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DESIGN OF A PARTICULATE MATTER AND CARBON MONOXIDE DETECTOR (PCD)

BY

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APPROVAL

THIS PROJECT REPORT HAS BEEN APPROVED FOR ACCEPTANCE BY THE MECHATRONICS ENGINEERING DEPARTMENT, FEDERAL UNIVERSITY OYE-EKITI AND MEETS THE REGULATIONS GOVERNING THE AWARD OF BACHELOR OF ENGINEERING OF FUOYE.

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DEDICATION

Firstly, I thank almighty Allah for the all-round success recorded in this project and I dedicate this project to my parents for their countless support and efforts on me throughout this journey. Furthermore, I also dedicate this project to the staffs and students of the department of mechatronics engineering, FUOYE.

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ABSTRACT

Air pollution has been a subject of concern in every society in this generation due to its immense contribution to numerous calamities that is befalling our environments. The effects of this air pollution has brought about series of damages to both human and environment posing to be one of the most dangerous problem of our age which calls for immediate action. Air pollution detectors are the devices used to monitor these pollutants for proper control and regulation. The aim of this project is to design a particulate matter (PM) and carbon monoxide (CO) detector (PCD) with low-cost, highly sensitive devices which will detect the presence PM and CO pollutants in the atmosphere and trigger an alarm when the level of Carbon monoxide is above safe level (WHO standard). NOVA SDS011 and MQ135 were used as PM and CO sensors respectively, 20 x 4 LCD was used as the display unit with a buzzer as the alarm device which is powered on when the pollutant level is high. The device utilizes Arduino Uno R3 as microcontroller for controlling the operation of the device. The device displays the Particulate Matter and Carbon monoxide levels in the atmosphere and triggers a buzzer when the CO level is above the safe level.

CHAPTER ONE

1.0 INTRODUCTION

Air pollution is perceived as a modern day curse: a by-product of urbanization and civilization. It has a long and evolving history with interesting transitions in line with economic, technological and political change, over the years, air pollution has drawn a lot of interest in terms of research and everyday life (Roser & Max, 2017). Air pollution can be grouped into two categories (outdoor or ambient air and indoor air pollution), deaths yearly as result of exposure to ambient air is estimated to be 4.2million while estimated mortality rate as a result of exposure to indoor air pollution from dirty cook stoves and fuels are 3.8million and was also reported that 91% of the world's population lives in places where the air quality exceeds World Health organization(WHO) standard (world Health organization , 2018).

According to the Annual state of the Global Air report published by the Health Effects Institute (HEI) in 2016, air quality in Nigeria has the highest burden of fatalities in Africa and the 4th highest in the world (the first three being Afghanistan with 406, Pakistan with 207 and India with 207) with 150 deaths per 100,000 people attributable to pollution. Nigeria and at least 10 other countries is among the deadliest anywhere on Earth with higher than ambient air pollution death rates as a result of environmental hazards combined with extreme pollution sources like generator fumes, vehicle emissions and crop burning among others. (Ogundipe, 2016)

Air pollution is caused by harmful particles and gases, released in high quantities in air. These pollutants cause diseases such as lungs cancer, stroke, Ischaematic heart disease, pneumonia, asthma and death to humans, damage to other living organisms such as animals and food crops and also harm the ecosystem (mohammed, 2018). Air pollution is not only harmful to the environment but, also to all other living beings on earth including plants and sea organisms (Divan, 2014).

Atmospheric pollution detectors are indoor and outdoor devices that use sensors to detect and to measure the presence of air pollutants in the surroundings. These detectors after measuring the Air Quality (AQ) of the surroundings reports the results to the operators and also gives warning to the inhabitants when the AQ is poor or hazardous to human health. Traditionally, air pollution situation is monitored by conventional air pollution monitoring systems with stationary monitors. These monitoring stations are highly reliable, accurate and able to measure a wide range of pollutants by using the conventional analytical instruments, such as gas chromatograph-mass spectrometers.

Modern miniaturized and low cost sensors of various types are now available due to technological advancement and some are used in special areas, they are becoming more affordable and available throughout the population (Environmental science, 2015). Most of these sensors detect ozone, particulate matter, carbon monoxide, sulfur dioxide and nitrous oxides. These gas sensors are made of Semiconductors and have been optimized for more than thirty years giving them a high sensitivity for certain gas detection, a fast response time of up to several seconds, a small size, low cost compared to other types of sensors, and ease of use in electronic systems which make them attractive cheap consumers devices (Barakeh, et al., 2016). Emerging low-cost sensors offer the opportunity to monitor air pollution with much greater spatial resolution; these Low-cost sensors are available for many pollutant gases, such as electrochemical sensors for nitrogen dioxide, carbon monoxide, oxides of sulfur and ozone. Low-cost sensors that measure particulate matter (PM) are also available, where mass concentration is typically based on the amount of light scattered by the airborne particles.

Combinations of these low-cost sensors are increasingly deployed in densely distributed sensor networks to provide greater spatial resolution than traditional networks (Caubel, et al., 2018).

The sensors for the measurement of gaseous pollutants belong to one of the following technologies: Amperometric (metal oxide—MO) sensors, electronic circuitry (electrochemical—EC) sensors, and non-dispersive IR (NDIR) sensors. The sensors for measuring the concentration of airborne particles include capacitive solid state sensors, miniaturized optical particles counters (OPCs), detectors of radiation absorption, or particle spectrometers. Depending on the sensor technology and algorithm, these sensors enable us to measure the particle number concentration (PNC) or the particulate mass concentration (particulate matter—PM). The emergence of these relatively low-cost sensor technologies opened new applications for air pollution data gathering beyond the regulatory and scientific uses. Such applications include the empowerment of citizens by providing them with quantitative information about pollutant levels in their vicinity, facilitating the measurement of indoor air quality at home and/or in public spaces, enabling measurement by mobile/personal/wearable sensors rather than only by stationary high-end instruments (Broday & Collaborators, 2017).

1.1 AIM AND OBJECTIVES

The aim of this project is to design and fabricate a hand-held device for detection of pollutants; CO (carbon monoxide) and Particulate matter (PM) in the atmosphere. The design is to be applicable for both indoor and outdoor detection. To achieve this aim, the objectives are to;

i. design a microcontroller based pollution detector; having an interface to communicate in real time the air quality to the users; and

ii. Test the device for effectiveness.

1.2 PROBLEM STATEMENT

Atmospheric pollution is increasing nationwide at an alarming rate, the effects of this pollution is beyond just environmental degradation because both the people and the environment are being affected by it. According to the United States of America's Environmental Protection Agency (US EPA), the six common air pollutants are particulate matter, ground-level ozone, carbon-monoxide, sulfur oxides, nitrogen oxides, and lead (EPA, 2017).

The evaluation of the effects of air pollution on public health and human-wellbeing requires reliable data. Standard air quality monitoring stations provide accurate measurements of airborne pollutant levels, but, due to their sparse distribution, they cannot capture accurately the spatial variability of air pollutant concentrations within cities. Dedicated in-depth field campaigns have dense spatial coverage of the measurements but are held for relatively short time periods. Hence, their representativeness is limited. Moreover, the oftentimes integrated measurements represent time-averaged records (Broday & Collaborators, 2017)

The effects of six of the most common pollutants as stated be United States Environmental Protection Agency (EPA) are shown in the table below (Yi, et al., 2015);

Table 1.1: **The six common pollutants**

Pollutants	Health effects
Carbon Monoxide (CO)	Reducing oxygen capacity of the blood cells leadsto reducing oxygen delivery to the body's organs and tissues. Extremely high level can cause death.

Nitrogen Dioxide (NO_2)	High risk factor of emphysema, asthma and bronchitis diseases. Aggravate existing heart disease and increase premature death.
Ozone (O_3)	Trigger chest pain, coughing, throat irritation and congestion. Worsen bronchitis, emphysema and asthma.
Sulfur Dioxide (SO_2)	High risk factor of bronchoconstriction and increase asthma symptoms.
Particulate Matter (PM2.5 & PM10)	Cause premature death in people with heart and lung diseases. Aggravate asthma, decrease lung function and increase respiratory symptoms like coughing and difficulty breathing.
Lead (Pb)	Accumulate in bones and affect nervous system, kidney function, immune system, reproductive systems, developmental systems and cardiovascular system. Affect oxygen capacity of blood cells

In order to prevent the escalation of the effects of air pollution in the environment, certain preventive and measures must be carried out; effective and efficient low-cost pollution detectors must be made available in our environment for both indoor and outdoor use which should be fostered by certain government policies which must be enforced to mitigate the release of pollutants into the environment. Furthermore, the adverse effects of Particulate matter pollutants and carbon monoxide aided with their invisibility qualifies the two pollutants as the deadliest types since we are exposed to it in our daily activities.

The inability of stationary pollution monitoring stations, necessitates the need to make these pollution detectors portable and available for personal and general use in all part of the city and all over the world.

