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DESIGN AND CONSTRUCTION OF A LOW COST AIR TEMPERATURE AND PRESSURE DATA-LOGGING EQUIPMENT USING RASPBERRY PI

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Abstract

This paper describes the design and construction of a low cost air temperature and pressure data-logging equipment using raspberry pi. The equipment is designed to perform automatic measurements of air temperature and atmospheric pressure and sendthe measured values to the Raspberry pi for logging.Raspberry pi logs the data on a comma-separated value (CSV) file format as well as store the data for records.The equipment was tested and validated against a standard atmospheric weather observatory. The results indicated a good agreement with coefficient of determination of . $R^2 = 0.83$, ***slope = 0.7, mean bias error, MBE=-0.77°C, and root mean squared error, RMSE=1.53°C. The equipment can be further improved to accommodate more sensors and provide data from remote locations***

Keywords: Microcontroller (PIC18F2550), LM35, Motorola MPX 4115 Pressure Sensor, Raspberry Pi.

1. Introduction

Generating electricity through renewable energy sources such as solar, wind energy and hydropower are on the rise globally. However, before such projects take shape, a key preliminary step is gathering and analysis of associated weather data, such as solar radiation, wind speed, air temperature, relative humidity at prospective location(s) to determine the viability and sustainability of the project. Insufficient studies or assessments may eventually result in the project being uneconomical. Most low-cost mini weather measurement devices are hand-held and lack capacity to store or log the measured data, and thereby render them unsuitable for studies involving post field analysis. In the category of such devices are a number of microcontroller-based environmental and weather monitoring systems that have capabilities for LCD and graphical display on desktop computer [1,2]. What this type of equipment mostly lacks is the capability for data storage for post-processing analysis. The alternative is sophisticated weather stations which are quite expensive [3]. They are usually interfaced with expensive stand-alone data acquisition system otherwise known as data logger. Data acquisition entails data logging and retrieving, and it can be defined as a process of recording events with the use of data loggers during a test or field use of a system or a product. It is one of the usability methods that can and should be used to gather more supplementary information as an integral part of the iterative design of the usability engineering cycle [4]. These loggers are versatile and flexible, very suitable for widely varying applications [5]. Roneel [6] developed a remote automatic weather station with a desktop computer-based data logger. It was designed for remote operation to perform automatic measurements of weather data such as air temperature, relative humidity, dew point, wind speed and rainfall. It transmits the data wirelessly to a desktop computer for logging and display by means of a graphical user interface. A microcontroller-based system that could measure, log and transmit temperature and relative humidity value via short message service (sms) to mobile phone was designed and implemented in[7]. Other wireless based environmental monitoring systems that could transmit measured values to computer through a transceiver had been developed [8, 9].It is however necessary to create a good balance between the cost of acquiring a suitable weather station and capacity for storage of the measured data. A simple and effective environment monitoring system for both industrial and domestic usage was designed and constructed in [10]. The project used cheap sensors and it was made portable and compact. The current work aims at designing and constructing automatic weather equipment that has capacity for expansive datalogging using cheap, readily available sensors and electronic components. The equipment will find applications in many areas such as agriculture, environmental monitoring, solar applications and climate change studies amongst others

2.0 Material and Methods

The materials used in the design and construction of the equipment consists of a temperature sensor (LM35) produced by National Semiconductor Corporation and are rated to operate over a -55 °C to 150°C temperature range [11], a pressure sensor (MPX4115) [12], a micro-controller unit (PIC18F2550) [13], a power bank unit (5 volts, 1ampere) and a Raspberry pi miniature computer[14].

The equipment was designed to have the following features: data collection, data storage, and data retrieval through the universal serial bus (USB). The equipment was configured to perform a remote measurement of the weather elements of interest, that is, air temperature and pressure, and log the values on an expansive secure digital (SD) card situated on raspberry pi.

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The equipment was powered by a 5V power bank and this supplied appropriate energy to the raspberry pi, microcontroller and the sensors. The microcontroller which is the core of equipment interfaces both the air temperature and pressure sensors and handled data acquisition and data transmission using the universal asynchronous-synchronous receiver transmitter (UART), to communicate with raspberry pi. The description of the raspberry pi which logs the data in a comma separated value (CSV) format for easy analysis is further given in details in the following section.

