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Design and Development of Multi-Channel Data Logger for Built Environment

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Abstract—**In this paper, an effort has been made to design and developed a 4-channel data logger for indoor environment. Initially the present work has concentrated to environmental parameter (temperature and humidity) and more polluted contaminants (concentration level of CO and CO_2). The Data logger is proposed to be developed with the use of microcontroller PIC 18F4458 (inbuilt 8 channel ADC), i.e. 4 channels will be used and 4 channel will open in external sensor. Real Time Clock is also interfaced for sampled data with the instance of sampling time and month/date/year. The sampled data will be stored in the EEPROM which is interfaced to the microcontroller. The data will be stored in the note pad tabular form corresponding to the Month/Date/Year with the help of graphical user interface.**

Index Terms—**GUI (Graphical User Interface), RTC (Real Time Clock), ADC (Analog Digital Converter).**

I. Introduction

Built environment and architecture are closely associated. The built environment affects indoor physical environments, and subsequently health and quality of life of occupants. There is evidence showing the pathways and mechanisms by which the built environment affects health and factor associated with specific aspects of physical and mental health. The problem has become acute in recent past because of the rapid industrial growth in last half century and has lead to change in lifestyles (Become more dependent on indoor environment), increased in dependence on artificial products and advances in medicines [1]. The main factors of the environmental condition are the air quality and environmental parameter of the inside unconditioned environment.

Across the world indoor air quality monitoring is gaining hotspot in present research works because recent study has put forth that 30 – 40% of total natural resources are exploited by the buildings and almost 50% of energy resources is used to condition buildings in industrialized countries. The major contaminants of indoor environment pollution include carbon mono oxide and carbon dioxide. The reality is that indoor air can be up to 10 times more polluted than outdoor air [2]. Many researcher are collect the data for different techniques, in different fields are facing similar difficulty in data collection. For example, a design engineer needs a system that is able to collect and transfer data from the testing laboratory to his work place and buildings such as factories and offices needs to monitor their environmental conditions for fire or smoke detection. The main aim of this paper is to develop low cost data logger. It can be summarized as follows- LCD interfacing to display the output of various modules, interfacing of real time clock with microcontroller, interfacing of EEPROM with microcontroller, interfacing the data logger to the personal computer by using the serial (RS-232), minimization of power consumption in order to enhance battery life and preparing the user friendly graphical user interface (GUI) in visual language to operate the data logger. Real time assessment of indoor air and environment parameters has got tremendous energy saving potential. To focus on this problem we are trying to develop multi-channel data logger for temperature, relative humidity, CO, and CO_2.

II. Sensor interfacing to the microcontroller

A sensor is a device that measures a physical quantity and converts it into an equivalent analog or digital signal which can be read by an observer or by an instrument. Monitoring of a indoor environment involves sensing the changes occurring inside it. The parameters which are of importance are the temperature, relative humidity, and concentration level of air pollutant CO and CO_2 inside the building [3]. In this paper we have used temperature, relative humidity, CO, and CO_2 sensors.

A. Semiconductor Gas Sensors

A gas sensor detects particular gas molecules and produces an electrical signal whose magnitude is proportional to the concentration of the gas [4]. Till date, no gas sensor exists that is 100% selective to only a single gas. A good sensor is sensitive to the measured quantity but less sensitive to other quantities. Available gas sensors are based on five basic principles. These can be electrochemical, infrared, catalytic bead, photo ionization and solid-state [5, 6]. We have selected these sensors because they produce a strong signal for the selected variable especially at high gas concentrations with adequate sensitivity. They have a fast response time, high stability, long life, low cost, low dependency on humidity, low power consumption, and compact size [4]. Four sensors along with their signal conditioning circuit are used to sense the desired parameter. One is temperature, second is humidity, third is CO, and fourth is CO_2. Signal condition circuit for that sensor needs to be connected externally. In software we can select any of the analog channel and hence the sensor. Interfacing of temperature, humidity, CO, and CO_2 sensor with microcontroller PIC 18F4458 is as follows.

