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Development of an Arduino-based Multi-Channel Temperature and Relative Humidity Data Acquisition System for Domestic and Industrial Applications

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ABSTRACT

Losses incurred during postharvest processes of food and other agricultural products in the rural and some urban areas of West African countries have been attributed to poor thermal conditions of the indoor air. The quality of these products at storage or after thermal processes such as drying, cooking, frying, etc. has been identified to be majorly dependent on the temperature and humidity of the air. The objective of this study was therefore to develop a low cost Arduino based multi-channel temperature and humidity data acquisition system for domestic and industrial applications. It comprises an ATmega 328P controller type, fourteen (14) DS18B20s temperature sensors, and six (6) DHT22 humidity sensors. The system was configured and programmed to log in readings every 30 minutes (30 min) on the SD card or through the Bluetooth module in Excel format directly into the computer. The results from the experiments conducted with this data acquisition system demonstrated reliability because they were within the reasonable and acceptable range for commercial logging devices.

1. Introduction

The condition of the environment in which we live, store food, grow crops, etc. plays an important role in human life. The need for collecting high quality data on temperature and relative humidity continues to increase as better information on system performance could improve understanding of energy usage [1,2]. Insufficient indoor air quality has a direct effect on building related health symptoms, known as sick building syndrome which negatively impacts the worker's performance and productivity [3]. Traditionally, the use of hand-held instruments for determining the conditions of the environment had been observed to be highly labourious and time consuming. The reason is that the user needs to be physically present at the site where measurements are meant to be taken. A device that aids in collecting and storing experimental data is called a Data acquisition system (DAS) or data

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logger. DAS comes in different forms; specific data loggers measure only single parameters and multipurpose ones which can measure any parameter depending on the probe used, and analyses with integrated displays [4]. In thermal fluid science, data loggers are mostly used to measure thermodynamic properties like temperature, pressure, humidity, etc. which, plays a key role in the monitoring of environmental variables for plants and animal growth, quality of food, usage of energy and thermal comfort, indoor environmental quality etc [2,5-9]. Climate change related problems such as water scarcity, environmental monitoring inadequacies, etc. necessitate the use of automated techniques and tools that allow adequate decision making intending to reduce negative consequences caused by monitoring of environmental parameters especially temperature and relative humidity, is necessary for many applications and industrial processes [10]. These include agriculture, food processing (drying, cooking, frying, baking, incubating, etc.), papermaking, hospitals, residential apartments, etc.

Commercial electronic weather monitoring devices for the above applications/industrial processes are not readily available in developing countries such as Nigeria, Ghana, and other West African countries. The imported ones are not just too expensive but also come with close codes that are difficult to integrate into an open code system, Also, the incorporation of sensors and epidemiological models calibrated for different conditions is not permitted [11]. Humidity and temperature conditions impact indoor air quality and thermal comfort amongst other environmental parameters [12]. Many houses have recently been equipped with vapour barriers, insulation, weather stripping, and caulk to effectively retain desired air temperature and reduce outdoor air infiltration [10]. Also, continuous monitoring and control of temperature and humidity are important for storing and transporting medicinal products [13].

Various designs and applications of Arduino-based data acquisition systems on data acquisition systems for monitoring temperature, relative humidity, etc within a system are available in the literature [8,10,13-19]. Most of these studies have been addressing building environments for human comfort in residential apartments and soil health and growth for crops. However, much has not been reported on weather monitoring during postharvest handling of food products or thermal food processes such as drying, cooking, frying, etc. In food industries, the proper control of the environment for food preservation at storage is an effective way of reducing the manifestation/spread of microbes. Conditioning agricultural or food products under unsuitable temperatures and relative humidity would cause a reduction in the product's quality.

Losses incurred while using thermal processing equipment such as dryers, silos, incubators, etc. where measurement and monitoring of temperature and relative humidity are highly required have been attributed to a lack of proper monitoring of environmental conditions. Also, the cost and adaptation problems of the imported data logger necessitates the development of a temperature cum humidity data acquisition system using locally sourced materials. With the advent of trouble free technologies, the authors, therefore, aimed at developing a simple, low-cost, Arduino-based temperature and humidity data monitoring system for both rural and urban industrial applications.

2. Methodology

2.1 Description of the Data Acquisition System Structure

The data-logging system is made up of many parts including the data logging device itself, temperature sensors, humidity sensors, and power supply unit. The structural details of the data logging system are shown in Figure 1 to Figure 7.

2.1.1 Data-logger device

The data-logging device diagrammatically and pictorially represented by Figure 1 and Figure 2 communicates with the sensors (Figure 3 and Figure 4) to measure temperature and humidity readings and stores the information into a memory card attached to it. It is made up of a micro-controller which acts as the brain of the system, an SD Card Module for mounting the memory card, a real time clock module for taking note of the time and date of the day, a temperature sensor port for mounting the temperature sensors, a humidity sensor port for humidity sensors. It has also a LED indicator and a small USB port for providing power to the system and allowing for reprogramming of the system.