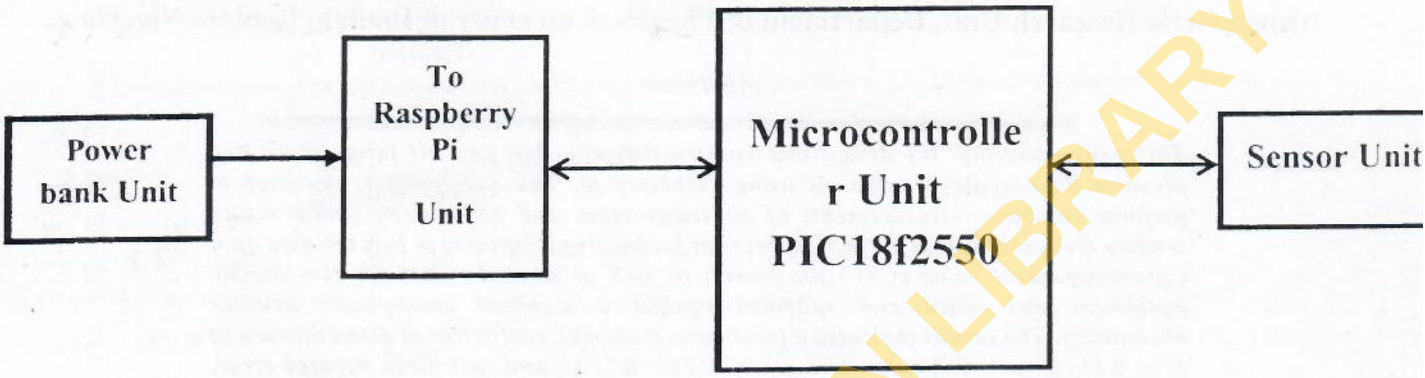

Figure 1: Block diagram of the Temperature-Pressure measurement system

2.1 A brief description of Raspberry Pi

Raspberry Pi (Figure. 2) is a miniature computer developed in the UK by Raspberry Pi foundation [14]. It has two models, model A and B; Model A has 256Mb RAM, one USB port and no network connection. Model B has 512Mb RAM, two USB ports and an Ethernet port. It has a Broadcom BCM2835 system on a chip which includes an ARM1176JZF-S700 MHz processor, Video Core IV GPU, and asecure digital (SD) card among other features. The foundation provides Debian and Arch Linux ARM distributions and also Python as the main programming language, with the support for BBC BASIC, C and Perl. The detailed description of Raspberry Pi board has been given in Raspberry Pi user guide [14].

Ali et al.[15] described the development of the Raspberry Pi minicomputer as having great potential in computing for the developing nations in areas such as educational tools and simple digital control systems in a school laboratory setting where with the aids of its GPIO module, other general purpose electronics can be interfaced.

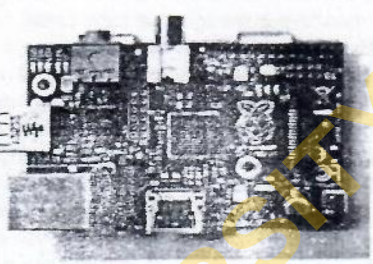

Figure 2: Raspberry Pi board.

2.2 The design and principle of operation of the Temperature-Pressure Measurement System

The microcontroller (PIC18F2550) which is the hub of the equipment has 10 analog pins which can also function as digital input and output (I/O) pins. Before any of the sensors is connected to one of these pins, the PIC18F2550 was configured to accept analog data from the sensor output on the specified pin. The PIC18F2550 then changed the analog data to 10 bits and stored it in the register which contains the value of the last completed conversion.

The air temperature sensor (LM35) is a precision integrated-circuit temperature sensor, with an output voltage linearly proportional to the Centigrade temperature. It is an analog sensor that converts the surrounding temperature to a proportional analog voltage. The output from the sensor is connected to one of input pins of the PIC18F2550 microcontroller to derive the equivalent temperature value in digital format. The sensor (LM35)is shown in Figures3 to be connected to the analog pin of the PIC18F2550 microcontroller. The output voltage of the sensor is a function of its temperature and it ranges from about 0volt to about 5volt (the maximum supply voltage. The sensor gives a sensitivity of 10mV per degrees Celsius. The voltage output is proportional to the temperature. The scale factor for temperature to voltage conversion is 10 mV per °C.

The pressure sensor (MPX4115) is designed to sense absolute air pressure in an altimeter or barometer pressure applications. It integrates on-chip, bipolar operational amplifier circuitry and thin film resistor networks to provide a high level analog output signal and temperature compensation. FromFigure 3,pin1 of the MPX4115 sensor which output proportional voltage to the pressure measurement is connected topin3 of the microcontroller. Pin3 is one of the analogue channels of the microcontroller through which analogue inputs are to be converted to digital form by the microcontroller's in-built analogue to digital converter (ADC).

Pin 2 and 3 of the sensor are connected to ground and VCC respectively. Figure 3 further indicated the possibility of extending the number of sensors to include humidity sensor.

