A Microcontroller Based Carbon Monoxide Monitoring and Mapping System using GPS Technology

Shivachi Newton Shuma
Department of Physics
Kenyatta University,
PO BOX 40844,
Nairobi, Kenya

Elijah Mwangi
School of Engineering;
University of Nairobi,
PO BOX 30197,
Nairobi, Kenya

Patrick Karimi
Institute Energy Studies and Research
Kenya Power,
PO BOX 30099
Nairobi, Kenya

ABSTRACT
Air pollution is a major factor of consideration in the evaluation of quality of life and as an environmental issue in urban areas. Among urban air pollutants carbon monoxide (CO) is one of the most prevalent. Information about its concentrations is vital in the determination of urban air pollution. In this paper, an automatic and cost effective prototype for CO monitoring and mapping is presented. The input of the system consists of TGS2442 sensor for measuring CO, DHT11 sensors for measuring temperature and humidity and a NEO-6 u-blox 6 GPS receiver module. The output is a 20X4 LCD and GSM/GPRS TTL modem. The PIC18F45K22 microcontroller has been used as a control device.

The designed system measures CO levels in the air and tags them with location information from the GPS receiver in terms of latitude, longitude and time at which the data has been collected as well as temperature and humidity. The collected data is displayed on the LCD screen and also transmitted to a central office via the GSM modem as a text message.

The system has been used to compare CO concentrations in an urban and a rural environment in Kenya. The CO concentrations recorded in a rural area ranged from 4 ppm to 2.5 ppm while the site in an urban area ranged from 6 ppm to 5.5 ppm. A comparison of CO levels in different sites within the urban area was also done. Along a busy public road CO levels were found to range from 5 ppm to 18 ppm while at a distance of about 300 metres from the road they ranged from 3.5 ppm to 6 ppm. The results obtained above have shown that CO concentrations are dependent upon time and location where the data has been collected. To provide this information a GPS receiver has been included in the design. Thus the designed system is a cost-effective microcontroller based system for CO monitoring and mapping.

Keywords
Carbon monoxide monitoring and mapping, TGS2442 sensor, GPS receiver, Global System of Mobile Communication, C programming

1. INTRODUCTION
Air pollution refers to an atmospheric condition in which certain substances are present in the air in concentrations and duration that may be harmful to human and animal health as well as the environment. Air pollution in urban areas is high due to high number of pollution sources, increased population growth and ineffective environmental regulations [9].

In urban areas carbon monoxide (CO) is one of the most prevalent air pollutant found to have serious effects to human health. It is a byproduct in the partial oxidation of carbon based compounds. The health effects of CO include tiredness for healthy persons, chest pains to hypertensive individuals, problems with vision, headaches, dizziness, confusion, nausea.

Carbon monoxide levels in urban areas have greatly increased especially in areas with heavy traffic. Data about its concentration therefore plays an important role in the determination of air quality. The collection of accurate data on CO concentrations lies in efficient monitoring of the carbon monoxide to determine factors with potential risk at local dimension [4].

2. RELATED WORK
The commonly used systems in air pollution monitoring consist of discrete stations with large, fixed sensors that provide continuous measurements of air pollutants. However setting up of these stations is limited by factors such as prohibitive costs of the control devices and sensors, large size of the sensors used, high power consumption and other technical complexities. The fixed site stations also perform stationary measurements. Since air pollution is highly varied, data obtained from these fixed site stations is not sufficient to adequately represent exposure levels at the local scale.

To address this shortcomings mobile air pollution monitoring systems has been considered. This can be done by interfacing sensors to a computer, a microprocessor or a microcontroller. Computer based environmental monitoring devices have been reported [8, 13 and 14]. However the cost involved in designing these systems is high.

Microcontroller based systems have the advantage of incorporating the processor, memory and input/output devices on one chip. This is unlike microprocessors systems which have the elements provided as separate chips and are linked through bus connections [6]. Thus microcontroller based systems are less expensive and easier to implement. Besides reduced cost microcontroller based systems are small in size as compared to computer based systems. This makes them portable allowing CO to be monitored in different microenvironments.

Microcontroller based air pollution monitoring systems have also been reported. Some are single point detection and warning systems. The warning mechanism in use include an alarm system that sounds whenever CO levels exceed safe limits [1, 2, 10 and 12] to those that flash light [18]. Besides the warning mechanisms other designs have enhanced capabilities that transmit the collected data. The mechanisms for data transmission under consideration include Zigbee network [1, 16]. [16] Recommended the use of a GSM modem to send alert messages to authorized person whenever the gas concentration exceeded the threshold levels. In line with this recommendation, a microcontroller based GSM enabled system for monitoring CO in vehicles has been presented. The system uses AT89V51RD2 microcontroller, has GSM modem, CO and temperature sensor, LCD and buzzer. The system monitors CO gas and temperature. When CO levels increase beyond safe limits, an alarm is triggered to alert the driver. It also sends a warning message to the authorized user via GSM indicating the critical situation of the vehicle [11]. This research paper presents a novel approach to real time CO monitoring. The system is microcontroller based making it low cost and low complexity as opposed to a computer based system. It has TGS2442 sensor for measuring CO levels, DHT11 sensor for measuring temperature and humidity and a GPS receiver that provides location information in terms of latitude, longitude and time. This allows for CO mapping. A GSM modem has also been incorporated to enable the collected data to be sent to a central office in the form of an SMS.