CHAPTER TWO

2.0 LITERATURE REVIEW

Air pollution detection devices have been a subject of interest over the years as a result of its impact on man and its environment. Several researches have been carried out on different materials to produce low-cost pollutant sensors with deferent mode of operation and target pollutants;

A review published by (Spinelle, et al., 2017) depicts the current state of commercially available sensors for the detection of VOCs (volatile organic compounds) in both outdoor and indoor air over a high range of concentrations. In particular, it describes the main technologies (electrochemical, non-dispersive infrared, pellistor and photoionization) and give a list other types supported by numerous references and some metrological parameters (range, accuracy, resolution, sensitivity and response time) based on the information available from the manufacturer. The authors concluded that the current sensors technologies present advantages, in particular economic advantage. However, the sensors face limitations, such as too high limit of detection or poor selectivity and also interference of signals.

2.1.0 Mobile and stationary monitoring networks

(Mead, et al., 2012) argued that; measurements at appropriate spatial and temporal scales are essential for understanding and monitoring spatially heterogeneous environments with complex and highly variable emission sources, such as in urban areas as against the traditional stationary monitoring stations. In the article it was proven that miniature, low-cost electrochemical gas sensors, traditionally used for sensing at parts-per-million (ppm) mixing ratios can, when suitably configured and operated, be used for parts-per-billion (ppb) level studies for gases relevant to urban air quality. In the paper, evidence for the performance of electrochemical sensors at the parts-per-billion level were provided, and then outline results obtained from deployments of networks of sensor nodes in both an autonomous, high-density, static network in the wider Cambridge (UK) area, and as mobile networks for quantification of personal exposure. The electrochemical sensors used for the study were low-power, robust and low-cost, and are based on widely understood amperometric sensor methodologies designed for sensing selected toxic gases at the parts-per-million-level in the industrial environment. The widely varying mixing ratios reported by the study confirmed that the urban environment cannot be fully characterized using sparse, static networks, and that measurement networks with higher resolution (both spatially and temporally) are required to quantify air quality at the scales which are present in the urban environment. Similarly, (Broday & Collaborators, 2017) was also of the view that Standard air quality monitoring stations provide accurate measurements of airborne pollutant levels, but, due to their sparse distribution, they cannot capture accurately the spatial variability of air pollutant concentrations within cities. in his report, data streams from eight cities (Barcelona, Belgrade, Edinburgh, Haifa, Oslo, Ljubljana, Ostrava and Vienna) across Europe was summarized. Overall, few sensors showed an exceptional and consistent performance, which can shed light on the fine spatiotemporal urban variability of pollutant concentrations. The result also showed that Stationary sensor nodes were more reliable than personal nodes. In general, the sensor measurements tend to suffer from the interference of various environmental factors and require frequent calibrations which calls for the development of suitable field calibration procedures, and several such in situ field calibrations are presented.

(Thompson, et al., 2016) developed a field portable device for logging $PM_{2.5}$ mass concentration data; the device combines the Arduino microprocessor with an SD card, a Sharp DN7C3CA006 optical dust monitor, and 10,000 mAh battery. The $PM_{2.5}$ dust sensor used a virtual impactor to size select particles prior to illuminating them with an LED. The LED is triggered by a circuit controlled with the Arduino. Nephelometric detection at 120° referenced to incidence is employed. The voltage signal reported by the dust sensor is converted to $PM_{2.5}$ mass through calibration onboard the Arduino. For a 60 s average, the $PM_{2.5}$ mass limit of detection was 9 $\mu g/m^3$ indicating the sensor will be useful for monitoring human exposure to fine particles.

(Barakeh, et al., 2016) designed three identical portable autonomous sensors arrays each containing nine commercial semiconductor sensors especially chosen to detect a large range of pollutants usually encountered in ambient air and for a large part of them regulated. In order to overcome the temporal instability and the lack of reproducibility of these sensors, a calibration and normalization procedure was developed. The obtained systems were used for on-site pollution monitoring in association with the French National Network of Accredited Associations for Air Quality Monitoring (AASQA). Gathered data from sensors systems and network data (NO, NO2, CO, PM2,5, PM10) were treated using nonlinear regression algorithms like Neural Networks with an original "fuzzy logic" type pre-treatment in order to compute a model able to predict the membership degree for three predefined pollution categories: traffic, urban and photochemical pollution, along with a pollution index describing the severity of the predominant pollution. The prediction rate was estimated system per system, and site per site for six sites.

(Caubel, et al., 2018) designed Aerosol Black Carbon Detectors (ABCD), which consists of a compact weatherproof enclosure, solar-powered rechargeable battery, and cellular communication to enable long-term, remote operation. The ABCD belongs to a class of instruments known as aerosol absorption photometers, which include the particle soot absorption photometer, the Aethalometer, and the multi-angle absorption photometer. These instruments measure the light absorption of ambient PM collected on a fibrous filter. The ABCD converts measured light absorption to BC (Black Carbon) mass concentration in the sampled air flow. The central component of the ABCD is the optical cell, is drawn into the cell with a rotary vane pump, and through two Teflon-coated glass-fiber filters that lie between light emitting diodes (LEDs) and photodiodes. The paper also demonstrates a data processing methodology that reduces the ABCD's sensitivity to ambient temperature fluctuations, and therefore improves measurement performance in unconditioned operating environments (e.g., outdoors). A fleet of over 100 ABCDs was operated outdoors in collocation with a commercial BC instrument housed inside a regulatory air quality monitoring station.

(Mukherjee, et al., 2017) equally examined the performance of two models of PM sensors, the AirBeam and the Alphasense Optical Particle Counter (OPC-N2), over a 12-week period in the Cuyama Valley of California, where PM concentrations are impacted by wind-blown dust events and regional transport. The sensor measurements were compared with observations from two well-characterized instruments: the GRIMM 11-R optical particle counter, and the Met One beta attenuation monitor (BAM). Both sensor models demonstrated a high degree of collocated precision (R2 = 0.8–0.99), and a moderate degree of correlation against the reference instruments (R2 = 0.6–0.76). Sensor measurements were influenced by the meteorological environment and the aerosol size distribution.

(Divan, 2014) designed a vehicle emission monitor and control device, since vehicle being an integral part of every one's day life contributes 30% of the atmospheric pollution apart from industries, majority of which are COx and NOx which are production of combustion. These gases are easily monitored with the help of semi-conductor devices where he used MQ-7 gas sensor for COx emission monitoring. The device was used to monitor the emissions from the vehicle and when the emission is above the safe level, the alarm is powered.

(kulkarni & Teja, 2014) designed a pollution control circuit. The pollution control circuit consists of various sensors like smoke sensor, temperature sensor and GSM, GPS kind of devices, and all of them are integrated and connected to a Controller. It is a real time work where a demo application has been made in which ARM 7 processor is used and a controller board is made where all these devices get integrated and work accordingly. The vehicle is controlled by this circuit. When a vehicle attains certain threshold pollution level then the engine gets automatically switched off and an SMS is generated and sent to the pre-defined number stored in the memory through the GSM module. The GPS module is used to locate the vehicle position where it is halted.

2.1.1 Wireless Pollution detection network and machine learning

Machine Learning (ML) is the process that automatically improves or learns from the study or experience, and acts without being explicitly programmed. This makes computing processes more efficient, reliable and cost-effective. ML produce models by analyzing even more complex data automatically, quickly and more accurately. It is mainly classified into supervised learning, unsupervised learning, semi-supervised learning and reinforcement learning. (Kumar, et al., 2018).

(Shah, et al., 2014) released an article on machine learning (ML) concepts of Wireless Sensor Networks (WSNs), in the report it was stated that one of the major design challenges in WSNs is minimizing consumed energy at the sensor in order to make efficient usage of limited energy of the sensor nodes, a number of routing schemes were designed part off which include; clustering technique hierarchical routing protocols which greatly reduce energy consumed in collecting and disseminating data but it is ineffective when a large amount of data is to be transmitted, which makes Machine learning the solution for WSNs. The paper explores numerous advantages of ML such as in energy efficient routing and many more. Similarly (Kumar, et al., 2018) also carried out a survey on the application of Machine Learning (ML) techniques to Wireless Sensor Networks (WSNs) operation. In the report, various ML-based algorithms for WSNs with their advantages, drawbacks, and parameters effecting the network lifetime were presented with ML algorithms for synchronization, congestion control, mobile sink scheduling and energy harvesting.

(Saad, et al., 2017) designed an Indoor Air Quality Monitoring System (IAQMS), where the few sources of Indoor Air Pollution(IAP) was discussed such as; cleaning products, construction activities, perfumes, cigarette smoke, water-damaged building materials and outdoor pollutants. His design was based on a sophisticated indoor air quality (IAQ) monitoring system which could classify the specific type of pollutants is very helpful. This study proposes an enhanced indoor air quality monitoring system (IAQMS) which could recognize the pollutants by utilizing supervised machine learning algorithms: multilayer perceptron (MLP), K-nearest neighbor (KNN) and linear discrimination analysis (LDA). Five sources of indoor air pollutants were tested: ambient air, combustion activity, presence of chemicals, presence of fragrances and presence of food and beverages. The results showed that the three algorithms (MLP, KNN and LDA) successfully classify the five sources of indoor air pollution (IAP) with a classification rate of up to 100 percent. An MLP classifier with a model structure of 9-3-5 was embedded into the IAQMS. The system was tested with all sources of IAP (: ambient air, combustion activity, presence of chemicals, presence of fragrances and presence of food and beverages) presented together. The result shows that the system is able to classify when single and two mixed sources are presented together. However, the system cannot classify more than two sources at a time.