B. Temperature sensor

National semiconductor's LM 35 IC has been used for sensing the temperature. It is an integrated circuit sensor that can be used to measure temperature with an electrical output proportional to the temperature (in °C). The temperature can be measured more accurately with it than using a thermistor. The pin configuration is shown in figure 1. The output voltage of LM 35 is converted to temperature in °C is [6]

$$Temp.(°C) = (V_{out} \times 100)/1°C$$

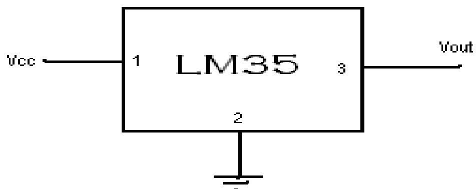

Figure 1. Pin configuration of temperature sensor

C. Humidity sensor

The sensor circuit develops a linear voltage vs. RH output that is ratio metric to the supply voltage. That is, when the supply voltage varies, the sensor output voltage follows in the same proportion. It can operate over a 4 to 5.8 supply voltage range. At 5V supply voltage, and room temperature, the output voltage ranges from 0.8 to 3.9V as the humidity varies from 0% to 100% (noncondensing). The humidity sensor functions with a resolution of up to 0.5% of relative humidity (RH), with a typical current draw of only 200 µA, the HIH-4000 series is ideally suited for low drain, battery operated systems. The operating circuit is shown in figure 2. The change in the RH of the surroundings causes an equivalent change in the voltage output. The output is an analog voltage proportional to the supply voltage. Consequently, converting it to relative humidity (RH) requires that both the supply and sensor output voltages (At 25°C) [6].

$$RH = ((V_{out} / V_{supply}) - 0.16)/0.0062$$

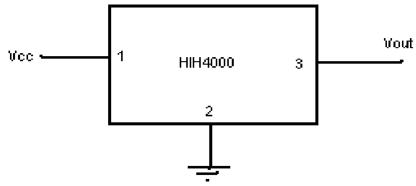

Figure 2. Pin configuration of Humidity sensor

D. CO and CO_2 sensor interfacing

The sensor operating circuit is shown in figure 3. In general, the correlation of the reducing gas concentration (C) in ppm and sensor resistance (R_S) is [4]- $C = [(\frac{R_S}{R_0} - 1)\,{}^{1}\!/_{K}]^2$

R_0 = Electrical resistance of sensor at zero ppm,
R_S = Electrical resistance of the sensor,
C = Gas concentration in ppm,
K = A constant for particular,
The relationship between output voltage and gas concentration in ppm

$$c = [(\frac{(V_C R_L / V_{OUT}) - R_L}{R_0} - 1)\frac{1}{K}]^2$$

R_L = Load resistance; V_{OUT} = Output voltage ; V_C = Input voltage

The Power dissipation is calculated by $P_S = (Vc)^2.R_S/(R_s + R_L)^2$. The standard circuit conditions are the heater voltage 5.0 V±0.2V, maximum sensing material voltage 5–24V (DC only) and the specification of electrical characteristics are sensor resistance R_S (5 KΩ– 15KΩ), heater resistance 30 ± 3 Ω [6].

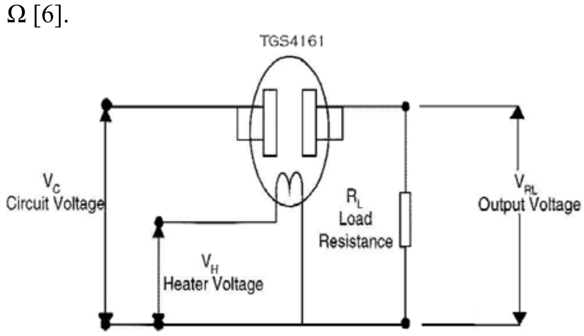

Figure 3. Circuit for CO and CO_2 sensor

III. Analog to Digital Conversion and LCD Interfacing to the Microcontroller

We are using the on chip analog to digital converter which is on the microcontroller PIC 18F4458. This analog to digital converter is having the 12 bit resolution with programmable acquisition time. It is sensing the analog signal from the sensor at the variable sampling rate (1 sec to 1hour). The

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sensed value is converted to its digital equivalent. This digital value is displayed on the LCD (liquid crystal display) which is interfaced to the microcontroller [7, 9-12]. Circuit diagram of ADC and LCD interfacing to the microcontroller is shown figure 4.