3. CO SENSOR WORKING PRINCIPLE

The TGS2442 sensor used in the design is a metal oxide semiconductor sensor provided by Figaro Engineering Inc. USA. The sensor has high sensitivity for carbon monoxide. In addition it is of low cost, has long life, its power consumption is low and it has miniature size [15].

The active sensing element used in TGS2442 sensor is tin dioxide. Tin dioxide changes its resistance when it comes into contact with CO gas. When the sensor is heated to a high temperature (about 400°C) in the absence of oxygen, free electrons flow easily through the grain boundaries of tin dioxide (SnO_{2-X}). When it is heated in clean air, the oxygen in the air gets adsorbed on the sensor surface. Oxygen having a higher affinity for electrons attracts and traps the free electrons on the surface and at the grain boundaries. This forms a potential barrier that prevents electron flow leading to a high sensor resistance as shown in figure 1 [7].

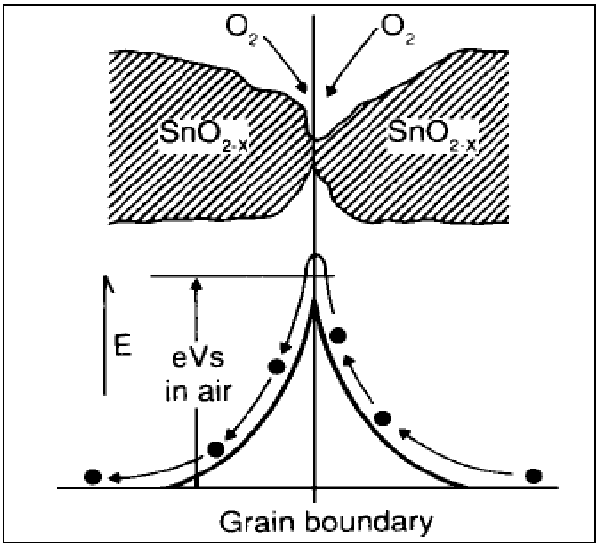

Figure 1: The TGS2442 sensing element reactions in clean air [7]

However when exposed to CO gas, tin dioxide in the sensor adsorbs CO gas molecules. An oxidation reaction takes place between CO and oxygen and releases free electrons as shown in figure 2 below. This reduces the density of the adsorbed oxygen leading to a reduction in the height of the barrier potential. The sensor resistance reduces and electrons can easily flow [7].

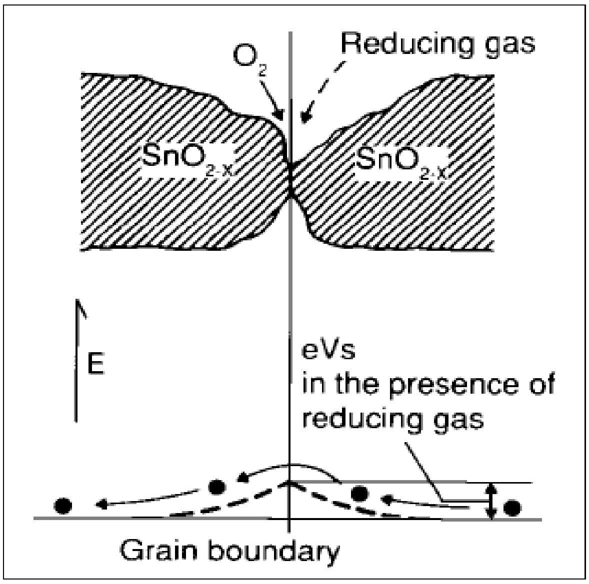

Figure 2: The TGS2442 sensing element reactions in the presence of a carbon monoxide gas [7]

The change in resistance of the sensor is then measured to indicate the amount of carbon monoxide in the air.

4. DESIGN AND IMPLEMENTATION

The designed microcontroller-based CO monitoring and mapping system has two important parts namely; the hardware and software. The hardware provides the required signals to the microcontroller while the software within the microcontroller analyzes these signals giving out the desired output. The next section describes how the specific hardware and software have been designed and integrated.

4.1 Hardware Design

The hardware components of the system comprises of TGS2442 carbon monoxide sensor, a PIC18F45K22 microcontroller, a Liquid Crystal Display, a DHT11 temperature and humidity sensor, a GPS receiver; a GSM modem and a power supply. A complete block diagram for the system is shown in figure