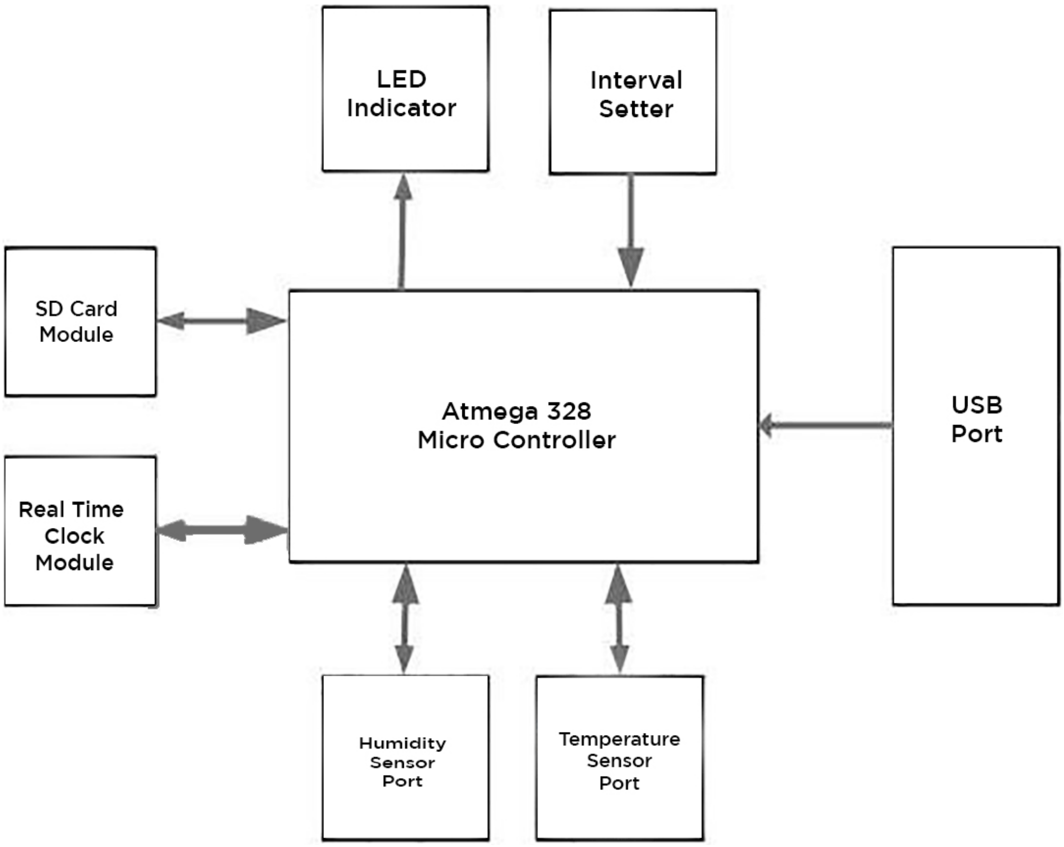

Fig. 1. Block diagram of the data acquisition system with other accessories

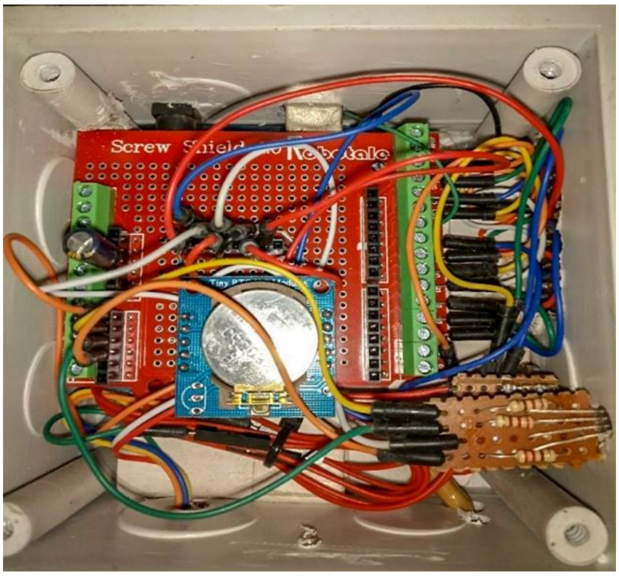

Fig. 2. Data logging system showing the connection of some components

Fig. 3. Data logging device indicating the SD card module

2.1.2 Temperature sensor

The temperature sensor (Figure 4) was the DS18B20 from Maxim Integrated. The DS18B20 digital temperature sensor provides 9-bit to 12-bit Celsius temperature measurements. The DS18B20 communicates over a 1-Wire bus that by definition requires only one data line (and ground) for communication with a central microprocessor. See the specification in Table 1.