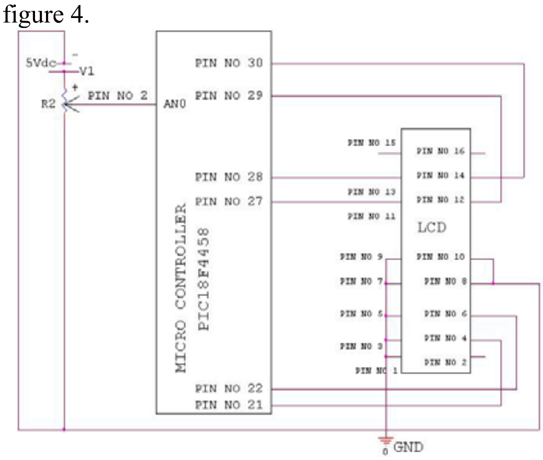

Figure 4. Basic circuit diagram of analog to digital converter

IV. Real time clock interfacing to the microcontroller

The DS1307 operates as a slave device on the I2C bus. Access is obtained by implementing a START condition and providing a device identification code followed by a register address. Subsequent registers can be accessed sequentially until a STOP condition is executed. When VCC falls below 1.25 x VBAT, the device terminates an access in progress and resets the device address counter. Inputs to the device will not be recognized at this time to prevent erroneous data from being written to the device from an out of tolerance system. When VCC falls below VBAT, the device switches into a low-current battery-backup mode. Upon power-up, the device switches from battery to VCC when VCC is greater than VBAT +0.2V and recognizes inputs when VCC is greater than 1.25 x VBAT. Figure 5 shows the basic circuit diagram of interfacing real time clock. We are using the DS1307 real time clock which is having the following features- real-time clock (RTC) counts Seconds, Minutes, Hours, Date of month, Month, Day of the week, and Year with Leap-Year Compensation valid up to 2100, 56-Byte, Battery-Backed, Nonvolatile (NV) RAM for data storage, I2C serial interface, programmable square-wave output signal, automatic power fail detect and switch circuitry, consumes less than 500nA in battery-backup mode oscillator running, and temperature range -40°C to +85°C [8, 9].

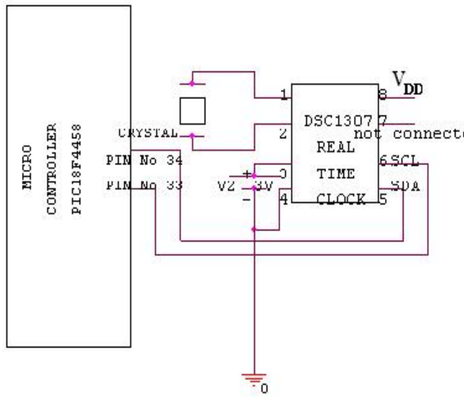

Figure 5. Basic circuit diagram of interfacing Real Time Clock

A. *Protocol used for interfacing*

We are using the I2C to interface the real time clock (RTC) and EEPROM to the microcontroller. The I2C bus is the most popular of the 3 serial EEPROM protocols. Figure 6 shows pin diagram and the basic circuit diagram of interfacing EEPROM. Here you can see the typical pin out of an I2C device showing pins 1 through 3 as address pins A0, A1 and A2. Pin 4 is V_{SS}, or ground. Pin 5 is SDA, the data line. Pin 6 is SCL, the clock signal. Pin 7 is write protect, and pin 8 is voltage, or V_{CC}. Finally, many I2C chips include address pins as an easy way to have multiple chips on a single bus while still only using two connections to the micro [8].