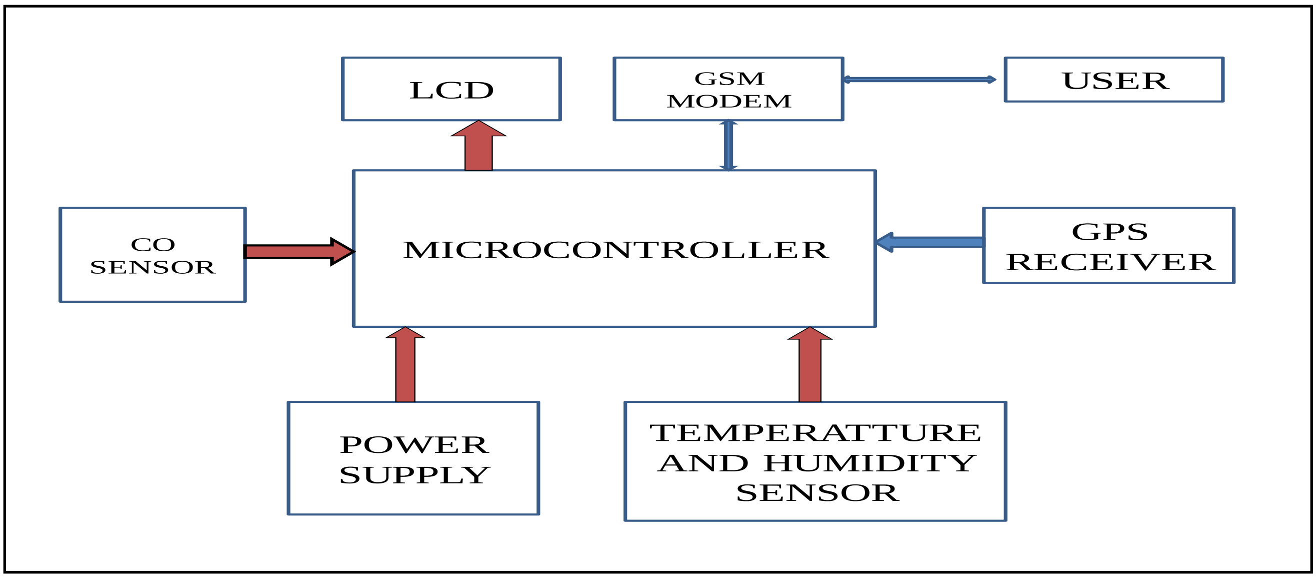

Figure 3: A block diagram of the hardware design of the Carbon Monoxide monitoring and mapping system

The TGS2442 sensor requires a one second heating voltage cycle (VH) used in connection with a one second circuit voltage cycle (VC). During the heating cycle 4.8V is applied for 14ms followed by 0V for the remaining 986ms. This switches the sensor between its "purge" (high heat) and measurement (low heat) cycles. During the "purge" cycle the sensor is freed of CO that accumulated on it in the previous measurement cycle. The circuit cycle consists of 0V applied for 995ms followed by 4.8V for 5ms. It prevents possible migration of heater materials into the sensing element. The sensors' output signal is measured after the midpoint of the 5ms circuit voltage pulse of 4.8V to achieve optimal sensing characteristics. In this design it was measured after 3ms [7]. The output from TGS2442 sensor is an analogue voltage signal. The sensor is therefore connected to the PIC18F45K22 microcontroller ADC module that converts it into digital form.

The DHT11 sensor is used to record temperature and humidity of the surrounding air. It is a reliable sensor, with fast response, strong anti-interference ability and excellent long term stability. It requires a voltage of 3.5-5.5V and a measurement current of 0.3mA and 60µA standby [5].

The location information of the system is obtained from a NEO-6 u-blox 6 GPS module. The module has a high performance u-blox 6 positioning engine. It is a flexible and cost effective receiver that offers numerous connectivity options in a miniature 16 x 12.2 x 2.4 mm package. The NEO-6 u-blox 6 GPS receiver module has an on board 3V to 5V level convertor that allows for direct interfacing to the PIC18F45K22 microcontroller.

The information obtained from this module that is useful in this design is latitude, longitude and time. The collected data is sent to a central office via the GSM modem in the form of a text message. The GSM modem used is compact in size and easy to use for it is a plug in modem. It is designed with 3V/5V transistor-transistor logic (TTL) interfacing circuitry that allows direct interface to PIC18F45K22 without the use of a level conversion chip. The PIC18F45K22 controls every aspect of the system from data acquisition, A/D conversions, display and commands for sending the data as a text message.

4.2 Software Design

The program code has been written in C using MikroC platform. PicKit3.0 programmer was then used to program the hex file into PIC18F45K22. The program performs signal acquisition from the TGS2442 sensor through the ADC, the DHT11 sensor and the GPS receiver through the EUSART. The signals acquired are then processed, analyzed and the results are displayed on the Liquid Crystal Display (LCD) and sent to a central office via the GSM modem.

4.2.1 The Flowchart for the system software

When the system is powered on, the software monitors carbon monoxide concentration, humidity and temperature. It also gets data from the GPS receiver and displays the information on an LCD. Figure 4 illustrates the steps followed in developing the software.

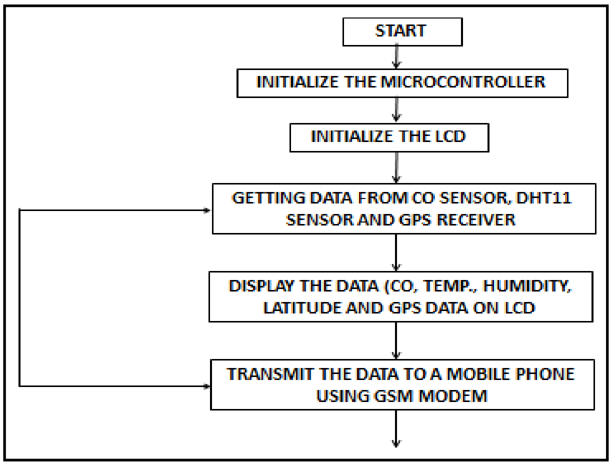

Figure 4: The flow chart for the system software design

4.2.2 Algorithm

In order to write the code to control the microcontroller operations, the following algorithm has been employed.

