf Sensors

Temperature, UV, humidity and sound level were tested, compared with the off-the-shelf sensors and the results were presented. Figure 4 showed the comparison between the standard infrared thermometer and the designed temperature readings.

Figure 4: Temperature reading of standard infrared thermometer and designed EC-DAQS.

3.2 Validating the EC-DAQS

In order to validate the EC-DAQS, observation from the digital thermometer and sound level meter 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

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

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

$$RMSE = \frac{1}{n}\left\{\left(Observation\right)^2 - \left(Measured\right)^2\right\} \tag{2}$$

Measurements were taken at 2 hours interval from 06:00 to 00:00 as shown in Table 1. The results of Mean Bias Error (MBE) = 0.21 °C (Using Excel to solve equation 5) and Root Mean Squared Error (RMSE) = 1.03 °C (Using excel to solve equation 6).

The MBE has a very low result of 0.21 °C and RMSE was 1.03 °C showing high proximity of CAQS readings with the standard laboratory digital thermometer. Also, the graph of the temperature measured for both Infra-red thermometer and the EC-DAQS are shown in figure 5.

Table 1: Comparison of temperature taken at 2 hours interval between digital thermometer (Observed) and EC-DAQS.

TEMPERATURE		
TIME	**OBSERVATION (°c)**	**EC-DAQS (°c)**
6.00	15.4	14.7
8.00	16.0	16.2
10.00	24 .6	25.7
12.00	27.1	27.0
14.00	28.5	28.3
16.00	30.3	29.8
18.00	29.8	29.3
20.00	26.6	26.4
22.00	24.2	24.0
00.00	23.4	22.9

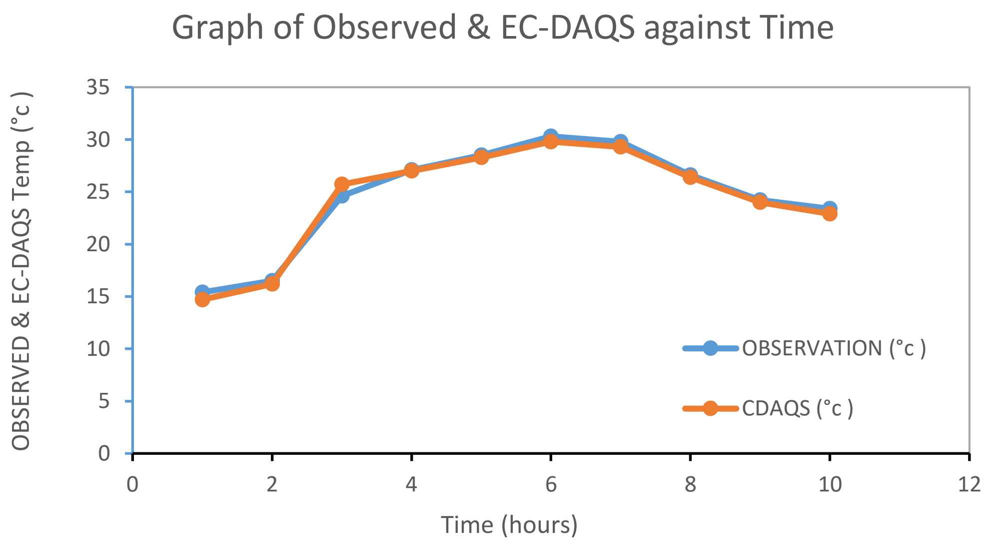

Figure 5: The relationship between Observed and EC-DAQS readings

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 EC-DAQS designed is home-grown with low cost, ease of repair, electronic sensors capable of detecting, recording, storing and displaying the amount of temperature, humidity, infrared and ultraviolet rays, dust particles and acoustic sound. The EC-DAQS was designed and constructed using Arduino IDE, C++ language programming and other peripheral modules. The EC-DAQS was tested and examined through intensive experimental work. The results of the MBE and RMSE were quite good showing high proximity between the EC-DAQS and digital thermometer measurement. The EC-DAQS developed will serve as an important tool for estimating daily, diurnal, monthly and seasonal variations of meteorological parameters with high accuracy. This EC-DAQS developed will give invaluable data needed for meteorological applications and enhance radio-communication research.

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