Fig. 4. Pictorial diagram of the temperature sensor

2.1.3 Humidity sensor

The DHT22 Humidity Sensor (Figure 5) is a basic, low-cost digital temperature and humidity sensor. It uses a capacitive humidity sensor and a thermistor to measure the surrounding air and spits out a digital signal on the data pin (no analog input pins needed). It's fairly simple to use but requires careful timing to grab data. See the specification in Table 1.

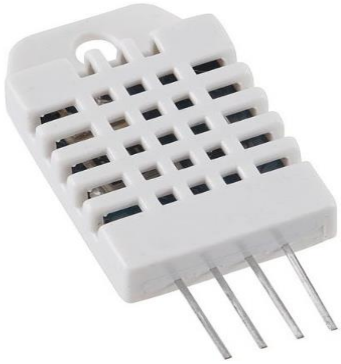

Fig. 5. Pictorial diagram of the relative humidity sensor

Table 1
Humidity and temperature sensor specification

Sensor type	Model	Measurement range	Output	Accuracy	Power range	Connection range
Relative Humidity	DHT22	0-100%	3-5 V	±3 RH	3-5 V	Up to 10 metres max.
Temperature	DS18B20	- 55 - + 125 °C	3-5.5 V	± 0.5 °C	3-5 V	Up to 30 metres max.

2.1.4 The microcontroller

The microcontroller used for the device is the Atmel ATmega 328P type. It was used to upload computer code (C/C++ programme Figure 6) through the USB port to the device. Also indicated in Figure 7 is the Programme flowchart for the logger. With this microcontroller, the device was capable of supporting a maximum of six (6) humidity sensors and a total of fifteen (14) temperature sensors.

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```
#include <avr/sleep.h>

#include <SD.h>
#include <SPI.h>
#include <OneWire.h>
#include <Wire.h>
#include <Time.h>
#include <DS1307RTC.h>
#include <DallasTemperature.h>
#include "DHT.h"

/*********************** LED Indicator Light Meaning ******************
Startup = Green Blinking for 3 times
Data Processsing = Pink Blinking for about 3 times
SD Card Error = Red Light Remain Active
Device Active = Quick Green blinking for 2 times
Wrong DHT Sensor Connection =  Cyan color active or blinking
DHT sensor not connected = Blue color active or blinking

/******************* DHT Sensors Configuration *********************/
/*#define DHT1PIN 2     // what pin we're connected to
#define DHT2PIN 3
#define DHT3PIN 4      // what pin we're connected to
#define DHT4PIN 5
#define DHT5PIN 6      // what pin we're connected to
#define DHT6PIN 7

const byte sensor_5[8] = {0x28, 0x36, 0xF0, 0x41, 0x07, 0x00, 0x00, 0xF2}; //5 Sensor
//byte sensor_5[8] = {0x28, 0xFF, 0x44, 0xEB, 0x70, 0x14, 0x04, 0x3A}; // sensor 5 new
const byte sensor_6[8] = {0x28, 0x4F, 0x06, 0x41, 0x07, 0x00, 0x00, 0xC6}; //6 Sensor
const byte sensor_7[8] = {0x28, 0xFF, 0xE5, 0xA0, 0x3E, 0x04, 0x00, 0xF8}; //7 Sensor

const byte sensor_8[8] = {0x28, 0xFF, 0x51, 0x18, 0x56, 0x14, 0x03, 0xAB}; // 8 Sensor
//byte sensor_1[8] = {0x28, 0xEA, 0x48, 0x50, 0x05, 0x00, 0x00, 0xC2}; // 1 sensor replacement
const byte sensor_9[8] = {0x28, 0x56, 0x6C, 0x35, 0x05, 0x00, 0x00, 0x4E}; // 9 Sensor
const byte sensor_10[8] = {0x28, 0xFF, 0x32, 0xB5, 0x55, 0x14, 0x03, 0x24}; // 10 Sensor
const byte sensor_11[8] = {0x28, 0xFF, 0x88, 0x64, 0x56, 0x14, 0x03, 0xBC}; // 11 Sensor
const byte sensor_12[8] = {0x28, 0xD9, 0x41, 0x48, 0x05, 0x00, 0x00, 0xA1}; //12 Sensor

const byte sensor_13[8] = {0x28, 0xFF, 0x11, 0x2C, 0x56, 0x14, 0x03, 0x04}; //13 Sensor
const byte sensor_14[8] = {0x28, 0x68, 0xC3, 0x34, 0x05, 0x00, 0x00, 0x63}; //14 Sensor
//const byte sensor_15[8] = {0x28, 0xFF, 0x11, 0x2C, 0x56, 0x14, 0x03, 0x04}; //15 Sensor

// Creating an array to hold the sensors
const byte* tempSensor[NoDevices] = {sensor_1, sensor_2, sensor_3,
                        sensor_4, sensor_5, sensor_6,
                        sensor_7, sensor_8};

OneWire oneWire2(9);
DallasTemperature sensors2(&oneWire2);
const byte* tempSensor2[6] = {sensor_9,
                        sensor_10, sensor_11, sensor_12,
                        sensor_13, sensor_14};

