Design and Construction of a Low Cost Digital Weather Station

Lanre Joseph Olatomiwa and Umoru Sam Adikwu

Department of Electrical and Electronic Engineering
Federal University of Technology, Minna, Niger State, Nigeria
E-mail: <olatomiwa.l@futminna.edu.ng; sam.adikwu@gmail.com>

Abstract

This work is focused on the design and construction of a low cost weather station which makes weather related data available for different purposes such as agriculture, aviation weather forecasting, etc. The design is made up of an outdoor module which measures four weather elements (temperature, atmospheric pressure, relative humidity and wind speed) through their respective sensors. This module transmits the sampled data wirelessly through radio frequency (RF) to an indoor module which receives the data and automatically logs the data to a database. A MATLAB® based graphical user interface (GUI) was also incorporated to view the logged data and perform some setup operations on the system.

Keywords: *Sensors, microcontroller, wireless, radio frequency, graphical user interface (GUI).*

1. Introduction

Weather is the state of the atmosphere of a given place at a particular time (Yates 1947). In order to describe the atmospheric conditions, certain key weather elements must be known and quantified. Some of those important elements are temperature, relative humidity, atmospheric pressure, wind speed, wind direction, cloud cover, precipitation, etc. In meteorology, the data collected on the various weather elements is used in weather forecasting (the act of predicting the weather) which is helpful in one way or the other in the course of daily living.

The study of weather is as old as man as he has always tried to figure out the causes of different weather conditions he finds himself in and possibly predict what the weather would be like in a short term. There cannot be a study of the weather neither its prediction without the knowledge of the prevailing conditions of the atmosphere (Yates 1947). For this reason, man has always devised means of measuring different elements of the weather. Table 1 shows some weather elements and instruments used for measuring them (Wang and Felton 1983).

Table 1. Weather elements and their measuring instruments.

S/N	Element	Measuring Instrument
1	Temperature	Thermometer Hygrometer
2	Relative humidity	
3	Precipitation	Rain gauge
4	Wind speed	Anemometer
5	Wind direction	Wind vane
6	Atmospheric pressure	Mercury barometer

Some of the measuring instruments listed in Table 1 are bulky, analogue, expensive and difficult to use. As such, newer techniques based on electronics were developed. This was made possible by the advances in digital electronics. Transistor-like sensors have been developed for measuring temperature, relative humidity and atmospheric pressure (O'Neil and Derrington 1979). These sensors give voltage or current output that is proportional to the magnitude of the measured element of weather. The earlier versions of these sensors were purely analog but recent developments have made their digital counterparts available so they could function in our present world which is fast becoming digitally inclined.

The aforementioned development of weather related electronic components made it possible for small and compact weather stations (data gathering devices) to be built. These sensors respond faster than their earlier counterparts and the data collected by them tend to be more accurate.

A weather station is an observation post where meteorological conditions are observed and recorded (Jackson 1993). It is a data acquisition system which begins with sensing of variables (i.e. elements of weather being monitored), signal conditioning and processing, storage, and finally analysis of the recorded data (Jackson 1993). The weather conditions over a considerably vast area vary widely, hence the need to localize weather stations to a small region. Modern weather stations are built around relatively high power digital processors that continually pool the sensors that serve as their link to the analog world. The primary benefit of a weather station is that it keeps the users abreast of the prevailing conditions of the atmosphere. The recorded (logged) data could also be analyzed by specialized meteorological software to predict the weather (Jackson 1993). Weather stations also provide data archives over a long period of time (Guo and Song 2010). Such archives could be used by the academia or research institutions.

The motivation for this work is centered on prevailing shortage of weather related data in Nigeria. The evidence of this fact could be seen in poor weather forecasting in the country, poor response to weather related natural disasters because of lack of foreknowledge, and unnecessary disruption of flights and flood disasters that destroy lives and properties. This is as a result of the unavailability of a network of weather stations dedicated for national weather service and partly due to the high cost of imported weather stations. Also, operating and managing imported weather stations requires much technical expertise making their use difficult for private users like small-scale agriculturists, industrialists and schools.