Figure 3: Schematic diagram of the raspberry pi interfacing the micro-controller (PIC18F2550) and the sensors

2.2 Experimental Test

An experiment was set up in the experimental field of the Atmospheric unit of University of Ibadan, Ibadan, Nigeria to test the performance the equipment. The set up consist of the current measurement system and a standard equipment (SM-28 Skymaster, hereafter call SM28) to measure both air temperature and pressure every fifteen seconds. The performance of the equipment was compared with that of the standard automatic weather station, SM28 through time series plot of the air temperatures from the two equipment, and by three other statistical tests: coefficient of determination (R^2), root mean square error (RMSE) and mean bias error (MBE).

Coefficient of determination (R^2) measures the successofa fit in explaining the variation in a data set. It can take on any value between 0 and 1, with a value close to 1 indicating that a greater proportion of variance is accounted for by the model.

Root Mean Square Error (RMSE) is an estimate of the standard deviation of the random component in the data, it is defined as:

$$\text{RMSE} = \left\{\frac{1}{N}\sum T_{LM35} - T_{SM28}))^2\right\}^{1/2} \qquad (1)$$

Where T_{LM35} *is* the measured air temperature from the equipment that was designed and constructed, and T_{SM28} *is*the observed air temperature from the standard equipment; N is total number of observations. The RMSE is always positive and a zero value is ideal.

Mean bias error (MBE) provides information on the long term performance of a model. It is defined as:

$$\text{MBE} = \sum(T_{LM35} - T_{SM28}) / N \qquad (2)$$

A low MBE is desirable. Ideally, a zero value of MBE should be obtained. A positive value gives the average amount of over-estimation in the measurand and while a negative value indicates the average amount of underestimation.

3.0 Results and Discussion

The circuitry design in Figure 3 was implemented using the necessary electronic components mentioned in the block diagram in figure 1 (Figure 4). Temperature and Atmospheric signals received by the sensors were converted from the analog to digital using the analog/digital converter (ADC) of the microcontroller unit (MCU). These values were transferred to the Raspberry Pi which logs the values and saved them in a comma separated values (CSV) format. The temporal variation of the air temperature values from the equipment (T_{LM35}) was compared with the values readi from a standard weather station (T_{SM28}) (Figure 5). The scattered plot of the air temperature of the equipment (T_{LM25}) against that of SM28 (T_{SM28}) gave a coefficient of determination which is close to 1, that is, R^2 is 0.83 and slope of 0.7 (Figure 6). The values of the mean bias error, MBE and the root mean squared error, RMSE are -0.77 °C and 1.53°C respectively. The underestimation is very small as MBE value is negative and very small.

Figure 4: Pictorial view of the raspberry pi interfacing the micro-controller (PIC18F2550) and the sensors

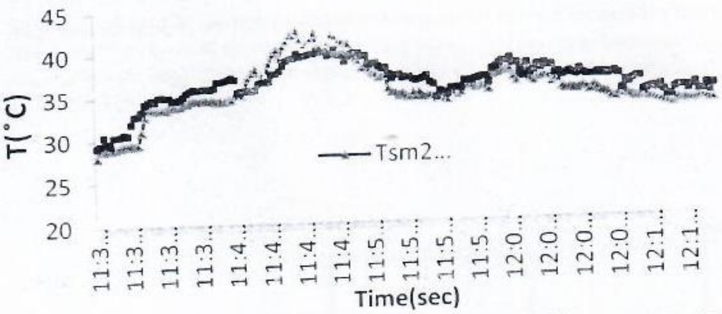

Figure 5: Temporal variation of air temperature from LM35 temperature sensor and SM28 (SM-28 Standard equipment) at Ibadan

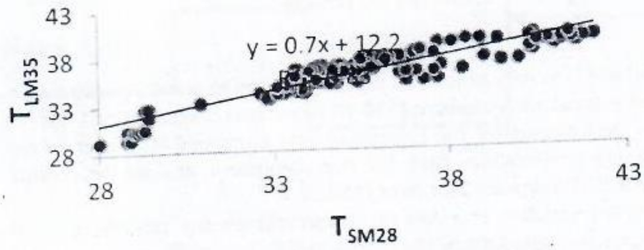

Figure 6: scattered plot of air temperature measured by the equipment (T_{LM35}) against a standard equipment (T_{SM28}) at Ibadan

4.0 Conclusion

An attempt has been made to design and construct a low cost temperature and atmospheric pressure equipment that has capacity for expansive data-logging. It was also made portable and has low power consumption. Future work on the equipment shall be extended to including more sensors, including a real time module (RTC) in the raspberry pi for accurate timekeeping, and activating the capacity of the raspberry pi as a server for online access of data from remote locations.

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