*/
#define DhtSensors 6
/*
// From pin 1 - 3 the sensors type is the blue one i.e dht 11 and the remmaing down one is dht22 port

*/
DHT* dht;

uint8_t dht_data[DhtSensors*2] ={0}; //Variable that stores all the result of the dht sensors

/******************* END of DHT Configuration ********************/

/******************* DS18b20 Sensors Configuration ********************/
#define tempSensorPin 8
#define NoDevices 14

OneWire oneWire(tempSensorPin);
DallasTemperature sensors(&oneWire);

// To Assign the address of the 1-wire temp sensors

const byte sensor_1[8] = {0x28, 0xFF, 0x3C, 0x72, 0x70, 0x14, 0x04, 0x1B}; // 1 Sensor
//byte sensor_1[8] = {0x28, 0xEA, 0x48, 0x50, 0x05, 0x00, 0x00, 0xC2}; // 1 sensor replacement
const byte sensor_2[8] = {0x28, 0xFF, 0x6A, 0x78, 0x45, 0x16, 0x03, 0xF0}; // 2 Sensor
const byte sensor_3[8] = {0x28, 0xFF, 0x88, 0xE8, 0x70, 0x14, 0x04, 0xB1}; // 3 Sensor
const byte sensor_4[8] = {0x28, 0xFD, 0xCF, 0x41, 0x07, 0x00, 0x00, 0x7E}; // 4 Sensor

//int sensor_data[NoDevices] = {0}; //This array will be used to hold the temperature readings for the ds18b20 devices

/******************** End of ds18b20 Configuration ******************/

/********************* Sleep Variable Configuration ********************/
// Note that our sleep value will be gotten from the variable resistor

#define minTime 30 // Means 30 mins
#define maxTime 600 // Means 10 hours wwhich is 600 mins

// This variable is made volatile because it is changed inside
// an interrupt function
volatile uint8_t activeCounter = 0;
volatile uint16_t sleep_count = 0; // Keep track of how many sleep
// cycles have been completed.
//uint16_t interval = 10; // Interval in minutes between waking and doing tasks.
uint16_t sleep_total; // Approximate number of sleep cycles needed before the interval defined above
// elapses. Not that this does integer math.