The design presented in this work was realized by using moderately inexpensive and commonly off-the shelf components to reduce the size, space and cost of running a weather station. This would make weather related data readily available to small-scale farmers, institutions and others that may need it without huge financial implications. Simplicity of operation was also factored into the design and as such a very high technical know-how is not necessary to operate the system.

2. Materials and Method

This design employs modern sensors to measure four elements of the weather, namely: temperature, relative humidity, atmospheric pressure and wind speed. It would be quite exhausting and a complicated project to build a weather station that monitors all elements of the weather. However, the measurement of the most important elements (temperature, relative humidity and atmospheric pressure) used in forecasting the weather has been incorporated into the design of this weather station. The said station is made of three principal parts:

- outdoor system that measures the elements;
- indoor system that links the outdoor system to a personal computer; and
- personal computer (PC) software for the visualization and storage of the data.

2.1 Outdoor Module

The outdoor module is made up of the following sub-systems: power supply, sensors bank, microcontroller unit and radio frequency (RF) transmitter module (TLP 315). Figure 1 shows the block diagram of the outdoor module.

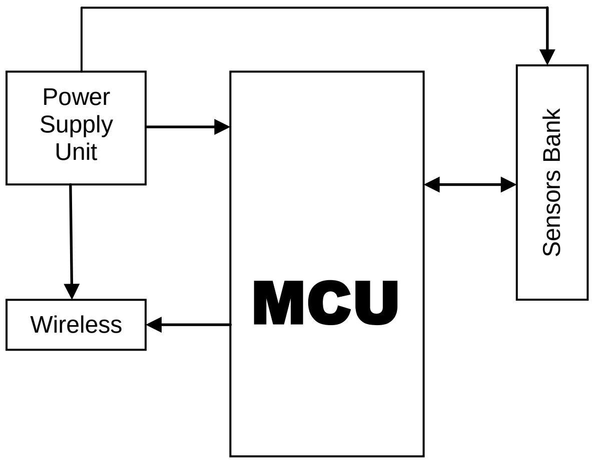

Fig. 1. Block diagram of the outdoor module.

2.1.1 Power Supply: This module is powered by a dual power source viz. a regulated DC supply and a battery supply. The switching between the two power supplies is automatic so that in the event of mains failure the battery takes over immediately without any system interruption.

2.1.2 Sensors Bank: This bank is made of four sensors (relative humidity, temperature, barometric pressure and wind speed sensors). The sensor used for temperature and relative humidity measure is a four-pin digital sensor, DHT11. It uses digital-signal-acquisition techniques and relative humidity/temperature sensing technique to ensure reliability and long-term stability (Measurement Specialties 2012). The sensing techniques used are resistive-type for relative humidity and with negative temperature coefficient (NTC) for temperature. An 8-bit microcontroller is embedded in the sensors bank to ensure high performance and easy interfacing to external digital circuits.

A Motorola MPX4250A sensor (Motorola 1997) is used in this design to measure the atmospheric pressure. It is an integrated silicon pressure sensor mainly used in altimeter, barometer and absolute pressure applications. The sensor has an on-chip signal conditioner and its reading is temperature compensated and calibrated. It gives an analogue output voltage which is proportional to the prevailing atmospheric pressure. The effective operation range is 0 to 250 kPa (0 to 36.3 psi) which corresponds to an output voltage range of 0.2 to 4.9 Volts.

The transfer function of the barometric pressure sensor as given by the manufacturer is (Measurement Specialties 2012):

$$V_S = V_o \times (0.00369 \times P + 0.04) \pm Error, \quad (1)$$

where V_o is the sensor output voltage and P is the applied pressure. The sensor error is negligible when operating within the temperature range of 0 to 85°C. The output voltage was fed to an analogue-to-digital input of the microcontroller which digitizes it based on the transfer function encoded into the microcontroller chip.