i) Start: In this step the microcontroller is reset and the first instruction to be executed shall be at address 0000h

ii) Initialize the LCD: The LCD display is cleared the cursor moves to the start of first line

iii) The LCD displays the Message “SHIVACHI NEWTON” who in this case is the designer

iv) Display the Message " CARBON MONOXIDE, TEMP AND HUMIDITY MONITORING AND MAPPING” which is the title of the system

v) Display the level of carbon monoxide "CO LEVEL IS = " on the LCD

vi) Display the temperature and humidity level on the LCD

vii) Read the time, latitude and longitude data from the GPS receiver and display on the LCD

viii) Send all this data to a predefined number via a GSM modem

ix) Go to step iv

When the system is powered ON, the LCD displays a short string showing the name of the system designer. The microcontroller then starts sampling the TGS2442 sensor output voltage signal (V1). After getting the V1 signal the microcontroller calculates CO concentration in ppm and displays it on the LCD. It follows by reading temperature and humidity data from the DHT11 sensor and displays it on the LCD. Finally it reads time, latitude and longitude data from the GPS receiver and displays it on the LCD. All the collected data is then sent to predefined number via a GSM

5. RESULTS AND DISCUSSION

5.1 The Designed carbon monoxide monitoring system

The figure 5 below shows a schematic diagram of the designed carbon monoxide monitoring and mapping system while figure 6 a. shows a screenshot of a) All the assembled hardware components of the designed carbon monoxide monitoring system b) The LCD display of the designed Carbon monoxide monitoring

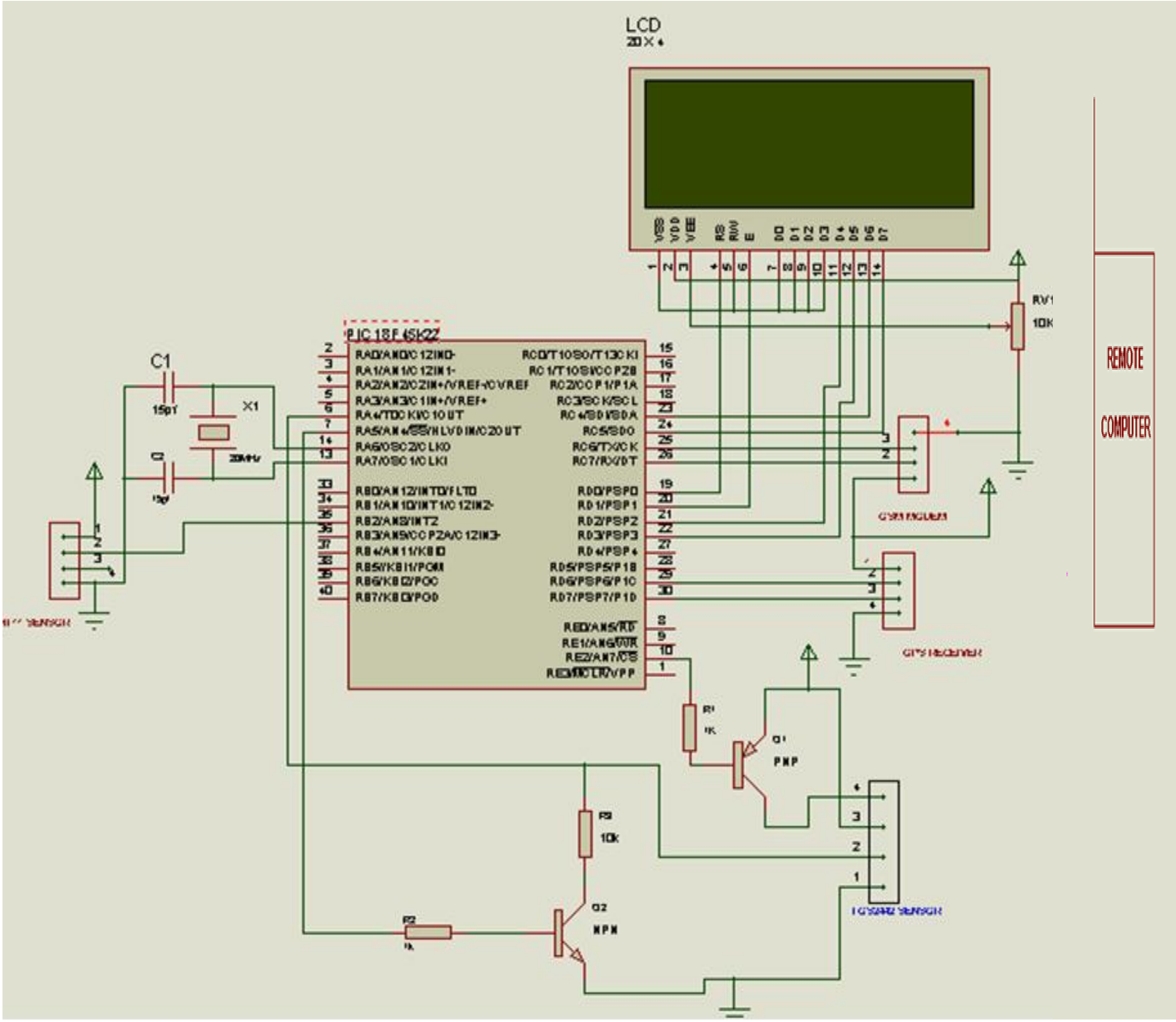

Fig 5: A schematic diagram of the designed carbon monoxide monitoring and mapping system