/********************* End of Sleep Variable Configuration ********************/

/************************* Other Configuration ***************************/
// Led Pins definition
#define Blueled 15
#define Greenled 16
#define Redled 17
```

Fig. 6. Code for operating the data logger

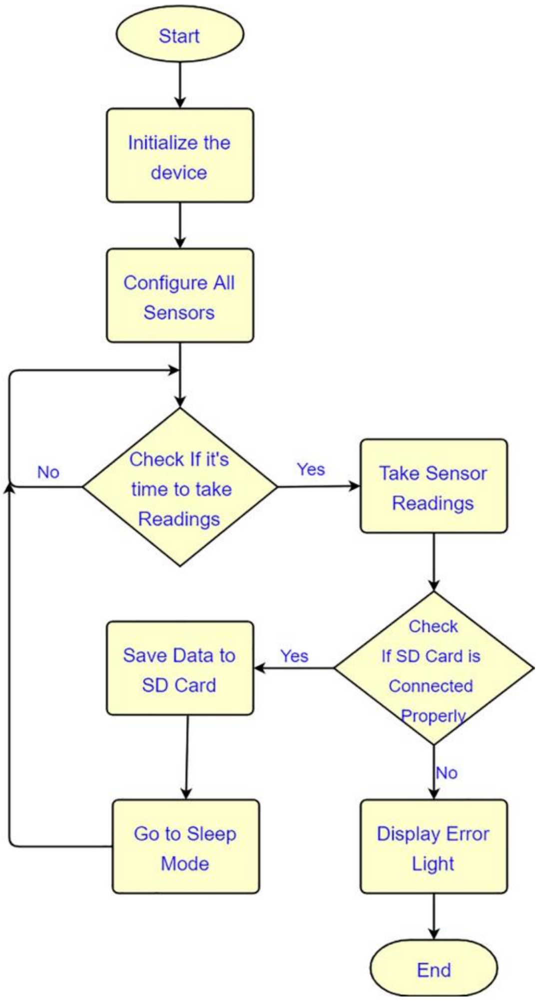

Fig. 7. Programme Algorithm

2.1.5 Power supply unit

The data-logger device is powered by a 4400 mAH power bank unit. This power bank unit gives the data-logger unit an uninterrupted power supply and allows the device to work for days before recharging. The power bank gives out 5 V at 1 Amp to the device. The power bank when fully charged can last for about 7 - 30 days. The device can be plugged into any micro USB power charger to charge the device. Power is supplied to the device using the USB port on it.

2.1.6 LED indicator

The LED indicator is made up of a single RGB LED which can produce up to 8 colours. The LED is used to signify different device modes of operation and it is quick to identify problems with the data logger device. The different mode of operation of the LED is given below:

(a) Start up = Green Blinking for 3 times
(b) Data Processing = Pink Blinking for about 3 times
(c) SD Card Error = Red Light Remain Active
(d) Device Active = Quick Green blinking for 2 times
(e) Wrong DHT Sensor Connection = Cyan colour active or blinking
(f) DHT sensor not connected = Blue colour active or blinking

2.2 Experimentation and Data Measurement

Testing of the device (Data acquisition system) was conducted after the connection and mounting of the sensors on a solar drying system (Figure 8 and Figure 9) and solar cooking system (Figure 10). The air's temperature and relative humidity at various points inside a solar drying as shown in Figure 9, were monitored and measured using sensors DS18B20 (Figure 4) that could measure temperatures from -55 to +125°C (with an accuracy of 0.5°C) and DHT22 (Figure 5) that could measure humidity levels from 0 to 100%. The sensors were linked to a data logger with an Atmel ATmega 328P type microcontroller, which serves as the system's brain. The data acquisition system was configured and programmed to log in readings every 30 minutes (30 min) on the SD card or through the Bluetooth module in Excel format into the computer as presented in Figure 11.

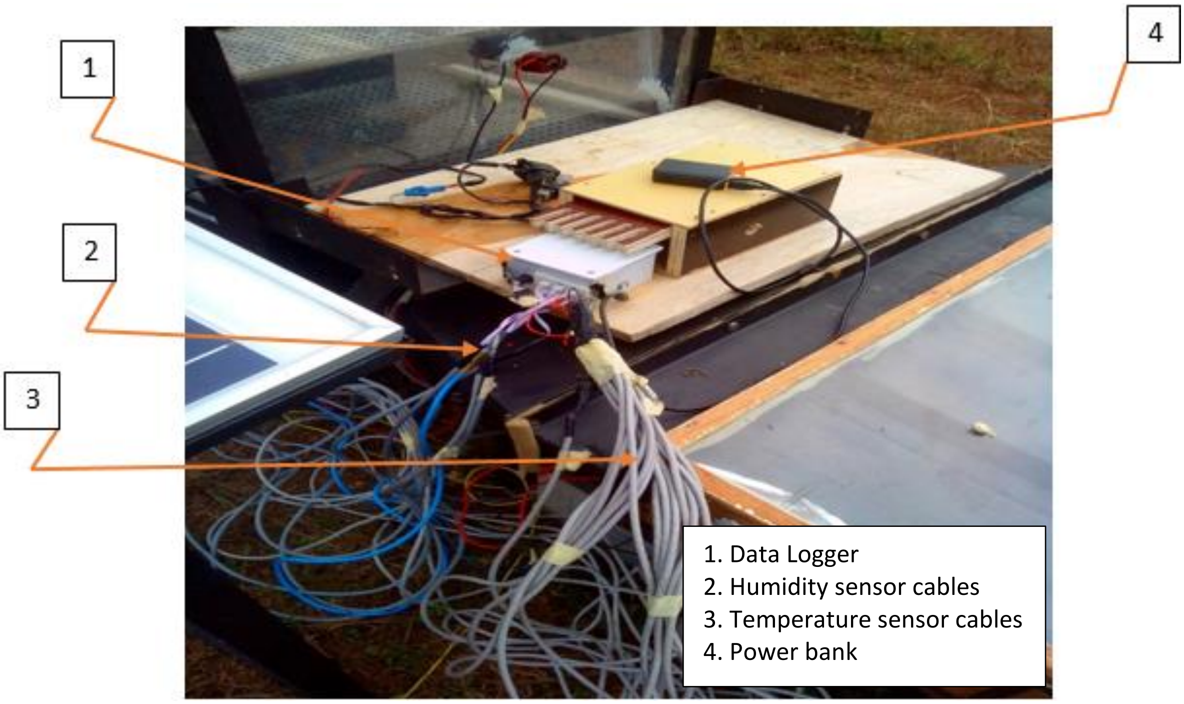

Fig. 8. Connection of all the sensors to the data acquisition system [20]

Fig. 9. Positioning of the sensors at different locations on a solar drying system for data capturing [21-25]