V. EEPROM Interfacing

The EEPROM will store the digital value which is coming from analog to digital converter. We will require the 52.73 MB of EEPROM if we are sampling all analog channels at the rate of 1 sample/Second. We are using the EEPROM AT24C256 of ATMEL Company. This will store the sample data at different instants. This EEPROM having the following features- low voltage and standard voltage operation 5.0 (V_{CC} = 4.5V to 5.5V), 2.7 (V_{CC} = 2.7V to 5.5V), and 1.8 (V_{CC} = 1.8V to 5.5V); 1 MHZ (5V), 400 KHZ (2.7V) and 100 KHZ (1.8V) compatibility, and 64-Byte page write mode [9, 11, 12].

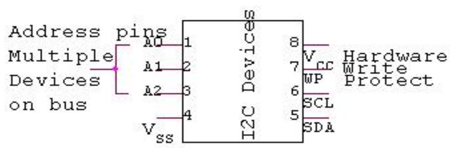

Figure 6. (a) General pin diagram of the I2C Devices

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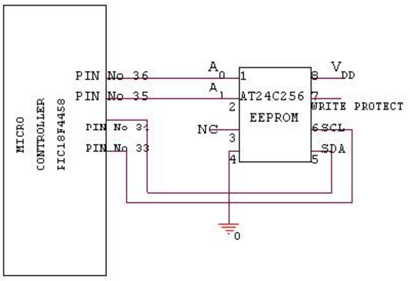


Figure 6. (b) Basic circuit diagram of interfacing EEPROM

VI. PC INTERFACING USING RS-232 SERIAL COMMUNICATION

PC is interfaced with PIC 18F4458 using MAX-232. It is the IC used to convert the TTL logic level to the RS-232 logic level. RS-232 is the serial communication protocol that does not require the clock along with data lines. Two data lines are there one is T_X and another is R_X for serial communication. MAX-432 has two receivers (converts RS-232 logic level to TTL logic) and two drivers (converts TTL logic to RS-232 level). Following Figure 7 shows the hardware interface of PIC with PC. Separate power supply has been provided because minimum power supply needed is 5V and MAX-232 consumes a lot of current for operation. External capacitors are required for internal voltage pump to convert TTL logic level to RS-232 level. For battery operated application MAX-232 can be used as level converter instead of MAX-232. it is low supply low power consumption logic converter IC for RS-232. It is pin compatible with MAX-232 [9].

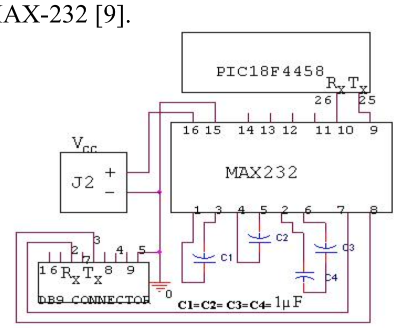


Figure 7. Schematic for PC interface using MAX-232 with PIC18F4458

VII. GRAPHICAL USER INTERFACE

The GUI is one of the important parts for this paper as it displays the data from microcontroller for data monitoring and analysis. The design template has to be user friendly for best usage. For this paper, the main objective is to display data received in graphical form. As a transducer detects and translate an analog signal, the data will go through a conversion at the ADC and become a digital format. This digital data is converted in a 12 bit data. This data will be stored to the EEPROM chip with the help of Visual Basic 6.0 software.

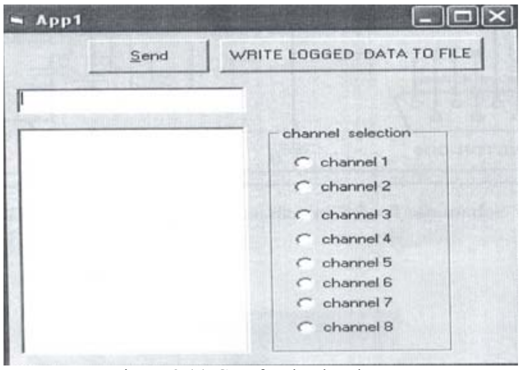
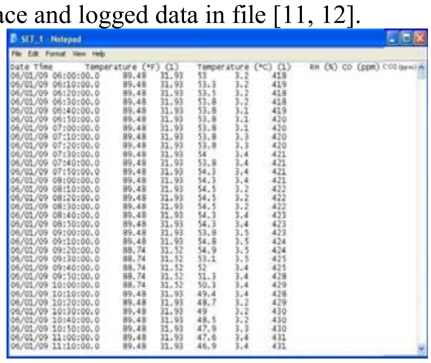