(Yi, et al., 2015) experimented on the concept termed The Next Generation Air Pollution Monitoring System (TNGAPMS) and achieved significant breakthroughs by utilizing the advance sensing technologies, MicroElectroMechanical Systems (MEMS) and Wireless Sensor Network (WSN). However, some potential problems of these newly proposed systems include; the lack of 3D data acquisition ability and the flexibility of the sensor network were highlighted and discussed in the paper. The existing works were classified into three categories which are; Static Sensor Network (SSN), Community Sensor Network (CSN) and Vehicle Sensor Network (VSN) based on the carriers of the sensors. However, at the end of the research, it was concluded that some of the current abilities of the current-state-of-art of the sensors such as Lack of 3-Dimensional Data Acquisition Ability, Infeasibility of Active Monitoring and Uncontrolled or Semi-Controlled Carriers must be implemented into TNGAPMSs and abilities such as Mobility of Carriers, Feasibility of Maintenance, Add-on Sensor Ability and spatio-temporal resolution need to be addressed for a better TNGAPMSs.

(Wu, et al., 2017) designed a field-portable cost-effective platform for high-throughput quantification of particulate matter using computational lens-free microscopy and machine-learning. The platform was termed c-Air and was integrated with a smartphone application for device control and display of results. The mobile device (c-Air) rapidly screens 6.5 L of air in 30 s and generates microscopic images of the aerosols in air. It provides statistics of the particle size and density distribution with a sizing accuracy of ~ 93%. We tested this mobile platform by measuring the air quality at different indoor and outdoor environments and measurement times, and compared our results to those of an Environmental Protection Agency–approved device based on beta-attenuation monitoring, which showed strong correlation to c-Air measurements. Furthermore, c-Air was used to map the air quality around Los Angeles International Airport (LAX) over 24 h to confirm that the impact of LAX on increased PM concentration was present even at 4 7 km away from the airport, especially along the direction of landing flights. With its machine learning-based computational microscopy interface, c-Air was adaptively tailored to detect specific particles in air, like various types of pollen and mold and provide a cost-effective mobile solution for highly accurate and distributed sensing of air quality.

The design in prospect is a Particulate Matter and Carbon Monoxide Detector (PCD) which will bridge the gap of unawareness of the high exposure level of the pollutants in this environment. Numerous households, offices and public places are exposed to these pollutants regularly but due to the fact their level of awareness is moribund and these pollutants are invisible, they have cause severe problems.

2.2 Existing Products

2.2.1 Air Quality Egg

Fig 2.1: Air quality Egg

Air quality egg is a crowd sponsored air quality monitor from 2012. It is designed to measure several aspects: nitrogen dioxide (NO_2), carbon monoxide (CO), temperature and humidity. It is also expandable if other inter-integrated circuit (I^2C) sensors need to be added.

The sensor is networked and data is intended to be shared to form a community driven monitoring of air quality. A map on their site allows viewing of all the online eggs to see air quality in some area. This is a great idea and ideally could be integrated into this product, or the system could be adapted to appear as an air quality egg.

Sensors used: E2V MiCS-5525 heated CO, and MiCS-2710 heated NO_2, and DHT-22 for temperature/humidity. O_3, SO_2, and particulate models are also available, but are not integrated into a single unit. Carbon monoxide and NO_2 are given in parts per billion (ppb) values, typical readings from the device are from 1,100 to 15,000 ppb.

Sensors do not come calibrated, and I wanted to avoid the cost and complexity of calibrating heated sensors in this project. I would not be comfortable relying on using uncalibrated sensor data to report air quality health aspects to a user.

The cost of the egg is $280, which is a good target budget for my device. It is in the range of a consumer purchase, but not too low to sacrifice by using lower cost and accuracy sensors (price, 2017).

2.2.2 Xiaomi PM2.5 Sensor

Fig2.2: Xiaomi's particulate sensor

Xiaomi Mi PM2.5 sensor is a compact and portable particulate matter sensor, with integrated fan and rechargeable battery. Xiaomi is a Chinese company, and China is widely reported as having air quality issues, particularly with particulate matter. So, it can be seen why this low cost single use design was brought to the market. It is available for under $120. The Mi is an example of modern consumer design, and would be something to strive for in a finished product (price, 2017).

The AQ standard by the most common Environmental protection Agencies such as United States of America Environmental Protection Agenct (EPA), World Health Organization (W.H.O), Ministry of Environmental Protection (MEP) of the People's Republic of China, European Commission (EC) and Environmental protection Department of Hong Kong (EPD) worldwide is given in the next figure (Yi, et al., 2015) ;

Table 2.1: **The AQ standards for the six common pollutants**

Pollutant	**EPA**	**WHO**	**EC**	**MEP**	**EPD**
Carbon Monoxide (CO)	9 ppm (8 h) 35 ppm (1 h)	100 mg/m3 (15 min) 15 mg/m3 (1 h) 10 mg/m3 (8 h) 7 mg/m3 (24 h)	10 mg/m3 (8 h)	10 mg/m3 (1 h) 4 mg/m3 (24 h)	30 mg/m3 (1 h) 10 mg/m3 (8 h)
Nitrogen Dioxide (NO2)	100 ppb (1 h) 53 ppb (1 year)	200 µg/m3 (1 h) 40 µg/m3 (1 year)	200 µg/m3 (1 h) 40 µg/m3 (1 year)	200 µg/m3 (1 h) 80 µg/m3 (24 h) 40 µg/m3 (1 year)	200 µg/m3 (1 h) 40 µg/m3 (1 year)
Ozone (O3)	75 ppb (8 h)	100 µg/m3 (8 h)	120 µg/m3 (8 h)	200 µg/m3 (1 h) 160 µg/m3 (8 h)	160 µg/m3 (8 h)
Sulfur Dioxide (SO2)	75 ppb (1 h) 0.5 ppm (3 h)	500 µg/m3 (10 min) 20 µg/m3 (24 h)	350 µg/m3 (1 h) 125 µg/m3 (24 h)	500 µ g/m3 (1 h) 150 µg/m3 (24 h) 60 µg/m3 (1 year)	500 µg/m3 (10 min) 125 µg/m3 (24 h)
Particulate	PM2.5	25µg/m3 (24 h)	25 µg/m3 (1	75µg/m3 (24 h)	75 µg/m3(24

Matter	35µg/m3 (24 h) 12 µg/m3 (1 year)	10 µg/m3 (1 year)	year)	35 µg/m3 (1 year)	h) 35 µg/m3 1 year)
	PM10 150 µg/m3 (24 h)	50 µg/m3 (24 h) 20 µg/m3 (1 year)	50 µg/m3 (24 h) 40 µg/m3 (1 year)	150 µg/m3 (24 h) 70 µg/m3 (1 year)	100 µg/m3 (24 h) 50 µg/m3 (1 year)
Lead (Pb)	0.15 µg/m3 (3 month)	0.5 µg/m3 (1 year)	0.5 µg/m3 (1 year)	1 µg/m3 (3 month) 0.5 µg/m3 (1 year)	1 µg/m3 (3 month) 0.5 µg/m3(1yr)

2.3 PARTICULATE MATTER

Particulate matter is present in abundance in the modern environment, and is recently being acknowledged as a major factor for health. In urban areas, greater access to technology extends life, but the emissions from this tech (automobiles, factories) counteract this. Particles are measured in reference to their sizes; PM10 refers to particles with a median diameter of 10µm. PM2.5 particles have a median diameter of 2.5µm. These are believed to cause the greatest risk to health, as the tiny particles will lodge deep into the lungs. Source of fine particulate matter (0 - 2.5µm) can originate from combustion. In an electrical environment, this can occur during soldering. If care is not taken to select appropriate temperatures and adequate fume extraction is not present, particulate matter will be generated and easily enter the lungs Coarser particulate matter (2.5-10µm) can originate from grinding operations or dust from roads. Coarse matter is less likely to originate in an electronics workplace. However, it is possible when maintenance is performed on a dirty product, these particles could come loose and enter the air (such as in an electronics repair facility) PM2.5 has been shown to increase the risk of coronary events, and hardening of the arteries, known as atherosclerosis (Thomas P, 2017).

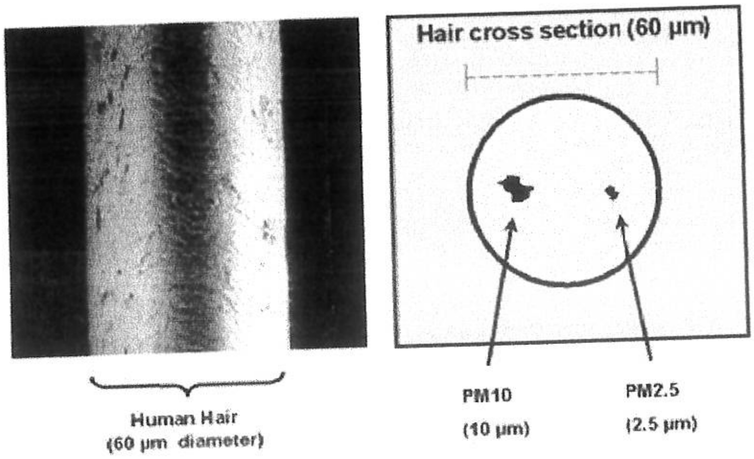


Fig 2.3 PM description

2.3.1 PARTICULATE MATTER LEVELS

There is no minimum recommended exposure level of PM2.5, all levels are dangerous. However, we must have some accepted level of harm, based on current science. The World Health Organization (WHO) guidelines state that cities with average annual PM2.5 exposures of 12µg/m3 and 15µg/m3 had significant increases in risk of health. Below that the uncertainty in risk widens, and is assumed to be safe at this time. Several other countries have set guidelines for reasonable exposure limits as well, and are listed in the next figure.