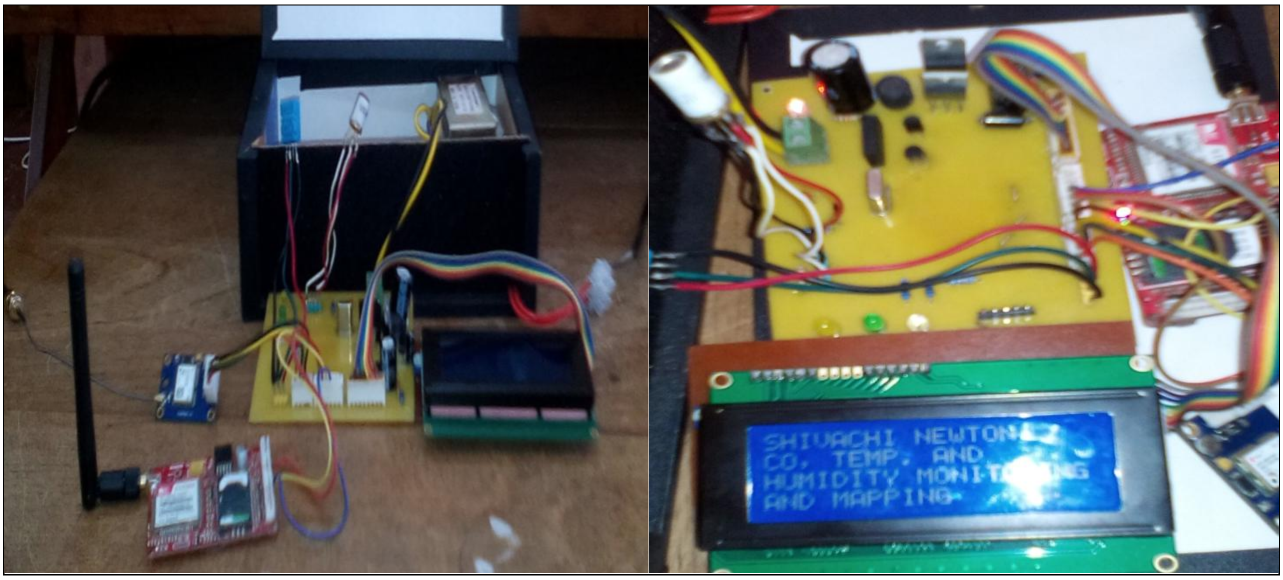

Figure 6: A screenshot showing a) All the assembled hardware components b) The LCD display of the designed Carbon monoxide monitoring and mapping system

5.2 Results from the TGS2442 sensor

The designed system has been used to monitor CO concentrations in varied environments. It reports CO data, temperature, humidity, time and the location (latitude and longitude) at which the data has been collected.

To study the variation in CO levels, the system has been used to compare CO concentrations in an urban area and a rural area. In an urban area a public university in Kiambu County, Kenya was selected. For a rural area a home in Erusui village, Hamisi Sub-county of Vihiga County, Kenya far from motorized traffic was selected. In the rural home two locations were considered; outside the house in an open area and indoors in a room with a stove that had burning wood charcoal. The CO emissions were monitored in each site for a period of 2 hours. For every location, average values have been computed and graphs plotted using microcal OriginPro8.1 software.

The data obtained is as presented in figure 7 below. The graph shows that values of CO emissions when the system was stationed outdoors in an urban area had a maximum of 6 ppm and a minimum of 5.5 ppm. These CO levels are higher than those of an open site in a rural area which recorded a high value of 4 ppm and a low value of 2.5 ppm. This shows that urban areas have high CO concentrations than rural areas. These CO levels are found to be higher when compared to the average outdoor CO levels which are about 0.12 ppm in the Northern hemisphere and 0.04 ppm in the Southern Hemisphere [3]. The high CO levels for the location in an urban area could be caused by the presence of motor vehicles. The increase in CO levels in the rural home could have come from wood charcoal that was used for cooking. The graph also shows that CO levels remain steady over the entire period with minimal fluctuations.

The CO levels as recorded in an indoor (a room with burning charcoal) environment in a rural area has also been done and presented in figure 7 below. The CO concentrations here started from 35 ppm and increased gradually to a high of 46 ppm over a two hour period. This is a dangerous amount of CO since exposures of 26 ppm over a period of 1 hour are considered harmful [17]. The CO levels are high can be attributed to the burning charcoal. The enclosed room also allows CO concentrations to accumulate leading to the gradual increase. The results show that when the system is in the vicinity of known sources of CO it records high levels. Hence it can be used to identify CO sources. It also shows that the use of fossil fuel for cooking can lead to high levels of indoor air pollution.

The designed system has also been used to study how CO varies with time and location. This has been done by placing the designed system in two different locations in an urban environment. The first location was on a public road with heavy vehicular traffic and the second location was at a distance of about 300 metres from the road. This was done to study the influence of motor vehicles on CO levels. For each location CO monitoring was done for a period of 10 hours from 8:00 a.m. to 6:00 pm. Average values were computed for a period of 15 minutes and graphs plotted using microcal OriginPro8.1 software. The figure 8 below presents the results obtained for the two places.