Figure 8 (a) GUI for the data logger

Since the data used the serial RS232 communication, therefore an initialization needs to be done which are the baud rate, data bits, parity, stop bit and the COM port at the PC. The baud rate is the number of signal changes per second or transition speed between Mark (negative) and Space (positive) which range from 110 to 19200, data bits is the length of data in bit which has one Least Significant Bit (LSB) and one Most Significant Bit (MSB), the parity bit is an optional bit mainly for bit error checking. It can be odd, even, none Mark and Space. Stop bit is used to frame up the data bits and usually combined with the start bit. These bits are always represented by a negative voltage and can be 1, 1.5 and 2 stop bits, and for the COM port is the selection of the available COM port at the PC. Most PC has 2 COM port which serial RS232 communication compatible. The commonly used setting to establish a serial RS232 communication is 9600 baud rate, none parity, 8 data bits, 1 stop bit and COM port 1. As this project relates with data collection, thus the data obtained from the microcontroller needs to be collected and saved. This can be done by using the GUI monitoring system where it automatically saves the data received in a note pad. The data being saved is the date and time during the data collected and data value it self. Figure 8, represents the graphical user interface and logged data in file [11, 12].


SET_1 - Notepad

Date Time	Temperature (°F) (1)	Temperature (°C) (1)	RH (%)	CO (ppm)	CO2 (ppm)
06/01/09 06:00:00.0	89.48	31.93	53	3.2	418
06/01/09 06:10:00.0	89.48	31.93	53.3	3.2	419
06/01/09 06:20:00.0	89.48	31.93	53.5	3.2	418
06/01/09 06:30:00.0	89.48	31.93	53.8	3.2	418
06/01/09 06:40:00.0	89.48	31.93	53.8	3.1	419
06/01/09 06:50:00.0	89.48	31.93	53.8	3.1	420
06/01/09 07:00:00.0	89.48	31.93	53.8	3.1	420
06/01/09 07:10:00.0	89.48	31.93	53.8	3.3	420
06/01/09 07:20:00.0	89.48	31.93	53.8	3.3	420
06/01/09 07:30:00.0	89.48	31.93	54	3.4	421
06/01/09 07:40:00.0	89.48	31.93	53.8	3.4	421
06/01/09 07:50:00.0	89.48	31.93	54.3	3.4	421
06/01/09 08:00:00.0	89.48	31.93	54.3	3.4	421
06/01/09 08:10:00.0	89.48	31.93	54.5	3.2	422
06/01/09 08:20:00.0	89.48	31.93	54.5	3.2	422
06/01/09 08:30:00.0	89.48	31.93	54.5	3.2	422
06/01/09 08:40:00.0	89.48	31.93	54.3	3.4	423
06/01/09 08:50:00.0	89.48	31.93	54.3	3.4	423
06/01/09 09:00:00.0	89.48	31.93	53.8	3.5	423
06/01/09 09:10:00.0	89.48	31.93	54.8	3.5	424
06/01/09 09:20:00.0	88.74	31.52	54.9	3.5	424
06/01/09 09:30:00.0	88.74	31.52	53.1	3.5	425
06/01/09 09:40:00.0	88.74	31.52	52	3.4	425
06/01/09 09:50:00.0	88.74	31.52	51.3	3.4	428
06/01/09 10:00:00.0	88.74	31.52	50.3	3.4	429
06/01/09 10:10:00.0	89.48	31.93	49.4	3.4	428
06/01/09 10:20:00.0	89.48	31.93	48.7	3.2	429
06/01/09 10:30:00.0	89.48	31.93	49	3.2	430
06/01/09 10:40:00.0	89.48	31.93	48.5	3.2	430
06/01/09 10:50:00.0	89.48	31.93	47.9	3.3	430
06/01/09 11:00:00.0	89.48	31.93	47.6	3.4	431
06/01/09 11:10:00.0	89.48	31.93	46.9	3.4	431