Table 1.2: PM2.5 particulate matter exposure limits

Country	Agency	Daily	Annual average
	WHO	25gg/m^3	10gg/m^3
Australia	NEPC	25gg/m^3	8gg/m^3
Canada	CCME	30gg/m^3	-
USA	EPA	35gg/m^3	12gg/m^3

Table 2.3: **PM10 particulate matter exposure limits**

Country	Agenc	Daily average	Annual average
	WHO	50gg/m^3	20gg/m^3
Australia	NEPC	50gg/m^3	-
Canada	CCME	No set limit	-
USA	EPA	150gg/m^3	-

However, despite the fact that there is no minimum level for PM exposure, the presence in the atmosphere is inevitable. Danger levels are being specified to signify the maximum exposure and the duration.

2.4.0 Carbon Monoxide (CO)

Carbon monoxide is an odorless colorless gas that can cause illness and death. CO is produced when burning fuel (oil, coal, wood, or gasoline) as well as incomplete combustion (such as smoking a cigarette). Low levels of CO will cause flu-like symptoms: tiredness, headaches, and weakness. High levels or long term exposure will cause dizziness, chest pain, vision issues, and difficulty thinking. Very high levels result in coma and death (price, 2017).

Table 2.4: carbon monoxide exposure levels and their symptoms.

CO concentration in Air	Inhalation Time and Symptoms
9 ppm	Maximum allowable concentration for short exposure in a living area.
50 ppm	Maximum allowable concentration for continuous exposure in any 8-hour period.
200 ppm	Headache, tiredness, dizziness and nausea after 2 to 3 hours.
400 ppm	Frontal headache within 1 to 2 hours and life threatening after 3 hours. Maximum allowable amount (air-free) in flue gases.
800 ppm	Dizziness, nausea and convulsions within 45 minutes. Unconsciousness within 2 hours. Death within 2 to 3 hours.
1,600 ppm	Headache, dizziness and nausea within 20 minutes. Death within 1 hour.
3,200 ppm	Headache, dizziness and nausea within 5 to 10 minutes. Death within 30 minutes.
6,400 ppm	Headache, dizziness and nausea within 1 to 2 minutes. Death within 10 to 15 minutes.
12,800 ppm	Death within 1 to 3 minutes.

The table above highlights various CO ppm levels and their respective impacts on health. The primary method of carbon monoxide (CO) toxicity is hypoxia. When inhaled, it is absorbed in the lungs and binds with hemoglobin at an affinity 234 times that of oxygen. This causes a greatly reduced level of oxygen in the blood (hypoxia). Additionally, CO reduces the oxygen release rate into the cells, a potent combination (Townsend, 2002).

2.4.1 Health Impacts of Carbon Monoxide (CO) at low levels

Table 2.5: **Carbon monoxide health Impacts**

CO level	Action
0.1 ppm	Natural atmosphere level or clean Air
1 ppm	An increase of 1 ppm in the maximum daily one-hour exposure is associated with 0.96 percent increase in the risk of hospitalization from cardiovascular disease among people over the age of 65.
3 – 7 ppm	Increase in the rate of admission in hospitals of non-elderly for asthma.
5 – 6 ppm	Significant risk of low birth weight if exposed during last trimester of pregnancies.
9 ppm	EPA and WHO maximum outdoor air level, all ages (2hrs). Lowest CO level producing significant effects on cardiac function.
10 ppm	Significant increase in heart disease deaths and hospital admission for congestive heart failure.
15 - 20 ppm	World health Organization lists it as causing impaired performance, decrease in exercise capability, and shorten time to angina response and vigilance element.
20 ppm	Typical concentration in flue gases (chimney) of a properly operating furnace or water heater boiler.
25 ppm	Chronic exposure during pregnancy to miniscule level of carbon monoxide damages the cells of the fatal brain, resulting in permanent impairment

27 ppm	Increase in cardiovascular complaints
30 ppm	Earliest onset of exercise induced Angina
35 ppm	The Level which most fire department require the fire fighters to put on their Oxygen mask. Maximum allowable outdoor concentration for one hour period in a year.
50 ppm	In healthy adults, CO becomes toxic when it reaches a level higher than 50ppm.

CHAPTER THREE

3.0 MATERIALS AND METHODOLOGY

The Particulate matter and Carbon Monoxide Detector (PCD) is aimed at monitoring Particulate matters and carbon monoxide pollutants in the atmosphere and also to detect adverse concentration of the mentioned pollutants in the atmosphere. In order for the device to function optimally, highly sensitive, low-power consuming and low cost devices must be used for the design, these brought about a thorough research about the devices to be used for the design.

Some Particulate Matter Detection Principles

- Tapered Element Oscillating Micro-Balance (TEOM) Analyzers

The TEOM analyzers are widely used in the conventional air pollution monitoring systems. The operation principle of TEOM is that the oscillation frequency of the tapered glass tube is proportional to the mass of the tube. The PMs deposited onto the tube will change the mass and oscillation frequency of the tube. By measuring the oscillation frequency change of the tube and the volume of air sampled, researchers are able to deduce the mass concentration (gg/m^3) of PM in ambient air.

Note that the air is sampled through a size selective inlet. For example, a PM10 size selective inlet rejects 50% (no design can reject 100%) of the particles with diameter more than 10 gm and let through particles with diameter of 10 gm and less. In order to eliminate the effect of humidity change, a heating element or a dryer is used.

- β-Attenuation Analyzers

The β -Attenuation Analyzers or β -Attenuation Monitors (BAM) are the most widely used PM measurement instruments in the conventional air pollution monitoring systems. The air is first sampled through a size selective inlet (PM10 or PM2.5) with or without heater/dryer that minimizes the water contained in the air. Then the air goes through a paper filter, which catches the PM. The paper filter with PM is exposed to β -attenuation source. After the measurement interval, researchers are able to deduce the mass of the PM on the filter by measuring the radiation intensity of the filter.

- Black Smoke Method

The black smoke technique collects the PM on a paper filter over 24 h period through a size selective inlet. The darkness of the paper filter is then measured by a reflectometer and converted to the PM's mass concentration. This kind of monitoring equipment is relative simple, robust and cost-efficient. However, the mass concentration is derived by measuring the darkness of the filter and the darkness of PM varies in different locations. This makes the darkness-to-mass coefficient change from time to time and location to location.

- Optical Analyzers

The optical analyzers utilize the interaction between the ambient PM and the imaging, laser or infrared light. These analyzers are small, lightweight and battery operated. Base on the optical principle, the optical analyzers can be classified into three categories, namely direct imaging, light scatting and light obscuration (nephalometer) analyzers.

Light Scatting:

This category of optical analyzers uses a high-energy laser as the light source. When a particle passes through the detection chamber that only allows single particle sampling, the laser light is scattered by the particle. A photo detector detects the scatting light. By analyzing the intensity of the scatting light, researchers can reduce the size of the particle. Also, the number of particle counts can be deduced by counting the number of detecting light on the photo detector. The advantage of this approach is that a single analyzer can detect particles with different diameters simultaneously (i.e., $PM_{2.5}$, PM_5 and PM10). However, the particle counts need to be converted to mass concentration by calculation (depends on the particle counts, particle types and particle shapes) and this will introduce errors that further affect the precision and accuracy of the analyzers.

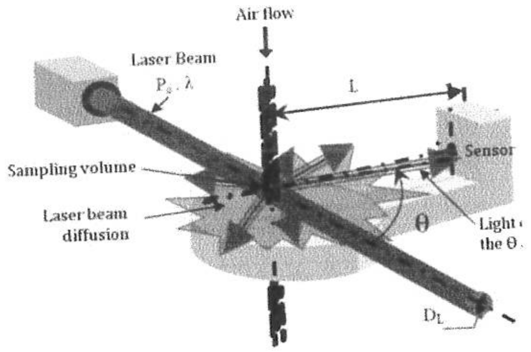


Fig 3.1: Laser beam particle detection

Direct Imaging:

In a direct imaging particle analyzer, a beam of halogen light illuminates the particles and the shadow of each particle is projected to a high definition, high magnification and high resolution camera. The camera records the passing particles. The video is then analyzed by computer software to measure the PM's attributes. Both size and counts of the PMs in the ambient air can be obtained. What's more, the color and the shape of the particles can also be detected.