A 12-V brushless DC motor was employed as the wind speed sensor. This was due to the non-availability of a ready-made anemometer. A mechanical system of three cups was used to propel the motor (used as a DC generator). The cups were arranged in such a way that the movement of one complements that of the other and as such the generator is guaranteed to turn only in one direction, thereby generating an output voltage of consistent polarity. The output voltage of the generator changes in accordance with the prevailing wind speed. This voltage was fed into an ADC input of the microcontroller chip and sampled for further processing.

2.1.3 Radio Frequency (RF) Transmitter: TLP 315 RF transmitter was used for data transmission from the outdoor module. It is a compact RF transmitter module that operates at a frequency of 315 MHz. The RF transmitter module is essentially a high frequency oscillator that modulates a digital string of data that appear on its input line. It utilizes Amplitude Shift Keying (ASK) for data transmission (Horowitz and Hill 1989). The module generates 315-MHz signal when '1' is present on its data line and generates no output for '0' on the data line.

2.1.4 The Microcontroller Unit (MCU): The microcontroller utilized in this design is an 8-bit controller, i.e. ATtiny48/88 from Atmel Corporation. It is a *R*educed *I*nstruction *S*et *C*omputer (RISC) with many onboard peripherals and improvements on the traditional 8051 controller core (Atmel Corporation 2011). The MCU was configured to run on its default 1-MHz internal RC oscillator and as such no external crystal was used in the circuit. The in-built serial peripheral transceiver was used in conjunction with the RF module for data transmission to the indoor module. One of the microcontroller onboard timers was used to synchronize all timing operations, especially the periodic sampling and transmission of weather data. The onboard analogue-to-digital Converter (ADC) was used for digitizing the pressure value from the MPX4250 sensor.

Beside the normal input/output pins, other onboard facilities used in the MCU are USART (*U*niversal *S*ynchronous and *A*synchronous *R*eceiver and *T*ransmitter) for the transmission of the measured data and timer for periodical data sampling (Atmel

Corporation 2011). The USART was configured to work with 8-bit data mode, no parity, one stop bit and 4,800 baud rate by writing a calculated value to its baud rate registers (UBRRL and UBRRH). The value written to the registers is calculated as follows (Atmel Corporation 2011):

$UBRR = 1 + [F_{CPU}/(16 \times BAUD)]$. (2)

The choice of 1 MHz for F_{CPU} and 4,800 for $BAUD$ in Eq. (2) gives a value of 12.02 for $UBRR$. Since only integer values can be written to the baud registers, the integer value was 12 giving an error of 0.17%. This is a very minute error and has no noticeable effect on the serial communication.

The timer zero was configured to generate the time base needed for the conversion through its interrupt overflow facility. The 1-MHz system clock is too fast for the timer operation and as such was pre-scaled to a much lower value before being applied to the timer. A pre-scaler factor of 64 was used resulting in the following clock frequency:

$F_{CLOCK} = 1{,}000{,}000/64 = 15.625$ kHz. (3)

The timer period (the inverse of the operating frequency) is 64 μs. Timer zero is 8-bit wide, it was configured to count upward from 0 to 255 and then roll back to zero and continue repeating the same cycle unless instructed by the CPU to stop counting (by writing to the appropriate register). Therefore, the time taken by the timer to count from zero to an overflow is:

$T_{overflow} = 64\ \mu s \times 256 = 16.384$ ms, (4)

and as such it would require 61 of such overflows for a time period of one second. The timer was configured to generate an interrupt each time an overflow occurred. The interrupt service routine (ISR) was used to increment a variable each time the timer interrupt occurred. This was in turn used to increment a variable known as *sec* (for second). The *sec* variable provided the basis for all other timing operations in the system.