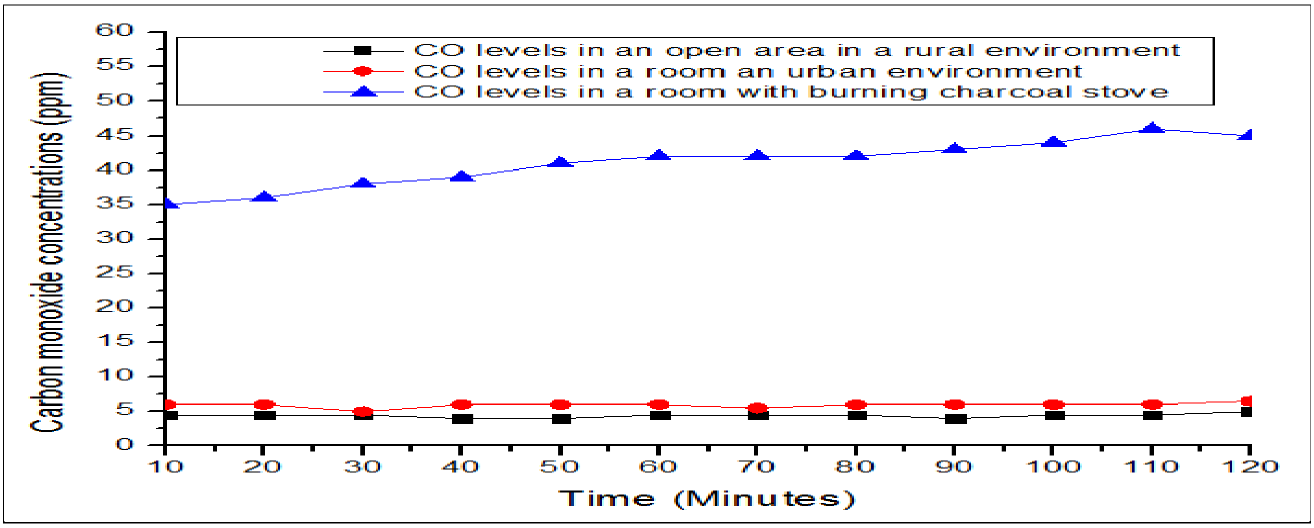

Figure 7: A comparison of CO concentrations as recorded in an Urban environment and a rural environment

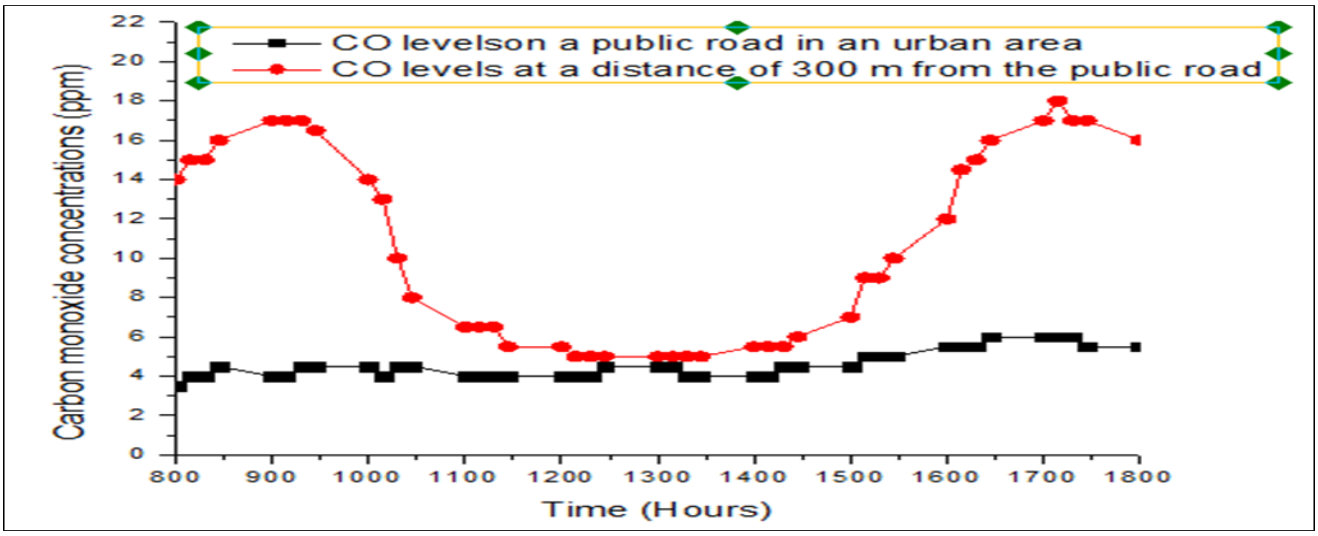

Figure 8: Carbon monoxide concentration as recorded along a public road and at a distance of 300m from the road in an urban area in Kiambu County, Kenya.