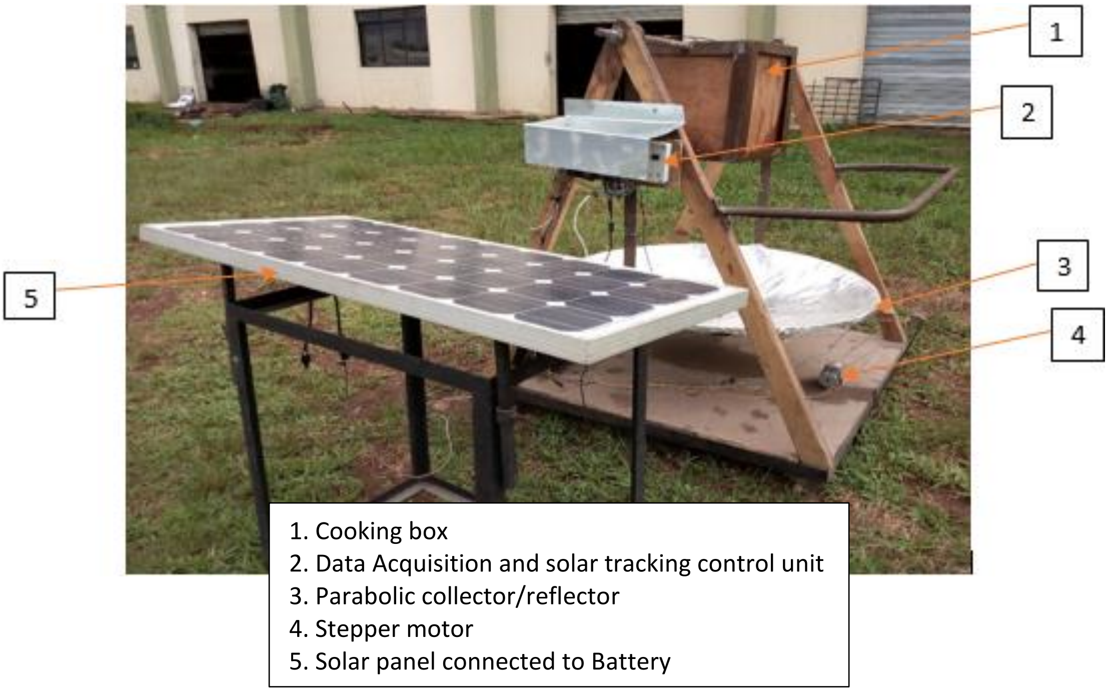

Fig. 10. Application on solar cooking system [26]

Date	Time	D1_H	D1_T	D2_H	D2_T	D3_H	D3_T	D4_H	D4_T	D5_H	D5_T	D6_H	D6_T
30/11/2019	09:00	54	36	57	31	58	35	60	34	64	32	58	32
30/11/2019	09:30	31	37	56	34	44	32	73	32	71	33	49	40
30/11/2019	10:00	28	38	53	36	41	33	50	42	43	42	36	44
30/11/2019	10:30	20	44	28	42	18	39	46	41	42	41	31	48
30/11/2019	11:00	20	45	30	42	21	41	47	41	42	41	27	51
30/11/2019	11:30	17	50	19	48	8	45	32	48	30	48	23	53
30/11/2019	12:00	8	46	18	48	8	46	28	50	29	49	21	53
30/11/2019	12:30	6	49	16	51	6	49	27	52	26	51	19	55
30/11/2019	13:00	17	51	16	52	6	47	25	53	24	52	19	54
30/11/2019	13:30	8	46	15	54	7	45	23	53	22	54	19	53
30/11/2019	14:00	19	46	18	48	8	45	25	50	23	51	23	49
30/11/2019	14:30	18	50	15	53	7	46	23	53	21	54	19	53
30/11/2019	15:00	19	47	17	50	8	43	22	52	19	53	19	50
30/11/2019	15:30	19	48	17	50	7	45	22	52	20	53	19	50
30/11/2019	16:00	22	39	18	39	11	37	26	45	25	46	28	40
30/11/2019	16:30	23	37	20	43	12	35	35	40	31	42	24	44
30/11/2019	17:00	22	39	24	42	10	41	38	36	37	35	27	39
30/11/2019	17:30	25	33	33	32	16	29	45	34	43	33	41	33
30/11/2019	18:00	28	30	49	28	44	24	61	30	61	29	60	28
30/11/2019	18:30	29	29	55	28	47	24	63	30	63	29	62	28
30/11/2019	19:00	42	27	63	25	57	22	72	27	73	26	72	25
30/11/2019	19:30	45	26	69	24	63	21	78	25	81	24	82	24
30/11/2019	20:00	47	25	71	24	65	20	79	25	82	24	83	24
30/11/2019	20:30	49	24	74	23	66	20	81	24	84	24	83	23
30/11/2019	21:00	51	24	82	22	69	19	84	23	87	23	85	22
30/11/2019	21:30	56	24	87	22	70	19	86	23	90	23	88	22
30/11/2019	22:00	57	23	90	22	72	19	87	22	91	22	88	22
30/11/2019	22:30	64	22	93	21	73	18	93	21	99	21	94	21
30/11/2019	23:00	65	21	93	21	72	17	95	21	99	20	93	20
30/11/2019	23:30	66	21	93	21	73	17	94	20	99	20	94	20
01/12/2019	00:00	65	21	94	20	74	17	95	20	99	19	92	20
01/12/2019	00:30	68	20	94	20	76	17	97	19	99	19	96	19
01/12/2019	01:00	71	21	94	20	81	17	98	20	99	20	97	20

Date	Time	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
30/11/2019	09:00	32.75	29.75	31.25	38	46.25	40.5	27.25	33.75	27	28.5	30.25	36	35.25	41.25
30/11/2019	09:30	40	40	37.5	48.25	60.75	52.25	35.75	37.25	30	30.75	30.5	33.75	35.5	46.25
30/11/2019	10:00	46.75	46.5	42.25	59.75	76.25	66.75	43	48.25	36	36	35.75	44.5	46	62.75
30/11/2019	10:30	55.75	53.5	49	69	83.75	76.75	45.75	52.25	34.5	36.5	35	46.25	45	49.5
30/11/2019	11:00	52.75	51	46.75	73.25	89.75	82.25	48.25	57.25	35.75	38.25	38.28	49.5	50.25	60.25
30/11/2019	11:30	61	55.25	54.5	75.5	88.75	86	49.5	65	36.25	38.75	37.75	51.5	53	64.25
30/11/2019	12:00	58.75	53.25	52.25	76.25	93.25	89.75	52.25	68.25	38.25	41	40.75	53.75	54.5	69.5