At power on, the MCU configures the necessary I/O pins, timer zero and USART by writing to the appropriate registers connected with the devices. The MCU then reads the weather conditions by sending a read command to the respective sensors and transmitting the read data wirelessly. The whole cycle is repeated after one-minute intervals. The flowchart of the outdoor module program is shown in Fig. 2.

2.1.5 Indoor Module: The block diagram of the indoor module is shown in Fig. 3. The indoor module has a power supply subsystem which is the same as that of the outdoor module and as such will not be further analyzed.

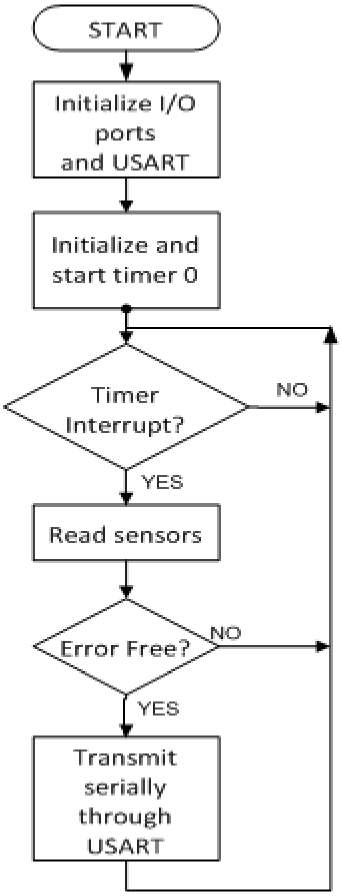

Fig. 2. Flowchart of the outdoor module program.

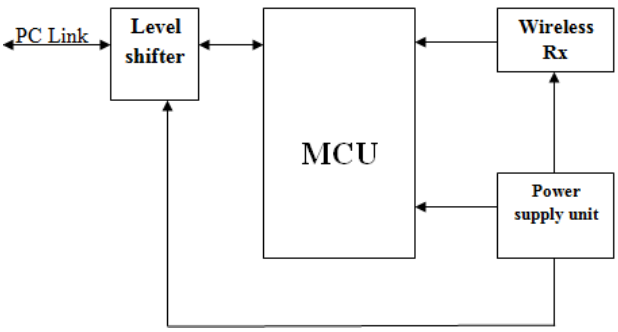

Fig. 3. Block diagram of the indoor module.

2.1.6 Indoor Microcontroller Unit: The microcontroller unit of the indoor module contains two ATtiny48/88 microcontrollers. The use of two microcontrollers was justified by the availability of only one USART per microcontroller and the module utilized two for its effective functioning (one for PC serial communication and the other for communicating with the outdoor module) (Silicon Labs 2010). An alternative design would have been the use of a single microcontroller with two USART facilities but none of such microcontrollers was readily available. The first microcontroller identified as "indoor_module_master" was set up to use its onboard USART and *S*erial *P*eripheral *I*nterface (SPI) (Microchip 2007). The USART configuration (data length, parity, stop bit and baud rate) is the same as that of the outdoor module in order to keep them in synchrony with each other. The USART Receive Complete Interrupt facility of the microcontroller was also enabled by writing to the appropriate register.

At power on, the microcontroller configures the necessary facilities and waits indefinitely for the USART to receive data. The received data is checked to ensure that it originated from the outdoor module. This was necessary because the receiver is subject to RF noise present in the atmosphere. The outdoor module sandwiches every data byte in between two other bytes; an 'S' and a checksum which equals the sum of 'S' and the data (ASCII code binary sum). After receiving three data bytes, the microcontroller checks the validity of the data using the above scheme. Invalid data bytes are discarded while valid ones are stored for further processing. The microcontroller transmits the data bytes to a slave indoor module through SPI. The above cycle is repeated indefinitely as long as there is power supply to the microcontroller. The flowchart of the program is shown in Fig. 4.