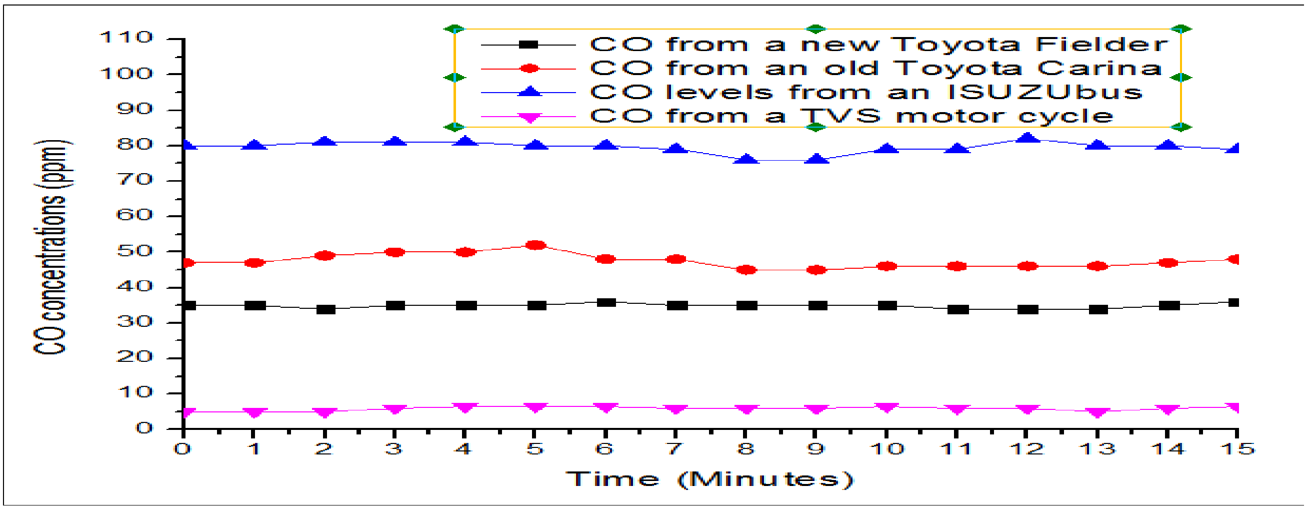

Figure 9: Carbon monoxide concentrations as recorded from different motor vehicle engines

The results presented in figure 8 show that CO levels on the public road had a high value of 18 ppm and a low value of 5 ppm. They also depict two peak periods between 0800 hours and 1000 hours and between 1600 hours and 1800 hours. The CO levels during the evening peak are slightly higher than the morning peak period. This coincides with the rush hours on the public road when the number of motor vehicles is high. The CO levels at a location of about 300 m from the road had a high of 6 ppm and a low value of 3.5 ppm and did not have well defined peak perods. The levels tend to increase slightly from morning towards evening.

According to the World Health Organization report [17], CO concentrations of 26 ppm for 1 hour and 9 ppm for 8 hour exposure are harmful to human health. On the public road during the 10 hour monitoring period CO levels exceeded the 9 ppm threshold for two hours 45 minutes in the morning and evening peak periods. The CO levels had a maximum value of 18 ppm which was short of the set 26 ppm for 1 hour. Therefore, though the CO levels are higher that the safe limits, they did not last long enough to become harmful to human health. These results also prove that CO concentrations vary with location and time within a given region. Therefore when reporting on CO concentrations in a given region, location information is vital to help in identifying these local variations.

The system was also used to monitor CO emissions from the motor vehicle engine. The system was placed about 10cm from the opening of the exhaust pipe of different vehicles and data collected for a period of 15 minutes. The vehicles whose emissions were monitored are new Toyota Fielder petrol driven saloon car, a more than 10 year old Toyota Carina saloon car that uses petrol, an Isuzu bus that uses diesel and a TVS motorcycle. The results obtained are as presented in figure 10 below. The engine capacity of the saloon vehicles is 1500cc, the bus is over 4000 cc and the motor bike is 150cc.

The results obtained are presented in the graph in figure 9 above. The results show that of the three motor vehicle engines, the bus produces the highest CO emissions. The CO levels from the bus had a high of 81 ppm and a low of 76 ppm. The old saloon car CO emissions had a high of 52 ppm and a low of 45 ppm. The new saloon car had a high value of 36 ppm and a low value of 34 ppm. The motor bike recorded the lowest CO levels with a high of 6.5 ppm and a low of 5 ppm. The difference in CO emissions has been attributed to the engine capacity of the vehicles. The bus has an engine capacity of over 4000 cc, followed by the saloon car which has an engine capacity of 1500 cc and lastly the motor cycle has an engine capacity of 150cc. The difference in CO levels between a new saloon car and an old saloon car has been caused by the condition of the vehicle. The new saloon car is in good mechanical condition unlike the old saloon car.

5.3 Testing the response of the GPS receiver

Since CO levels have been found to be dependent upon the time and location, a GPS receiver has been included in design. It gives the latitude, longitude and time CO concentrations have been monitored. This information enables the study of how CO varies with time and location. The designed system provides this information as displayed in figure 10 below.

5.4 Results from the GSM modem

The GSM modem was used in the transmission of the collected data to a central office predefined as mobile phone number. This is dependent on the availability of network coverage from the service providers. When the system was tested it was found to send all the data periodically as displayed in figure 10.

```
T=25.0*C H=49.0%
Time13:13:51
CO Valueis12PPm
Location is01.10 DegreesS and036.55 DegreesE
```

```
T=25.0*C H=50.0%
Time13:15:09
CO Valueis14PPm
Location is01.10 DegreesS and036.55 DegreesE
```

```
T=26.0*C H=53.0%
Time13:16:27
CO Valueis14PPm
Location is01.10 DegreesS and036.55 DegreesE
```

Figure 10: A sample of the SMS received by a mobile phone from the GSM modem

6. CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

A simple and cheap microcontroller based carbon monoxide monitoring and mapping system has been designed, fabricated and tested. The main components of the system are a microcontroller (PIC18F45K22), carbon monoxide gas sensor (TGS2442), a temperature and humidity sensor (DHT11), a GPS receiver module and a GSM modem. The control software based on C programming language has also been designed and tested.