30/11/2019	12:30	65	59.5	56.25	80.25	92	92.25	54.5	69.25	39.25	42	41.5	55.25	55.25	71.25
30/11/2019	13:00	61.5	56.5	55	83.25	97	93.5	55	70.75	42.25	45	43.75	55.5	56.25	73.75
30/11/2019	13:30	60.25	54	55	74.25	80.25	81.75	48	63.5	39	41.5	40.5	51.75	52.75	65
30/11/2019	14:00	62.25	45.75	54.5	75.75	84	85.5	53.5	66.75	39.75	46.5	44.5	55	54.75	53.5
30/11/2019	14:30	56.75	42.5	50.25	71	78	80.25	50	60.25	39.25	45.75	45.25	54.25	53.5	62
30/11/2019	15:00	59	46	53	72.25	74	82.25	48.5	55.25	39.25	46.25	45.25	54.5	52.5	61.75
30/11/2019	15:30	42.25	34.75	40	45.75	47	50	36	45	35.25	36.25	35.5	47	46.25	43
30/11/2019	16:00	48.75	37	44.75	52.5	54	59	39.75	49.75	37.5	41.5	40.5	51	49.5	50.5
30/11/2019	16:30	50.5	41.5	46	54.25	51.75	60.75	38.5	36.25	40	39.75	39.5	42.75	42.75	44.75
30/11/2019	17:00	47	39.5	43.5	48.75	46.25	54.75	35.75	34.5	36.75	36	34.25	35.5	37	37
30/11/2019	17:30	37.5	35.25	36	37.25	37.5	39.75	32	34.25	32.5	32.75	32.5	35	36.25	34.5
30/11/2019	18:00	29	28.5	28.5	27.75	27.75	27.75	27.75	29	29.25	29.5	29.25	30.25	30.5	29.75
30/11/2019	18:30	26	25.5	25.75	24.75	24.5	24.25	25.5	26.5	27	27	27.25	27.5	27.5	27
30/11/2019	19:00	24.5	24.25	24.25	23.25	23	22.75	24.25	25	25.5	25.5	25.5	26	26	25.75
30/11/2019	19:30	23.75	23.5	23.25	22.5	22.25	22	23.5	24.25	25	24.75	25	25.25	25	25
30/11/2019	20:00	23.25	23	23	22	21.5	22	23.25	23.75	24	24.25	24.25	24.75	24.5	24.25
30/11/2019	20:30	22.75	22.5	22.5	21.5	21	21	22.25	23	23.5	23.5	23.75	24	23.75	23.5
30/11/2019	21:00	22	21.75	22	21.25	20.75	20.5	22	22.5	23.25	23	23.25	23.5	23.25	23.25
30/11/2019	21:30	22	21.75	22	21	20.5	20.25	21.75	22.25	23	22.75	22.5	23.25	23	22.75
30/11/2019	22:00	21.25	21.25	21.5	20.5	20.25	19.75	21	22.25	22.25	21.25	22	22.25	22.25	21
30/11/2019	22:30	21	20.5	20.75	20.25	19.5	19.5	20.5	21.25	21.5	20.75	21.25	21.5	21.75	20.5
30/11/2019	23:00	21	20.5	20.75	20	19.25	19.25	20.25	20.75	21.25	20.5	21.5	21	21	20.25
30/11/2019	23:30	20.25	20	20.25	19.25	18.75	18.5	19.75	20.5	21	20	20.75	20.5	20.5	19.5
01/12/2019	00:00	20	19.75	20.25	19.25	19	18.5	19.75	20.25	20.75	19.75	20.5	20.5	20.25	19.5
01/12/2019	00:30	20.5	20.25	20.5	19.75	19.5	19	20	20.5	20.5	20.5	21	21	20.75	20.5
01/12/2019	01:00	20.75	20.5	20.75	20.75	20.5	20.5	20.75	21.25	21.75	21.5	21.5	21.75	21.5	21.5

Fig. 11. Sample of the captured data

3. Results and Discussion

The results of the captured relative humidity and temperature data by the developed data acquisition system during preliminary, no-load, and full-load solar drying experiments are presented in Figure 11 to Figure 13 [21,24,25].