A second microcontroller, called the slave unit, receives the data from the master unit and transmits it through SPI to the serial port of the PC. The program flow of the slave unit is similar to that of the master unit except that the data direction for the USART and SPI were reversed. At power on, the MCU configures its USART to transmit at a predefined baud rate, and SPI as slave. The slave unit essentially serves as a data bridge between the PC and the master unit of the indoor module. The firmware for the microcontrollers was developed using C language on the AVR® Studio 4 platform. The flowchart of the program is shown in Fig. 5.

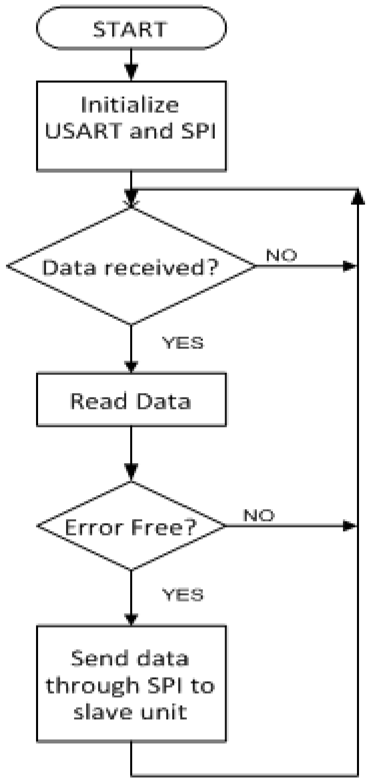

Fig. 4. Flowchart of the master unit program of the indoor module.

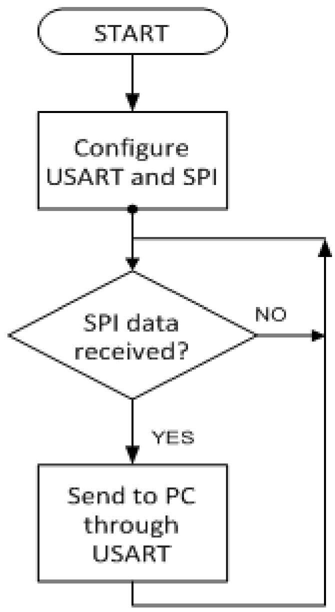

Fig. 5. Flowchart of slave unit of the indoor module.

2.1.7 Voltage Level Converter: The PC and the microcontroller communicate at different voltage levels. The PC uses RS 232 while the MCU uses TTL. The RS 232 protocol uses voltage levels more positive than +3V to represent logical zero and voltage levels more negative than -3V to represent logical one. The MCU, on the other side, uses 0 V to represent logical zero and 5 V to represent logical one. Therefore, there is a need for the conversion from RS 232 to TTL and vice versa. MAX 232 was used for this purpose. It is a level-shifting IC manufactured by Maxim Integrated, San Jose, CA, USA. It uses internal active capacitors to do the level conversion (Horowitz and Hill 1989). The circuit connection of the voltage level converter is shown in Fig. 6.

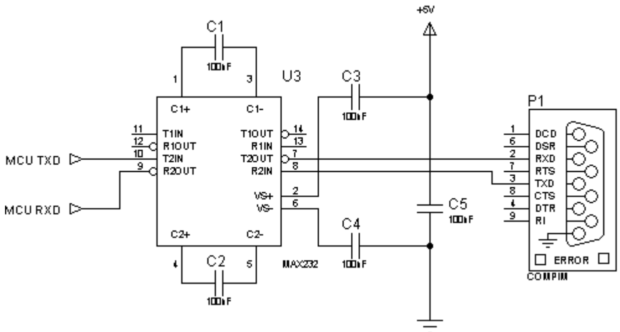

Fig. 6. Voltage level converter circuit.

3. Development of Graphical User Interface (GUI) and Database

The graphical user interface (GUI) was developed using MATLAB® platform. The basic functions of the GUI are to:

- provide a user friendly operation platform;
- provide a connection interface with the indoor module hardware; and
- establish communication with the PC resident database.

