Development of a Low-Cost Arduino-Based Weather Station

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Abstract- A weather station is a facility located either on land or sea consisting of instruments and equipment which can be used to measure atmospheric conditions so as to provide weather forecasts information and to study the weather. The existing instruments used for measuring the weather elements are expensive which led to the development of a low-cost Arduino-based weather station. The developed low-cost weather station consists of three separate modules which are data collection, data storage, and data communication. These modules communicate serially with each other and are controlled by three separate microcontrollers (Arduino Uno). The data collection module is interfaced with a set of sensors that collects temperature and humidity. The weather data were viewed in real-time through a graphical user interface (GUI) located at the central station. The developed weather station was able to measure the temperature and humidity of a controlled environment, giving the reading at interval of five minutes. It was observed that the average temperature from results obtained (27.36°C) with the developed low-cost Arduino based weather station falls within the range of the Accuweather readings (24.00-28.00°C). Also, the average humidity of the developed low-cost Arduino based weather station (80.41%) falls within the range of the Weatherspark humidity (78-82%) on 20th August 2019. Therefore, this system can be adopted as a weather station facility. The design can be extended to be web-based in the future to make it available worldwide.

Keywords- Arduino Uno, Humidity, RF Transceiver, Temperature, Weather Station

1 INTRODUCTION

The weather could be defined as the state of the atmosphere which describes for example the degree of hotness or coldness, wetness or dryness, calmness or stormy, clear or cloudy (Merriam-Webster Dictionary, 2008). It refers to day-to-day temperature and precipitation activity. Climate is the term for the averaging of atmospheric conditions over longer periods (America metrological society, 2008). A weather station is a facility which is located either on land or sea and consists of instruments and equipment used to measure atmospheric conditions thereby providing information for weather forecasts study of weather and climate (Verbelen and Yannick, 2016). The measurements taken are temperature, atmospheric pressure, humidity, wind speed, wind direction, and precipitation amount.

In the early 1800s and 1900s, home weather stations typically consist of a few specialized analog tools. Humidity gauges measure the moisture content in the air, while rain gauges and barometers help determine previous and future rainfall. Manual observations are taken at least once daily, while automated measurements are taken at least once an hour. There must be knowledge of existing atmospheric conditions before weather can be predicted (Yates, 1947). Therefore, there is a need to create a means of measuring the different elements of weather.

Before the invention of weather measuring equipment, weather monitoring and forecasting was done mostly through experiences of human (mostly farmers) about cloud cover and wind movements. With the progress in the field of science and technology, various electronic devices were developed to measure, monitor, predict, and forecast various weather parameters. This development, therefore, contributed to understanding of the atmosphere which enables individuals to make, measure, monitor, and record the atmospheric measurements (Farvez, Saha and Hossain, 2016).

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Previous studies carried out by Okhakhu, (2014) discovered that the utilization of inadequate climate information for environmental planning, inaccurate monitoring and forecasting of the atmospheric condition resulted in widespread climate-induced inundation of cities such as mud-flows on the streets, ravine formation on the highways, destruction of farm produce, the collapse of several buildings, deteriorated and impaired visibility on the roads and airports.

For example, in Nigeria, essential services of weather reports are carried out by the Nigerian Meteorological Agency (NMA), but some factors such as inadequate funding on the part of the government and corporate bodies, presence of few experts, and poor maintenance of installed apparatus have weakened the institutional effectiveness and sustainability of the meteorological services in Nigeria (Okhakhu, 2014).

The fact is, it is not genuine to accept entirely that all weather reports from both private and government-owned meteorological stations throughout the country are completely pooled and documented at the NMA as most rural areas in the country do not have functional meteorological stations (American Meteorological Society, 2009). There is a need to verify the genuineness of the weather reports generated using accurate land-based weather stations which is a major disadvantage in the documentation and provision of precise weather and climate information which can be used for weather predictions and forecasting for disaster prevention in our community (Okhakhu, 2014).

Currently, digital weather stations that are easy to view and understand and can combine and report information has been developed. Some can even connect to smartphone apps or online services such that people can access their weather information from anywhere. It can be used to manage gardens and monitor farms and also as a hobby. Digital weather stations are more accurate and
easier to use (Acurite, 2018).

In developed countries, various satellites are orbiting in the space just to monitor the climatic conditions; but it is notable that such devices are very robust, expensive, and are associated with high-end technologies. So, there is a need for a system that can monitor the weather parameters precisely and also cost-efficient and real-time operational so that it can be installed at any place like small industries, institutions, home (Akhilesh, Tejas, Chinmay, Kolwalkar and Mahalaxmi, 2015).

The existing instruments which are used for measuring weather elements are costly. Thus, the need for the development of a low-cost Arduino-based weather station. (Arduino design, 2008) based weather station to solve the stated problem. This study collects weather elements and transmits them to digital data with the aid of a simple digital device. The data gathered over a period of time can be used to predict the atmospheric condition of a place. The information can help in adequate planning for any weather dependent activity such as agriculture, civil construction work, etc.