The plot of the temperature and relative humidity of the ambient, exit, and in the drying chamber of the dryer versus time is illustrated in Figure 12. The ambient, drying chamber, and exit temperatures were also plotted over time in the figure to reflect their effects on the relative humidity. The figure shows that the relative humidity of the ambient, drying chamber, and exit decreased with time from the morning hour as their corresponding temperatures increased. The relative humidity in the drying chamber was lower than those of the exit and ambient during the daytime. A minimum value of 27% relative humidity was measured in the drying chamber at 11:30 hr, while the corresponding ambient and exit humidities were 70.8 and 22% respectively. The relative humidities remained fairly constant till 17.00 hours when they increased monotonically until the maximum value of 99.9% was attained in the night to morning hours.

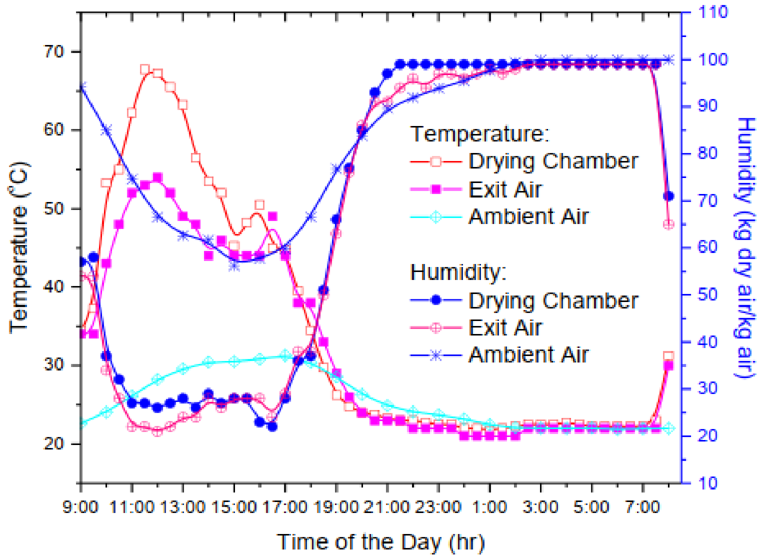

Fig. 12. Plots of temperature and humidity versus time at no-load condition [25]

Figure 13 explains the variation of various temperatures and relative humidities with time under full load condition. From the figure, it can be seen that during the daytime (9:00 -13:00 hr), temperatures increased with time while there was a decrease in humidity with time. In the nighttime, it was the other way round, there was an increase in humidity with time as temperatures decreased with time. Also, it was observed that the profiles for ambient and exit relative humidities sometimes at night were almost the same. The minimum and maximum relative humidities of the drying process were 34.0 and 98.0% at 13:00 and 18:00 hr respectively. As expected, an increase in temperature caused a decrease in relative humidity and vice versa.

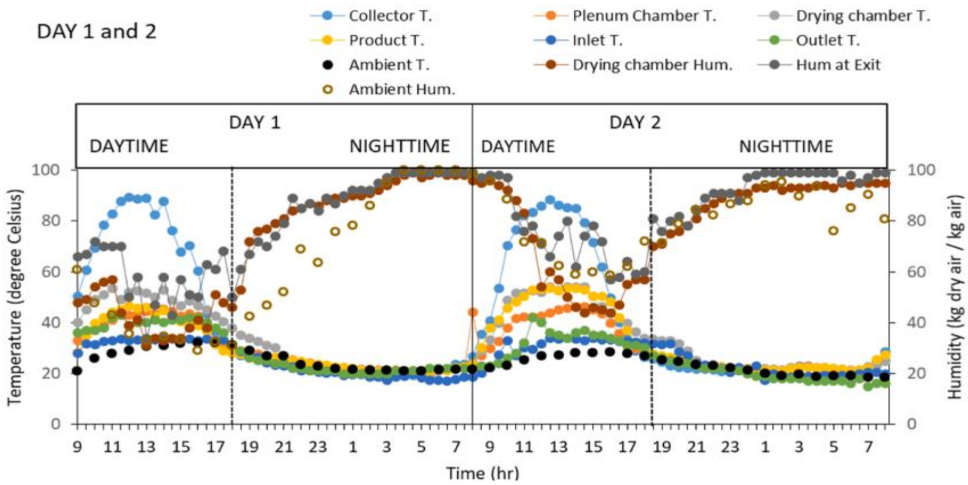

Fig. 13. Plots of temperature and humidity versus time at full-load condition [22]

4. Conclusion

In the present study, the development of an Arduino based multichannel temperature and humidity data acquisition system for industrial applications was presented. The locally developed low cost data acquisition system which consists of fourteen and six temperature and humidity sensors respectively was configured and programmed to log in readings every thirty minutes on the SD card. The flexibility of the system design features makes it easy to reproduce for many industrial applications. The data captured by the developed data acquisition device during various solar drying experiments were within the reasonable and acceptable range for commercial logging devices.

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