The GUI was made of labels, buttons, menu items and a view table. The labels were used for captions. The buttons, on the other hand, were used to execute specific functions. The buttons employed in the GUI were “Connect”, “Refresh” and “Exit”. The “Connect” button was designed to establish a serial connection with the outdoor module and its caption changes to “Disconnect” when a connection has been made. The “Refresh” button serves for the real-time update of the data viewed in the table while the “Exit” button disconnects the indoor module from the PC, closes the communication path with the database, and closes the GUI. The screen capture of the GUI is shown in Fig. 7.

The database was realized using Microsoft® Excel®. An Excel® worksheet was created and named “Weather_Station_ Database”. The worksheet houses different recording (sheet) for each sampled data. The GUI interacts with this database by writing to it and reading from it.

4. Test

The following materials were used in carrying out the test on this digital weather station:

- a personal computer with terminal testing software (Tera Term);
- a graphical user interface (GUI) developed using MATLAB®;
- Microsoft® Excel®; and
- USB-to-serial converter.

The indoor module was powered and attached to the computer through the USB to a serial converter after which the PC resident terminal software was launched. The terminal software (Tera Term) was launched and configured to communicate with the indoor module by selecting the indoor module connection port (COM 3) and baud rate of 4,800 bps. The outdoor module was then powered up. The said module was programmed to send a simple text string “Hello World” to ensure that a communication link has been established between the two modules. The string was transmitted once every fifteen seconds by the outdoor module. The indoor module received the text strings and sent them to Tera Term through the USB-to-serial converter. Successive strings received were then displayed on the computer screen. Both modules were then powered off to prepare for the next testing stage.

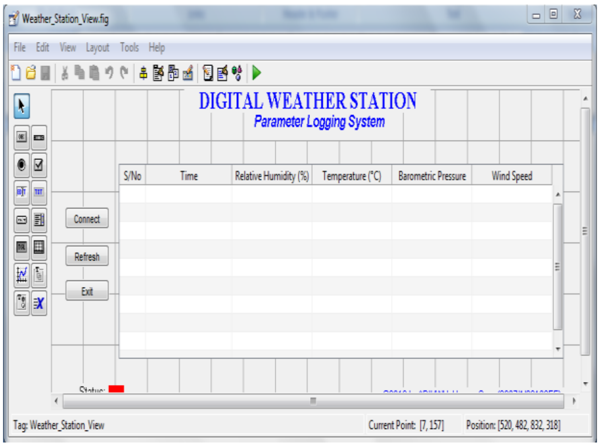

Fig. 7. Screen capture of the GUI development.

A Microsoft® Excel® worksheet was created by the name "Weather_Station_ Database" holding the different sheets for the logged data. The developed GUI was launched in the MATLAB® platform, by changing the MATLAB® default path to the directory of the Excel® spreadsheet (database). The GUI automatically loaded the spread sheet for the day. The connection between the GUI and the outdoor module was established using the required baud rate and connection port.

The modules were powered on, after which the outdoor module periodically sampled and transmitted the weather data to the indoor module. The setup was allowed to run for some time with the indoor module logging each received data to the database.

5. Results and Discussion

The device was used to log weather data in two different locations, the Mini Campus and the Main Campus of Federal University of Technology, Minna, Niger State, Nigeria, on 15 September 2012 and 9 October 2012, respectively. The obtained test results are shown in Figs. 8 and 9, respectively.

It can be seen from Figs. 8 and 9 that the device measures weather data periodically and logs the data to a database for further processing. These results were compared with results obtained using 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 in good agreement with those obtained from the device.

6. Conclusion

The purpose of this work was to produce a simple and cost effective weather station considering the importance of the availability of weather related data. From the results obtained throughout the tests carried out, it can be concluded that the work achieved its aims and objectives.