Light Obscuration (Nephelometer):

This category of optical analyzers uses the fastest particle concentration (p g/m^3) measurement method with high precision and low detection limited. A nephelometer is an instrument that measures the size and mass concentration of PM in the ambient air. In a nephelometer, a near infrared LED is used as the light source and a silicon detector is used to measure the total light scattered (which is majorly responsible for the total light extinction) by the PMs (see Figure 6). By analyzing the intensities (in magnitude) of the scattered light and the shape of the scattering pattern, both the size distribution and the mass concentration can be determined right away. (Yi, et al., 2015)

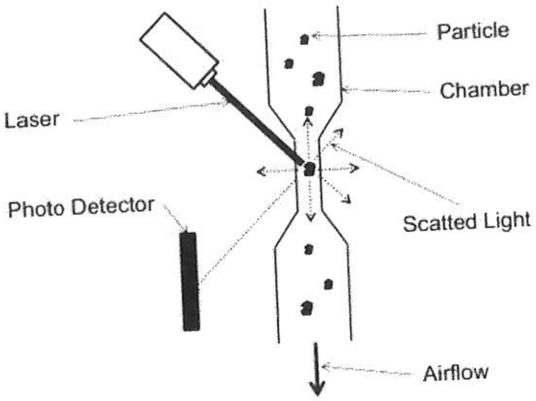


Fig 3.2: light scattering particle counter

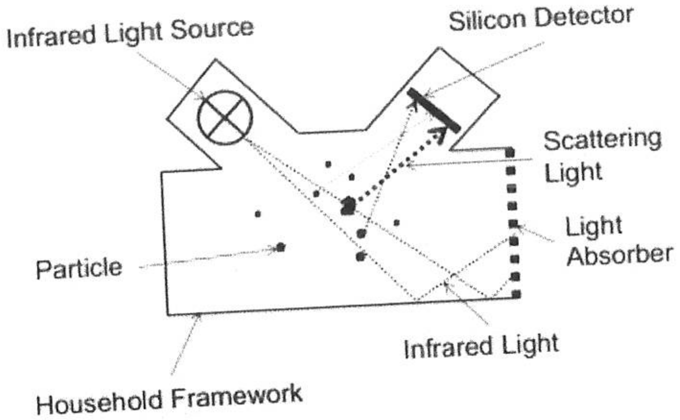


Fig3.3: Basic nephelometer

- Weight based measurement

Particles may be trapped by either a sticky pad, or a filter that will trap particles of desired size. Gravimetric analysis is used to determine how much particulate is deposited over a certain time (usually 24 hours). Air flow must be carefully controller or measured to ensure accuracy.

This method uses a large number of disposables (filters or pads) and would require daily manual measurements. This is not ideal for this project as our requirements are for a standalone device with live measurement viewable (for emergency purposes). It is unlikely PM levels would reach a dangerous level in normal circumstances, but live display may prompt users to turn on additional filtration or equip face masks (Price, 2017).

3.1.0 Comparison of four types of particulate matter (PM) measurement methods

Table 3.1: **PM measurement methods comparison**

Measurement method	Advantages	Disadvantages	Accuracy
Tapered Element Oscillating Microbalance (TEOM) analyzers	Provide real time (<1 h) data with high precision.	A heater must be used which leads to lose of semi-volatile material. Usually with large size, heavy weight and high cost.	±0.5 pg/m^3
B -attenuation analyzers (BAM	Provide real time (<1 h) data with high precision.	A radioactive source is used. If heater is used some semi-volatile material may be lost. Need to replace the paper filter periodically. Usually with large size, heavy weight and high cost.	±1.0 pg/m^3
Black smoke method	Simple, robust and inexpensive. Easy to maintain. Short sample time (in minutes).	Measure the darkness rather than the mass concentration of the particulate matters. Darkness-mass factor may change from time to time and location to location.	±2.0 pg/m^3, or higher
Optical analyzers	Small, light-weight and usually battery operated. Short sample time (in seconds or minutes). Can measure different sizes of particles simultaneously.	Depends on some assumptions of particle characteristics (e.g. Each particle is perfect bean-like shape). These assumptions may be different from time to time and location to location.	Depends on the analyzer type and usually not specifically declared by the manufacture.

3.2.0 Carbon Monoxide (CO) Measurement Methods

The common methods of carbon dioxide measurement are electrochemical and catalytic bead.

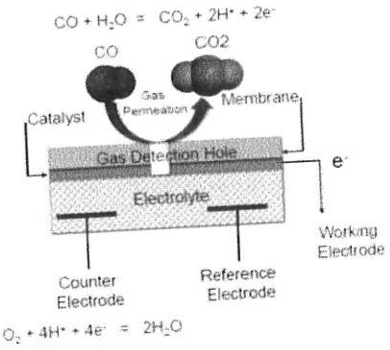


Fig 3.4: Carbon monoxide electrochemical sensor

In an electrochemical sensor, a small voltage is applied to the reference electrode with respect to the counter electrode, anywhere from 0 to a few hundred mV is common. The gas sensor produces and output current that is in proportion to the gas concentration. This current appears on the working electrode, and is converted to a voltage with a transimpedance amplifier.

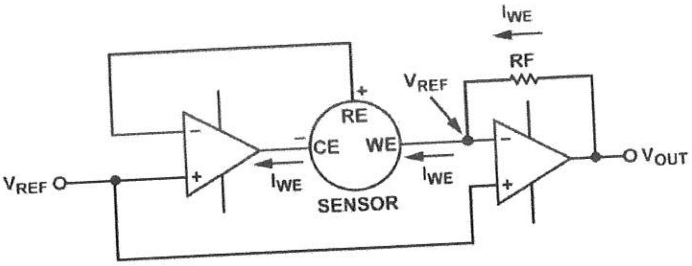


Fig 3.5: Transimpedance amplifier and sensor in the middle.

Gain of the transimpedance amplifier is set with a feedback resistor, and in the case of 3SP CO sensor, is 100kV/A. In this case, we can use a 100kQ resistor. This is a very sensitive amplifier, so provisions are taken to reduce noise. After the gas level is converted to a voltage, it can be processed into a digital signal with an ADC. Equation from user manual SDK17:

$$Cx = 1/M * (Vgas - Vref - Voffset)$$

Temperature compensation:

$$Cxc = 1/Mc * (Vgas - Vref - Voffset)$$

$$Mc = M*(1+Tc*(T-20))$$

M = sensor calibration factor, found on the sticker.

Common gas sensors (CO as well as VOC) operate with a suspended ceramic substrate in a metal can. They often run at high power (0.5 to 2W) and have limited lifespan. On the bottom of the substrate is a coil of nichrome wire, forming the heater. This is surrounded by AhO3 tubular ceramic, to handle the high temperature and act as an electrical insulator. On the top, two wires connect to a sensing circuit whose resistance varies with concentration of applied gas. This is due to the catalyst in the sensing bead allowing the compounds to oxidize, further heating the bead and changing its resistance. External circuitry is required to convert the resistance to a voltage that can be monitored on a microcontroller. Examples of this is the MQ-series gas sensors,

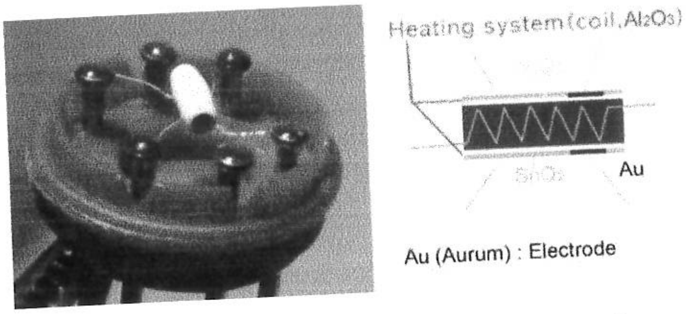


Fig 3.6: HeatedMQ3 gas sensor internal construction

The selected components for the design were;

- Arduino Uno R3 microcontroller
- NOVA PM sensor SDS011
- MQ135 gas sensor and
- 20 x 4 LCD

3.3.0 DESIGN IMPLEMENTATION

The pollution detection device is designed with an Arduino microcontroller programmed in C+ + on the Arduino IDE, the sensors and other peripherals that will be connected to the Arduino board includes; particulate Matter (PM) sensor, MQ135 (as Carbon dioxide) gas sensor, power supply, the display unit (LCD 20 x 4) and the buzzer as the alarm device. The MQ135 gas sensor generates an analog output of the CO level in the atmosphere, therefore its output pin connected to the Analog port (A0) of the Arduino Microcontroller, the SDS011 PM sensor is a digital device with its own inbuilt microprocessor (8-bit), the output of this sensor is in digital form; so the receiver and transmitter pins of this sensor is connected to the TX and RX port of the digital ports on the Arduino Microcontroller board. The outputs of this sensors (SDS011 and MQ135) will be monitored by the Arduino Microcontroller at regular intervals and this values will be displayed on the LCD in Parts Per Million (PPM), whenever the output of this sensors (that is the pollutant concentration) is above the allowable exposure in the surrounding atmosphere, the Arduino will trigger the Alarm to warn the inhabitants of the impending danger.