Figure 8. (b) Representations of the logged data in file

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VIII. Schematic of the Data Logger

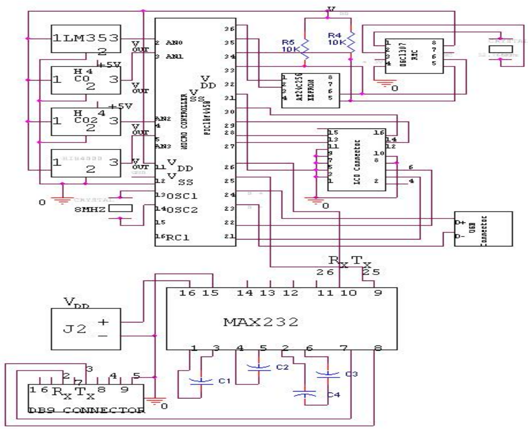


Figure 9. Full Schematic of the data logger

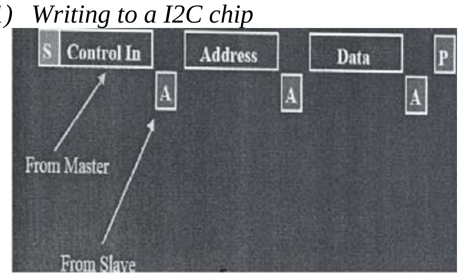
IX. Software Design of Data Logger

This subsection includes the software design for all the modules interfaced with PIC 18F4458. It covers complete software design for data logger. For register names and name of the pins PIC 18F4458 data sheet has been referred.

A. Programming Steps for I2C interface

I2C is also bi-directional. This is implemented by an "Acknowledge" system or "ACK" system allows data to be sent in one direction to one item on the I2C bus, than, that item will "ACK" to indicate the data was received. Normally, the master device controls the clock line, SCL. This line dictates the timing of all transfers on the I2C bus. Other devices can manipulate this line, but they can only force the line low. This action means that item on the bus cannot deal with more data in to any device (Clock Stretching).

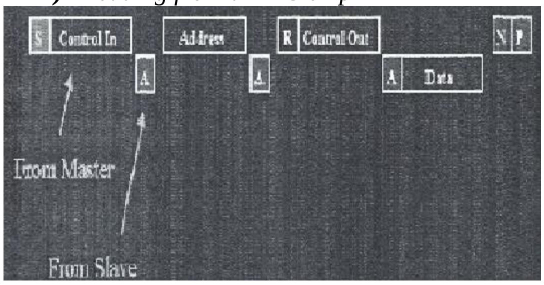
1) Writing to a I2C chip



The function of writing to the EEPROM is shown here as "Control IN", which represents putting the EEPROM in an "input" mode. Since we are only sending data to the EEPROM, we use the "Control IN" byte. We will use "Control OUT" later.

Next, the EEPROM acknowledges this byte. This is shown by the "A" after the byte. It is put on the next line to indicate this is transmitted by the EEPROM, not the PIC micro-devices. Next the PIC micro sends the Address Byte. The Address Byte contains the address of the location of the EEPROM we want to write data to. Since the address is valid, the data is acknowledged by the EEPROM. Finally, we send the data we want to write. The data is then acknowledged by the EEPROM. When that finishes, we send a stop condition to complete the transfer. Remember the "STOP" is represented as the "T" block on the end. Once the EEPROM gets the "STOP" condition it will begin writing to its memory. The write will not occur until it receives the "STOP" condition.