Olatomiwa and Adikwu (2012) designed a low-cost weather station which was used to measure four weather elements namely temperature, atmospheric pressure, relative humidity and wind speed using their respective sensors. The logged data was used to view the logged data using a MATLAB based graphical user interface (GUI) and some setup operations were performed on the system. The results obtained were compared with the results obtained from a separate weather monitoring instruments and showed a high correlation. Standard meters were also used to check the readings from the weather station and the results were consistent with the ones obtained from the device. Sharara (2014) developed a prototype weather station which was used to measure the air temperature, relative humidity, dew point, wind speed, and rainfall remotely. The recorded weather data was transmitted wirelessly to a Personal Computer (PC) for logging and display by means of a graphical user interface. The results show that the difference between the measured data with similar weather measurement devices is quite consistent.

Kedia (2016) developed a localized weather monitoring system to measure temperature, pressure, humidity, wind speed, and precipitation. The accuracy predicted by these weather stations is not too high to predict the actual weather condition for a particular area. There is an error difference of around 10%. Ukhurebor et al. (2017) proposed a weather monitoring device using Arduino Mega 2560 microcontroller and some modern proper sensors with a real time data logger and LCD. The device was used to measure temperature, relative humidity, atmospheric pressure, light intensity, dew point temperature, and altitude. The results obtained from the device were in good consistence with the results obtained from other sources.

Islam et al. (2018) developed a microcontroller based wireless humidity monitor. The accuracy of the developed system was tested using a digital standard humidity meter and shows a very good accuracy with a mean error of approximately 2% which is mainly as a result of the hysteresis effects of the sensor. Dada et al. (2018) developed a microcontroller based remote weather monitoring system to measure temperature, relative humidity and light intensity. The major advantage of this method is that it does not need a computer or internet service to monitor the locations remotely thus making it cost effective.

2 METHODOLOGY

The general basic module of the developed low-cost weather station is as shown in Figure 1. It is divided into four modules which includes transmitter, receiver, desktop application and a database server. The transmitter module continuously reads atmospheric parameters, using appropriate sensors, and sends them to the receiver module using Radio Frequency (RF) communication link. The RF transceiver used can only transmit or receive twenty-four (24) bytes of data at a time. However, the data read from the sensors is more than than the transceiver limit. Therefore, the data read was divided into three packets and each packet is sent one after the other. Transmission of the last packet depends on the successful transmission of the second packet while the transmission of the second packet depends on the successful transmission of the first packet. Thus, the receiver sends an acknowledgment to the transmitter to indicate receipt of data. Hence, Half-duplex mode of transmission was employed.

The receiver module merges the packets and sends the received data to the database server through a desktop application using the Recommended Standard 232 (RS-232) protocol. The desktop application module builds up queries, sends requests to the database server, and presents information gathered in a user-friendly way to the personnel using the system.

![Fig. 1: Basic Modules of the Arduino-based Weather Station](image)

2.1 TRANSMITTER MODULE

This module is an Embedded System. It comprises hardware and software components as shown in Figure 2. The hardware sub-modules include a Temperature and Humidity sensor (DHT11), a Transceiver module (nRF24L01), a Power Supply Unit, and a microcontroller unit that houses the software component. The DHT11 output pin was connected to pin 2 of the Arduino board. The Inter-Integrated Circuit (I2C) of TSL2561 pins (SDA and SCL) were connected to the Analog pins A4 and A5 of the Arduino board respectively. The Serial Peripheral Interface (SPI), Digital pins 9, 10, 11, 12, and 13 on the Arduino board were used to interface the nRF24L01 module.
The software for the transmitter and receiver module contains the control program written in the C++ language and sketched in Arduino IDE. The algorithm for the transmitter module is as shown in Table 1.

Table 1. Algorithm for the Transmitter Module

| Step | Description |
|------|-------------|
| 1.    | Start       |
| 2.    | Initialize Sensors and Transceiver |
| 3.    | Fetch Data from Sensors |
| 4.    | Format Data into three 24-byte wide Strings including separators |
| 5.    | Transmit Transmitter Data |
| 6.    | If transmitter data successful then Transmit carry data |
| 7.    | Repeat Step 3 |
| 8.    | Repeat Step 1 |
| 9.    | Stop |

Under the instructions of the control program, the microcontroller continuously probes the sensors, using appropriate communication protocols as presented in Table 1 and fetches the atmospheric parameters. The Arduino fetches temperature (°C) and humidity (%) from DHT11. After fetching, it formatted the data into acceptable Strings, and sends the data through the transceiver module to the receiver module.

2.2 RECEIVER MODULE

The block diagram of the Receiver module is shown in Figure 3. It comprises hardware and software components. The hardware sub-modules include a Transceiver module (nRF24L01), a power supply unit, and a microcontroller unit that houses the software component. The Serial Peripheral Interface (SPI), Digital pin 9, 10, 11, 12, and 13, on the Arduino Uno board were used to interface the nRF24L01 module. The algorithm of the control program is as presented in Table 2. It directed the host to listen on a particular channel, received strings of data, sent acknowledgments, concatenated the string data, and sent the data to a computer server using an RS-232 communication protocol. The algorithm for the receiver module is as shown in Table 2.