The device can therefore be divided into three parts;

- The microcontroller (ARDUINO UNO R3)

- The output unit; Liquid crystal display (LCD 16 x 2) and the BUZZER.
- The sensors (NOVA SDS011 and MQ135)

The Arduino IDE is used to program the microcontroller, before scanning deeply into the design details, sufficient knowledge about the sensors used in this device need to be established. The NOVA FITNESS sensor SDS011 used as the PM sensor and MQ135 is used for CO detection have different operating principles.

3.3.1 MICROCONTROLLER

The operation of the PCD requires a microcontroller to control the outputs of the device in response to the data from the sensors since the microcontroller is required in the design to read signals from environmental sensors, process the data, display the values on the LCD and also trigger the alarm when the pollutant level is above the predefined safe level. Arduino Uno R3 was selected from the numerous choices due to its advantages over the other Microcontrollers;

Arduino Uno is an open- source microcontroller board based on the Microchip ATmega328P microcontroller with 14 digital pins and 6 analog pins. It communicates via the STK500 protocol and it is programmed via the Arduino IDE and the programmed is uploaded to it via a USB cable.

Arduino Uno R3 specifications

Table 2.2: **Arduino Uno specifications**

properties	Description
Microcontroller	Microchip Atmega328P

Analog input ports	6
Digital I/O ports	14
Speed	20 MIPS (20MHz)
Flash	32KB
SRAM	2KB
ADC	1 x 10-bit (8 channel)
DAC	Nil
Operating voltage	5volts
Input voltage	7 to 20 volts
UART	1
DC current per I/O pin	20mA
DC current per 3.3V pins	50mA
Length	68.6mm
Weight	25g
Width	53.4mm

Cost	$10

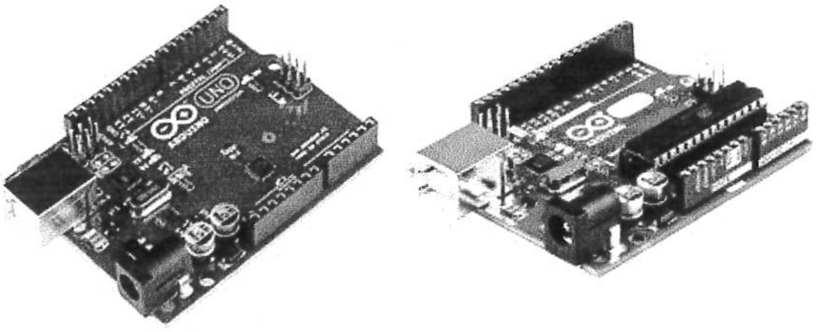


Fig 3.7: Arduino Uno R3

3.3.2 User Interface

The function of the User Interface (UI) is to comm

also to alert the users when the pollutant level is ha

Requirements:

- To display the pollutants level
- To inform the user when the pollutant level is above safe level.

Display:

- A 20 x 4 Liquid Crystal Display (LCD) screen was chosen as it has good visibility, and is very compact and simple to operate.

Audio:

- A simple piezoelectric buzzer is used to alert the user if a sensor reading enters an unsafe range.

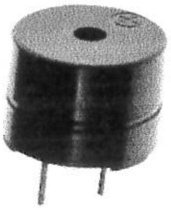


Fig 3.8: piezo buzzer

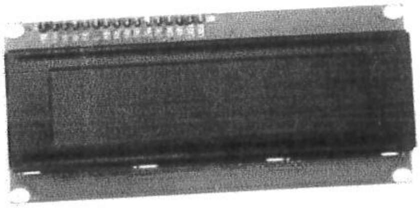


Fig 3.9: 20 x 4 Liquid crystal display

3.3.2.1 LCD CONNECTION

The LCD is a sixteen pin or terminal device namely;

1. pin 1 –VSS ; the ground terminal
2. pin2 –VDD ;the 5V power supply terminal
3. pin 3 –V0 ;for contrast adjustment
4. pin 4 – RS ; H/L Register select signal
5. pin 5 – RW ;H/L read/write signal
6. pin 6 – E ; H-L Enable signal
7. pin 7 – BD0 ; H/L Data bus line 0

8. pin 8 –DB1 ; H/L Data bus line 1
9. pin 9 – DB2 ; H/L Data bus line 2
10. pin 10 – DB3 ; H/L Data bus line 3
11. pin 11 – DB4 ; H/L Data bus line 4
12. pin 12 –DB5 ; H/L Data bus line 5
13. pin 13 – DB6 ; H/L Data bus line 6
14. pin 14 –DB7 ; H/L Data bus line 7
15. pin 15 –A/VEE ; +4.2 volt for LED / Negative voltage output
16. pin 16 –K ; power supply for B/L (0V0

The LCD is connected to the Arduino as listed below;

1. pin 1 is connected to the ground
2. pin two is connected to the 5V supply
3. pin three is connected to the middle terminal of the 10k potentiometer to adjust the screen brightness.
4. Pin 4 is connected to the RS terminal on the Arduino
5. Pin 5 is connected to the ground
6. Pin 6 is connected to pin 11 of the Arduino
7. Pin 11 is connected to pin 5 0f Arduino
8. Pin 12 is connected to pin 4 of Arduino
9. Pin 13 is connected to pin 3 of Arduino
10. Pin 14 is connected to pin 2 of Arduino
11. Pin 15 is connected to the VCC via a 220 ohm resistor to set the bacl light brightness.
12. Pin sixteen is to the ground\

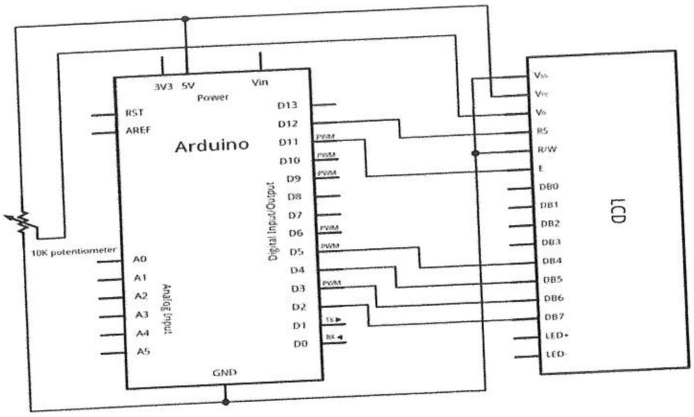


Fig 3.10: LCD to Arduino interfacing

3.3.3 SENSORS

3.3.3.1 NOVA FITNESS SENSOR SDS011 OVERVIEW

This category of sensor operates with the principle of optical analyzers which uses a high-energy laser as the light source. When a particle passes through the detection chamber that only allows single particle sampling, the laser light is scattered by the particle. A photo detector detects the scatting light. The design includes a custom microcontroller and various power supply circuitry as can be seen in the image. A small fan is attached to ensure adequate circulation of sampled air at a known rate. A microcontroller and low noise amplifier is integrated on this sensor (LNA shielded by metal can). The lower noise design likely allows for greater detection of small particles compared to the PMS3003. The large size of SDS011 is not necessarily a disadvantage as capturing greater volume of air will result in more sensitive particulate readings. Shielding is provided by folded sheet metal around the outside of the unit. Counting yield is specified to 70% at 0.3µm and 98% at 0.5µm.

3.3.3.2 Mode of operation

An infrared diode is lit inside a dark cavity; infrared is chosen as it avoids interference of any daylight that might enter the measurement chamber. Dust passing the sensor cavity will cause reflection of light. The phototransistor measures the reflected light and will output a signal proportional to the density and size of particles. In low cost modules, comparators are used to give estimation of particulate size (PM2.5 or PM10). The comparator will trigger when the photodiode reaches a certain voltage.

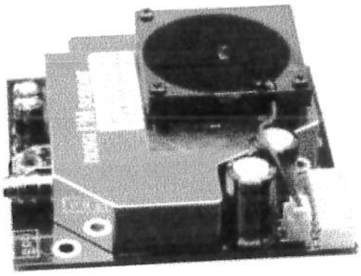


Fig 3.11: NOVA SDS011

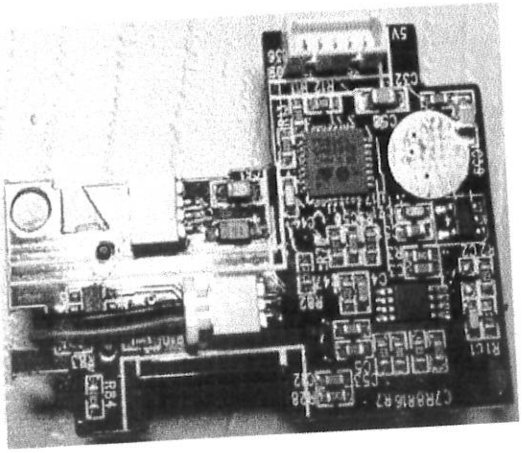


Fig 3.12: NOVA SDS011

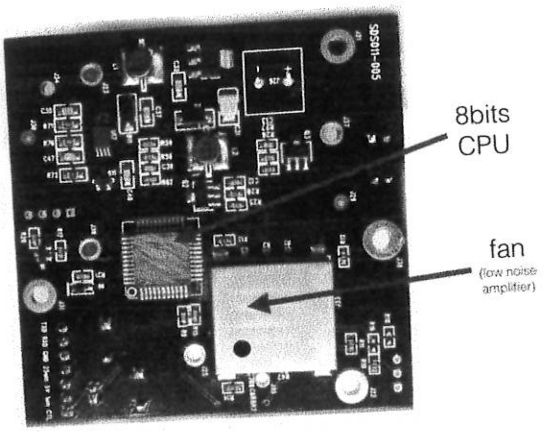


Fig 3.13 SDS011 components

Table 3.3: **SDS011 specifications**

Pin number	Pin name	Comment
1	NC	No connection
2	1µm	PM2.5: 0-999µg/m³;PWM Output
3	5V	5V Input
4	2.5µm	PM10: 0-999 µg/m³;PWM Output
5	GND	Ground
6	RX	RX ofUART（TTL） @3.3V
7	TX	TX ofUART（TTL） @3.3V

3.3.3.3 IMPLEMENTATION STEPS

The SDS011 sensor library is not available in the Arduino IDE, therefore the first thing to do is to get the library file and add it to arduino Library files (.h extension files).