2) Reading from an I2C chip



The transfer will use the "Control IN" byte to load the address into the EEPROM. This sends data to the EEPROM which is why we use the control in byte. Once the address is loaded, we want to retrieve the data. So, we send a "Control OUT" byte to indicate to the EEPROM that we want data FROM it. The EEPROM will acknowledge this and then send the data we requested. When we are done getting data, we send a "NACK" to tell the EEPROM that we do not want more data. If we were to send an ACK at this point, we could get the next byte of data from the EEPROM. Since we only want to read one byte, we send a "NACK". This is detailed in the specifications for the EEPROM.

B. Programming Steps for LCD interface

1) LCD module is initialization and configuration to work in 4 bit module

Set RS = 0 to send command; Send 0b0010 to data lines three times with a delay of 2ms; to send a byte on 4 data line, send higher nibble first and give a RE pulse of 100uS at RE; send a set of instruction one after another with a delay of 2ms between each command to configure various setting as given in instruction set of LCD datasheet; send instruction set again.

2) Display a character

Set RS=1; Send higher nibble at 4 data lines. Send 100uS RE pulse; Send lower nibble at data lines. send RE pulse; Keep track of number of character already displayed on display panel using LCD_count. Go to line 2 or line 1 according to that.

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C. Programming steps for sensor data collection

There are connected four sensors temperature, humidity, CO, and CO_2. Data is collected by the ADC inbuilt in PIC. ADC provides 10 bit of data after the conversion is completed.

1) Temperature sensor data collection

Selected the analog channel AN0, sampling frequency, and alignment of bits for ADRESH and ADRESL, Vref, power on the ADC module by setting ADCON0, ADCON1 and ADCON2 registers; start A to D conversion by setting ADGO bit high; wait till ADIF flag will not indicate the completion of conversion; copy the results from ADRESH and ADRESL to variables.

2) Humidity sensor data collection

Select the AN3 and set other features of ADC as temperature sensor; after completion of conversion copy the result in variable.

3) CO and CO_2 sensor data collection

Select the analog channel AN1, sampling frequency, and alignment of bits for ADRESH and ADRESL, Vref, power on the ADC module by setting ADCON0, ADCON1 and ADCON2 registers; START A to D conversion by setting ADGO bit high; wait till ADIF flag will not indicate the completion of conversion; copy the results from ADRESH and ADRESL to variables.

Now repeat the same process to collect the CO_2 data on the channel number AN2.

X. RESULTS AND DISCUSSION

Sensors have been interfaced with the microcontroller successfully and the EEPROM and RTC have been successfully interfaced to the microcontroller. So that EEPROM is successfully storing the logged data with the time and date tag. The sensor data has been displayed on LCD module. A simple GUI has been designed with the help of that we are capable to store a logged data to a text file so that it can be analyzed further.

XI. CONCLUSIONS

In this paper we have developed a low cost data logger which has 12 bit resolution analog to digital converter. In this paper we have used the microcontroller with inbuilt 12–bit analog to digital converter besides using the 12-bit external analog to digital converter. The GUI has been designed and work be done successfully. The developed system is successful in measuring the temperature, humidity, and concentration of CO and CO_2 gases. Initial results are encouraging. To increase the level of accuracy we are planning to improve the interfacing and GUI module.

XII. FUTURE SCOPE

We can improve the data logger by incorporating the wireless communication in it. There fore, by combining the term data acquisition and wireless communication, it becomes wireless data acquisition. This new innovation technology has become the trend for most industries and companies around the world to gather information due to its reliability and outstanding outcome. The advantage of this technology is that it did not use any physical components or wires to transfer the data obtained from sensor at transmitter side to the receiver side. As a result, an effective system is developed where it is not only removes all the conventional hardware and replace with a transceiver modem for data transfer but also a cost effective system as well. Moreover, the data transmission range can be extended into longer range depending on the transceiver modem capability. With this feature, information from the transducer could be transmitted faster and acts as an early alert in case of accident or disaster such as fire, food and earthquake. We can improve the graphical user interface. By modifying the GUI we can display the waveforms of the data on the computer console where as presently we are logging the data to the file. We also can incorporate the USB (universal serial bus) communication so that we can transfer the data at higher data rates.

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