Table 2. Algorithm for the Receiver Module

| Step | Description |
|------|-------------|
| 1.    | Start       |
| 2.    | Initialize Transceiver |
| 3.    | Declare String sr_data and byte buff_data |
| 4.    | Receive buff_data |
| 5.    | Send Acknowledgement |
| 6.    | If buff_data[0] = 1 Then Delete buff_data[0] and Compare sr_data = buff_data |
| 7.    | If buff_data[0] = 1 Then Delete buff_data[0] and Compare sr_data = sr_data + buff_data |
| 8.    | If buff_data[0] = 1 Then Delete buff_data[0] and Compare sr_data = sr_data + buff_data |
| 9.    | If buff_data[0] = 1 Then send sr_data to Computer Server |
| 10.   | Clear sr_data |
| 11.   | Repeat Step 4 |
| 12.   | Stop |

2.3 DATABASE SERVER AND DESKTOP APPLICATION MODULES

Figure 4 shows the block diagram of the database server and the desktop application modules. It also comprises hardware and software components. The hardware is a computer server that houses the software component. The software components include Database Management System (DBMS) and a desktop application written in Microsoft Visual Basic.Net. The .Net program receives data from the receiver module using RS-232 communication protocol and stores the reports in a MySQL database. The Desktop Application also builds up queries, sends requests to the database as shown in Figure 5, and exports records of atmospheric data into an Excel file for a neater representation.
Plate 1 shows the arrangement of the hardware components on a breadboard before transfer to Veroboard for permanent soldering while plate 2 is the complete black box of the designed low-cost Arduino based weather station.

**3 RESULTS AND DISCUSSION**

The developed weather station readings were effectively retrieved at North campus Federal Polytechnic Ede on 20th August 2019 and stored in files. The files were then imported to excel automatically using macros and the data was cleansed and formatted for a neater representation. Graphical charts were then plotted using the data which presented a nice analytical view of the weather pattern based on sensor readings. The following table shows some weather data recorded by the system on 20th August 2019.

| S/N | Time (Hrs.) | Temperature (°C) | Humidity (%) |
|-----|-------------|------------------|--------------|
| 1   | 11.33       | 28.00            | 81.10        |
| 2   | 11.38       | 27.40            | 0.00         |
| 3   | 11.42       | 27.40            | 82.00        |
| 4   | 11.47       | 27.40            | 82.00        |
| 5   | 11.52       | 27.40            | 82.80        |
| 6   | 11.57       | 27.20            | 83.50        |
| 7   | 12.02       | 27.20            | 84.50        |
| 8   | 12.07       | 26.90            | 85.40        |
| 9   | 12.12       | 26.80            | 85.90        |
| 10  | 12.17       | 26.70            | 85.70        |
| 11  | 12.22       | 27.00            | 84.80        |
| 12  | 12.27       | 27.30            | 83.50        |
| 13  | 12.32       | 27.40            | 82.80        |
| 14  | 12.37       | 27.60            | 82.70        |
| 15  | 12.42       | 27.70            | 81.80        |
| 16  | 12.47       | 27.70            | 82.00        |
| 17  | 12.52       | 27.60            | 82.30        |
| 18  | 12.57       | 27.50            | 82.80        |
| 19  | 13.02       | 27.70            | 31.80        |
|    | Average     | 27.36            | 80.41        |

From Figure 6, it was observed that the temperature was stable in the earlier minutes between 11:33 - 11:52 and decreased from 11:57 - 12:17 after which the temperature increases steadily. Figure 7 shows that humidity was high early and become stable between 11:38 - 12:57 before it dropped.

**Table 1. Temperature and Humidity reading at 5 minutes interval on 20th August 2019**
4 CONCLUSION AND RECOMMENDATION
The developed low-cost Arduino-based weather station was effective in collecting some chosen weather element, transmitted the data, processed the data into information, stored the information, and output the information in digital format. The system is portable due to the use of the Arduino microcontroller, unlike the conventional weather station. It is recommended that the work can further be analyzed by taking readings for two or three months for two or three different seasons in order to determine optimal conditions of an environment which will help farmers and event organizers.

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Figure 6 and Figure 7 were compared with the online weather station of two various sources (Accuweather i.e. Figure 8) and (Weatherspark i.e. Figure 9) respectively for both Temperature and Humidity Reading on 20 August 2019. It was observed that the average temperature from the results obtained (27.36°C) with the designed low-cost Arduino-based weather station falls within the range of the Accuweather reading (24.00-28.00°C) as shown in Figure 8, for that day. Also, the average humidity of the designed low-cost Arduino-based weather station (80.41%) falls within the range of the Weatherspark humidity (78-82%) as shown in Figure 9 for that particular day. The average temperature and humidity results obtained from the designed low-cost Arduino-based weather station ascertain that the results were within the range of the actual weather readings.

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