- Download SDS011 library file online (www.githhub.com)
- Add to the Arduino IDE library file.

  Goto> ArduinoIDE>Sketch>includeLibrary>add.ZIPLibrary> select the .ZIP file location.

After updating the library, SDS011 can now be controlled by Arduino. The next step was programming the Arduino to control the sensor (SDS011) to verify its operation

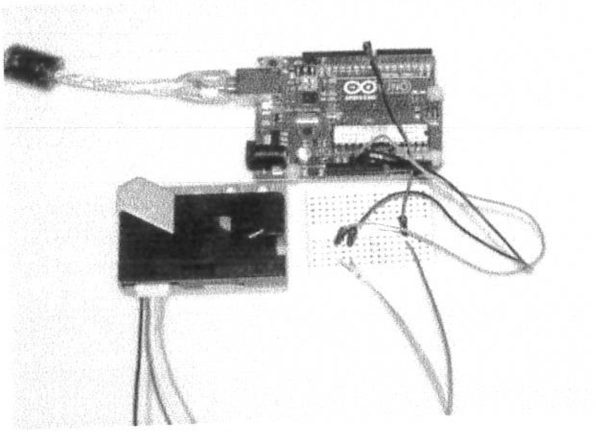


Fig 3.14: SDS011 plus Arduino

Interfacing SDS011 to Arduino Uno

Table 3.4: **SDS011 and Arduino Uno interfacing**

SDS011 pin	ARDUINO UNO PORT
TX	0 (RX)
RX	1 (TX)
GND	GND
VCC	5V
2.5µm	Not connected
10m	Not connected

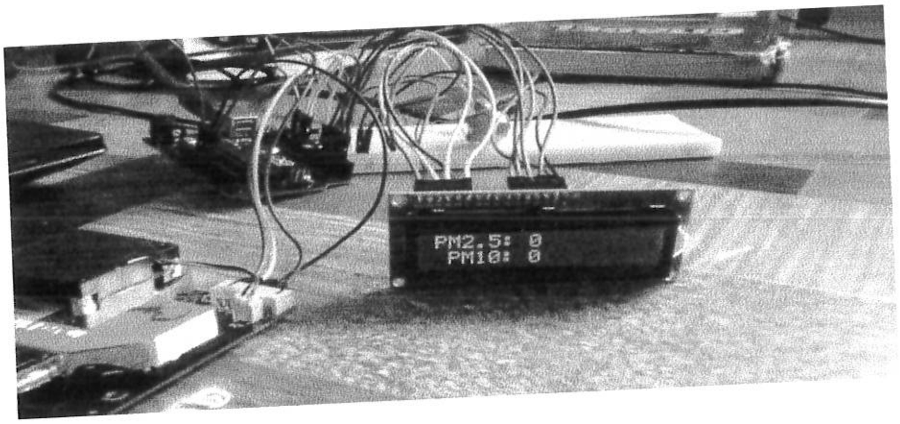


Fig 3.15: PM sensor and Arduino setup

3.3.3.2 MQ135 GAS SENSOR

The principles and characteristics of chemical gas sensors is of several types each sensor has different operation principles. The operational characteristics of a gas sensor are generally classified into three types: heating semiconductor, non-dispersive infrared (NDIR), and light emitting diode (LED). The size, accuracy, and power consumption of a compact gas sensor all vary with sensor type. MQ135 is a heating semiconductor type of gas sensor; heating semiconductor sensor evaluates a target gas concentration by measuring the electrical conductivity of a sensing layer that is composed of a metal-oxide material such as tin dioxide (SnO2) or zinc oxide (ZnO), when toxic gases reach the sensor's surface and are absorbed, its electrical conductivity changes.

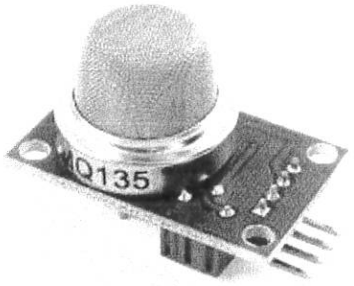


Fig 3.16: MQ 135 gas sensor

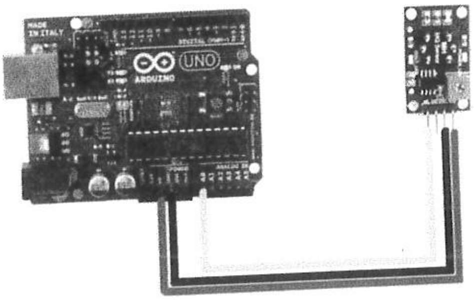


Fig 3.17: MQ135 with Arduino Uno

MQ135 is used for Carbon monoxide sensing in this design due to its fast response, low power consumption, low cost and versatility in air quality monitoring projects.

3.3.3.2.1 IMPLEMENTATION STEPS

MQ135 sensor library is not available in the Arduino IDE, therefore the first thing to do is to get the library file and add it to arduino Library files (.h extension files).

- Download MQ135 library file online (www.githhub.com)
- Add to the Arduino IDE library file.

  Goto> ArduinoIDE>Sketch>includeLibrary>add.ZIPLibrary> select the .ZIP file location.

After updating the library, MQ135 can now be controlled by Arduino. The next step was calibration of the sensor; this is done for a period of 12hrs in an indoor air atmosphere and in outdoor air atmosphere for additional 10minutes.

The sensor circuit was designed and simulated on Proteus VSM and the design is given below.

The components used include; an Arduino Uno R3 board, MQ135 gas sensor, 10K potentiometer, 20x4 LCD, 5V power supply and jumper cables.