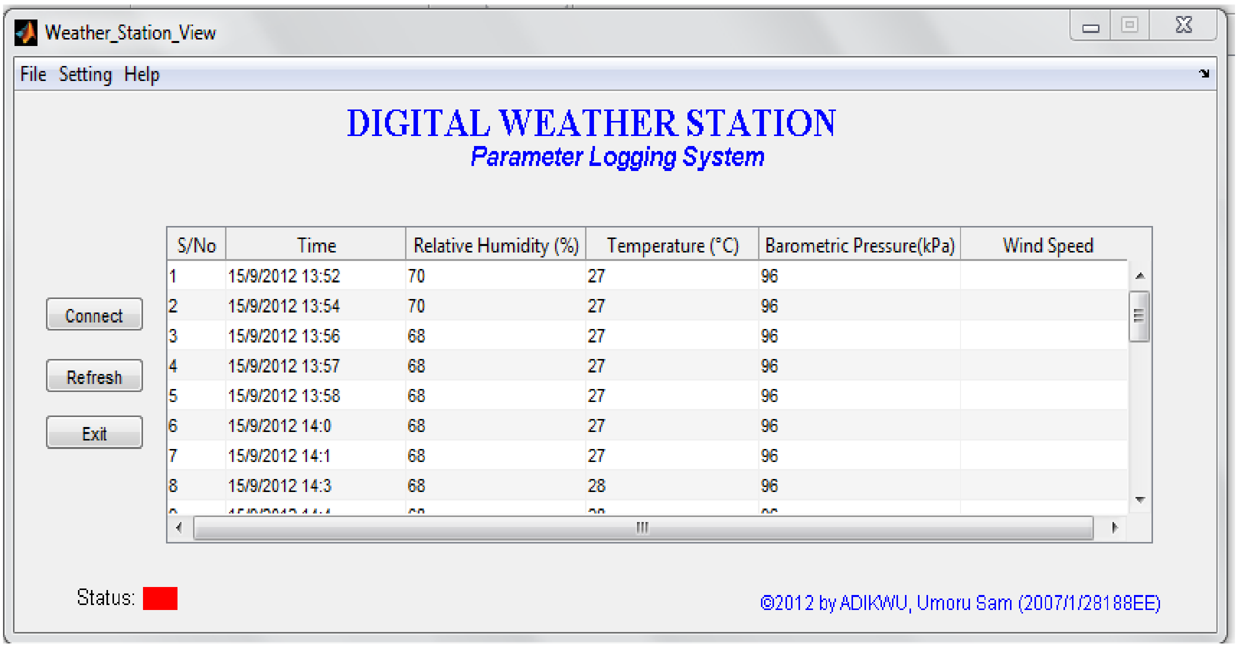

Fig. 8. Logged data display on the GUI at the Mini Campus of Federal University of Technology, Minna, Niger State, Nigeria.