The PIC18F45K22 microcontroller has been used to acquire inputs from the TGS2442 sensor and DHT11 sensors. Interfacing the GPS receiver module to the microcontroller through the EUSART module was also achieved making it possible to get location information from the GPS module. The system was therefore able to report real time CO levels, temperature, humidity, latitude, longitude and time.

The designed system has demonstrated the capture of CO concentration, temperature and humidity data in real time and displayed it locally and also sent via GSM to a central office as a text message.

6.2 Recommendations

The system could be extended to include other air pollutants such as carbon dioxide and nitrogen dioxide by employing several sensors. The PIC18F45K22 microcontroller would be ideal for multiple analogue sensors since it has 30 analogue to digital channels. In addition a website can be developed that shows carbon monoxide concentrations and certain hotspots within a town. The designed system can also be used to study how CO varies with height above the ground by taking CO measurements at the same location but different heights above the ground.

7. ACKNOWLEDGMENTS

I thank the Almighty God who, through his mercies and love, gave me good health and strength to handle the challenges that I faced during the period of study. I salute my parents the late William Shuma and Catherine Lugasi for taking me to school and the support they gave me.

My appreciation also goes to Kenyatta University for giving me an opportunity to undertake my research at the university. I also acknowledge the work of my supervisors Professor Elijah Mwangi and Dr. Patrick Karimi., who tirelessly read and corrected my work. Their input, critique, valuable suggestions and encouragement throughout this research is highly recognized. I extend the same to the lecturers and technical staff in the Physics Department for their immense support. Special acknowledgement is accorded to the National Commission for Science, Technology and Innovation (NACOSTI) for offering me a grant that assisted to carry out my research work.

Special thanks are also given to my postgraduate colleagues: Francis Kamau, Jared Maato, Wycliffe Nyaberi, Reuben Shikambe, Shadrack Muthoka among others for their support and encouragement throughout the research period. Our thanks to the experts who have contributed towards development of the template.

8. REFERENCES

[1] Chandra A. C. D., and Vidyabharathy J., (2014). Wearable Carbon Monoxide Warning System Using Wireless Sensors; Journal of Electronics and Communication Engineering ISSN: 2278-8735.Volume 9, Issue 2, Ver. VIII, PP 25-29; http:/ www.iosrjournals.org

[2] Dubey A., Shamshad M., and Patel K. (2013). Design and Implementation of Pollution Monitoring and Recording System Using Microcontroller; e-Journal of Science & Technology http://e-jst.teiath.gr (5), 8, 2013.

[3] Environmental Protection Agency (2000)

[4] Hedgehock W., Volgyesi P., Ledeczi A., Koutsoukos X. and Aldroubi A. (2010) Mobile Air Pollution Monitoring Network. Institute for Software Integrated Systems - Vanderbilt University Nashville, TN, USA 37203

[5] http:/ www.droboticsonline.com [Accessed March 205]

[6] http://www.electronicshub.org/difference-between-microprocessor-and-microcontroller [Accessed January 2015]

[7] http:/ www.figaro.co.jp/en/tecnicalinfo/principle/mos-type.html

[8] Mohammed A. H. (2012). Using inexpensive home alarm for computer based carbon monoxide monitoring. Asian Transactions on Engineering (ATE ISSN: 2221-4267) 02: 02

[9] Odhiambo G. O., Kinyua A. M., Gatebe C. K. and Awange J. (2010). Motor Vehicles Air Pollution in Nairobi, Kenya; Research Journal of Environmental and Earth Sciences 2 (4): 178-187, 2010

[10] Ofoegbu O. E. (2014). A Microcontroller Based Data Acquisition System For Industrial Air Pollution Concentration Measurement In Nigeria; Journal Of Multidisciplinary Engineering Science AND Technology Vol. 1 Issue 3, http:www.jmest.org

[11] Patil S. S. and Jaykaran S. (2015). Monitoring and Controlling of Hazardous Gases inside Vehicle and Alerting Using GSM Technology; International Journal of Advanced Research in Computer Science and Software Engineering www.ijarcsse.com ISSN: 2277 128X Volume 5, Issue 1

[12] Pokhsraryan D., Vladimir A., Chilingaryan H. (2010). Gas monitoring system Armenian Journal of Physics, 2010, vol. 3, issue 1, pp. 78–81

[13] Rudman P., North S. and Chalmers M. (2005). Mobile pollution mapping in the city. In Proceedings of the UK-UbiNet workshop on eScience and ubicomp.

[14] Schreiner C., Branzila M., Trandabat A. and Ciobanu R.C. (2006). Air Quality And Pollution Mapping System, Using Remote Measurements And Gps Technology. Global NEST Journal, Vol 8, Pg. 315-32.

[15] Technical Information for Carbon Monoxide Sensors (2007) http:// www.figarosensor.com [accessed September, 2012].

[16] Vidap R., and Shahane G. (2015). Development and implementation of arm microcontroller based co gas monitoring system; International Journal of Advances in Engineering & Technology, ISSN: 22311963; Vol. 8, Issue 5, pp. 783-793

[17] World Health Organization (2004) Environmental Health Criteria. 2nd Edition, Vol. 213, Carbon Monoxide.

[18] Yadagiri R. Y. and Abu B. M. (2012). Design and fabricated model of an improved emission monitoring and warning system for automobiles. International Journal of Scientific & Engineering Research 3:7, July-2012 1 ISSN 2229-5518