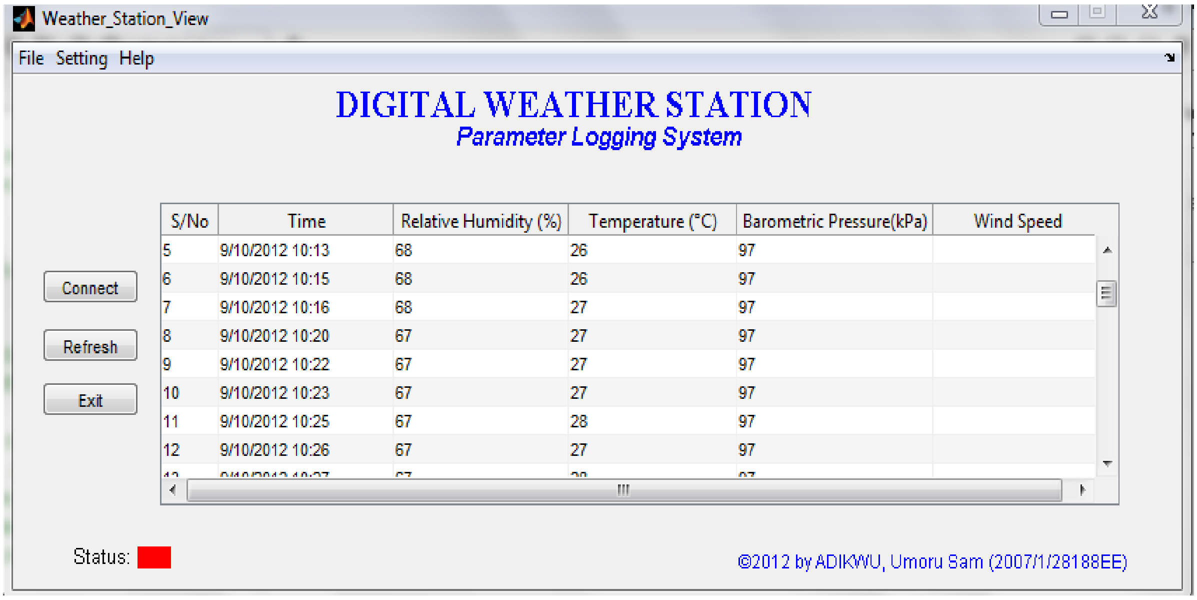

Fig. 9. Logged data display on the GUI at the Main Campus of Federal University of Technology, Minna, Niger State, Nigeria.

7. References

Atmel Corporation. 2011. ATtiny48/88. 8-bit AVR® Microcontroller with 4/8K Bytes In-System Programmable Flash. Rev. 8008H-AVR-04/11. Atmel Corporation, San Jose, CA, USA. Available: <http://www.atmel.com/dyn/resources/prod_documents/doc8008.pdf>.

Guo, X.; and Song, Y. 2010. Design of automatic weather station based on GSM module. Proc. Int. Conf. on Computer, Mechatronics, Control and Electronic Engineering (CMCE), Changchun, China, 24-26 August 2010, Vol. 5, pp. 80-2.

Horowitz, P.; and Hill, W. 1989. The Art of Electronics. 2nd ed. Cambridge University Press, Cambridge, England, UK.

Jackson, R.M. 1993. Weather station. Electronics Now 64(10): 31-8.

Microchip. 2007. MCP2510. Stand-Alone CAN Controller with SPI™ Interface. Microchip Technology Inc., Chandler, AZ, USA. Available: <http://ww1.microchip.com/downloads/en/DeviceDoc/21291F.pdf>.

Measurement Specialties. 2012. HS1101LF - Relative Humidity Sensor. Measurement Specialties™, Inc., Hampton, VA, USA; MEAS France, Toulouse, France. Available: <http://www.meas-spec.com/downloads/HS1101LF.pdf>.

Motorola. 1997. MPX4250 Series. Integrated Silicon Pressure Sensor Manifold Absolute Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated. Motorola, Inc., Denver, CO, USA. Available: <http://pdf1.alldatasheet.com/datasheet-pdf/view/5181/MOTOROLA/MPX4250A.html>.

O'Neil, P.; and Derrington, C. 1979. Transistors - a hot tip for accurate temperature sensing. Electronics 52(21): 137-41.

Silicon Labs. 2010. CP2102. Single-Chip USB to UART Bridge. Rev. 1.4. Silicon Laboratories Inc., Austin, TX, USA. Available: <http://www.silabs.com/Support%20Documents/TechnicalDocs/cp2102.pdf>.

Wang, J.Y.; and Felton, C.M.M. 1983. Instruments for Physical Environmental Measurements, with Special Emphasis on Atmospheric Instruments. 2nd ed. Kendall Hunt Publishing Co., Dubuque, IA, USA.

Yates, R.F. 1947. The Weather for a Hobby: A Guide to the Construction and Use of Weather Instruments Intended for Amateurs. Dodd, Mead & Co., New York, NY, USA.