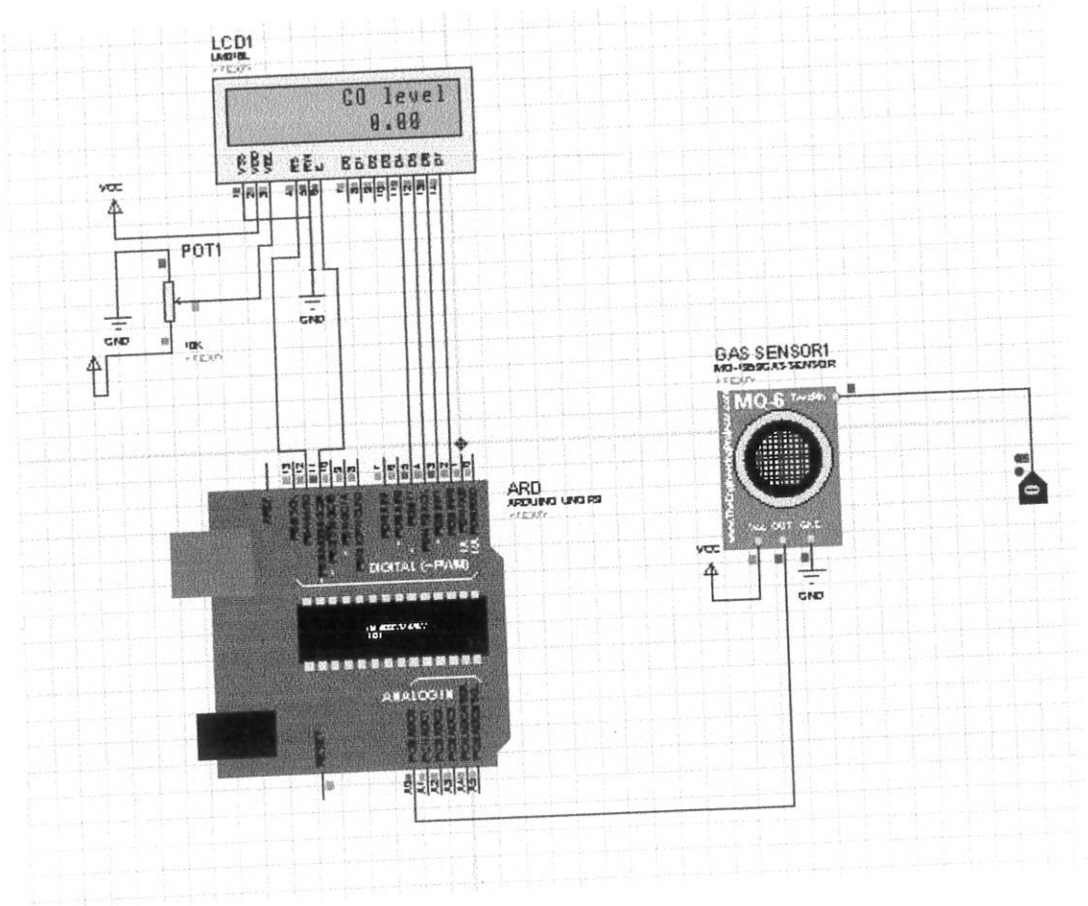


Fig 3.18: MQ135, Arduino and LCD circuit schematic on Proteus VSM

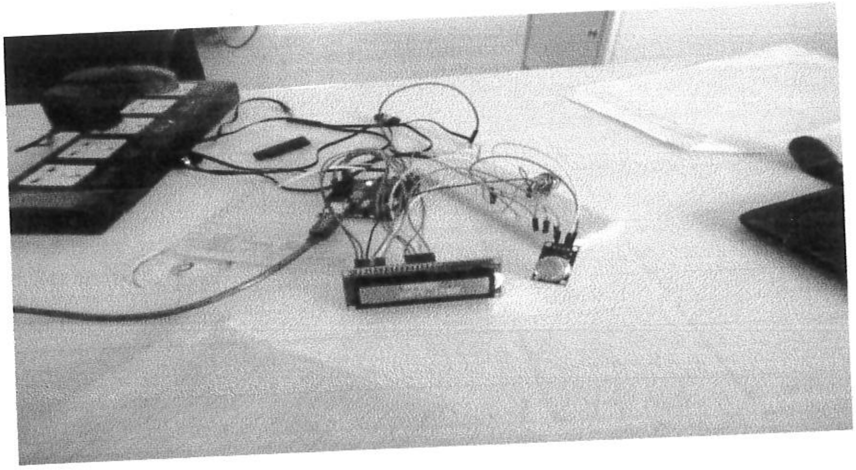


Fig 3.19: Experimental setup

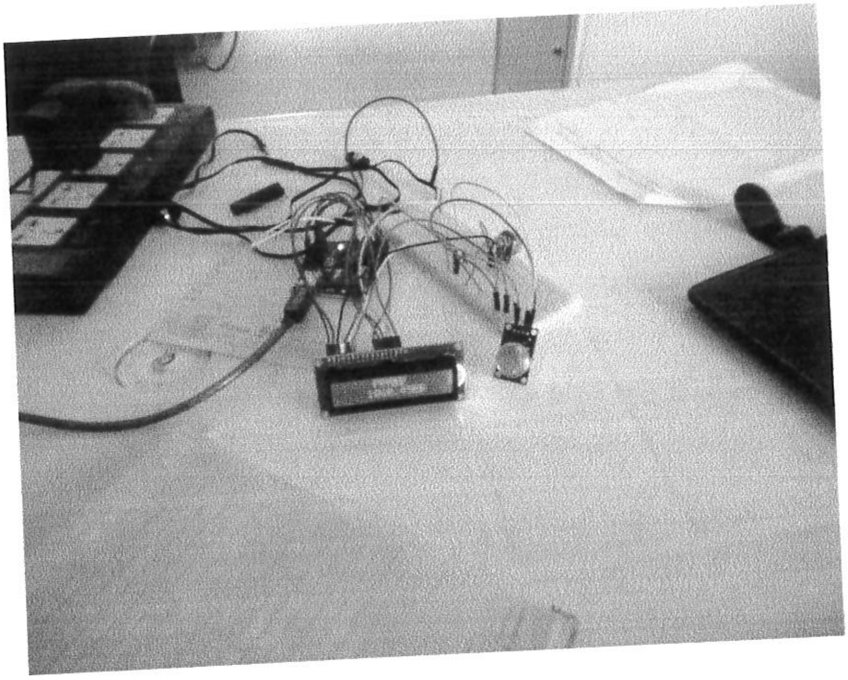


Fig 3.20: MQ135 calibration process

After calibrating the MQ135 sensor for the period of 12hrs to determine the Rzero (379.13), the value is added to the header file (.h extension file) in the MQ135 Library files and the Read operation code was uploaded onto the Arduino Board.

3.3.3.3 Power Consumption Estimations

Total power consumption needs to be known as our supply must be capable, or the device could shutdown unexpectedly. It is also useful to know if the device were to be operated from rechargeable batteries, knowing consumption will give us an estimated operating time. The power rating for individual components is given below.

Table 3.5: **power requirement estimations**

Components	Current (mA)	Voltage (V)	Power (W)
Arduino UNO	40.00	5.00	0.2000
SDS011	77.00	5.00	0.3850
MQ135	40.00	5.00	0.2000
20 x 4 LCD	40.00	5.00	0.2000
Piezo Buzzer	20.00	5.00	0.2000
Total	217.00	5	1.1850

CHAPTER FOUR

4.0 TESTS, RESULTS AND DISCUSSION

The device was tested under series of conditions to validate its operation and also to compare various results of its output under different circumstances. The device was used to test for the atmospheric carbon monoxide concentration in both indoor and outdoor of an environments and as well as both indoor and outdoor concentration of Particulate matter of both indoor and outdoor atmosphere of the environment; during these process, certain changes was brought about in the sensor's surrounding such as introduction of combustion process and also generating dust particles into the atmosphere so as to check the operation and the speed of response of the device to these changes. The details and the Arduino IDE Serial plotter and Monitor Output for these processes is given below.

- Particulate Matter Indoor test; the device was used to measure the indoor PM level for a period of five hundred seconds (500s) and the plot on the Arduino IDE Serial plotter is shown in the following figure.

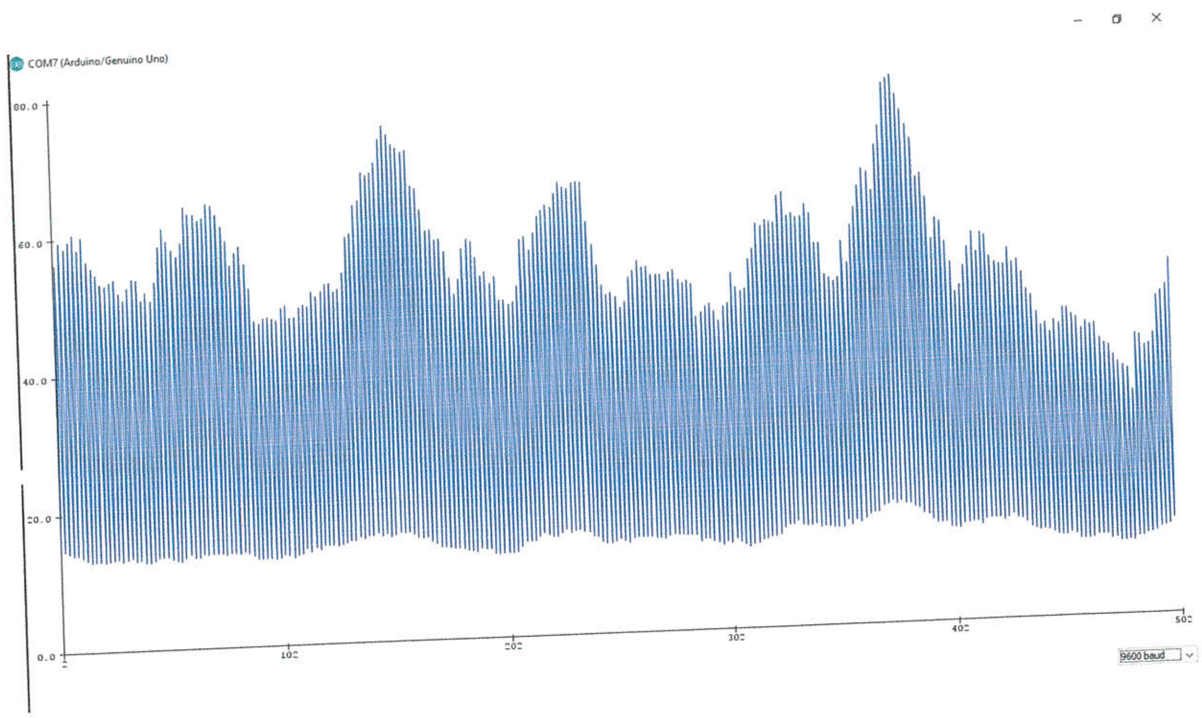


Fig 4.1: indoor PM level chart

From the figure above, it can be seen that the PM2.5 level is within the range of $16\frac{\mu g}{m^3}$ - $19\frac{\mu g}{m^3}$ which is still safe according the WORLD HEALTH ORGANIZATION (WHO) standard for Particulate Matter (PM2.5 which is $25\frac{\mu g}{m^3}$ for daily average) throughout the cycle while the PM10 value is within the range of $43\frac{\mu g}{m^3} - 80\frac{\mu g}{m^3}$ throughout the cycle.

- Particulate Matter Outdoor test; the SDS011 was also tested in the outdoor environment and the Arduino IDE Serial plotter Output was also examined; from the output of the plotter it was observed that the PM level of the outdoor environment was okay due to low activities in the neighborhood and also low movement of particles due to low moment of vehicles and other related activities. The plot is given in the next figure.

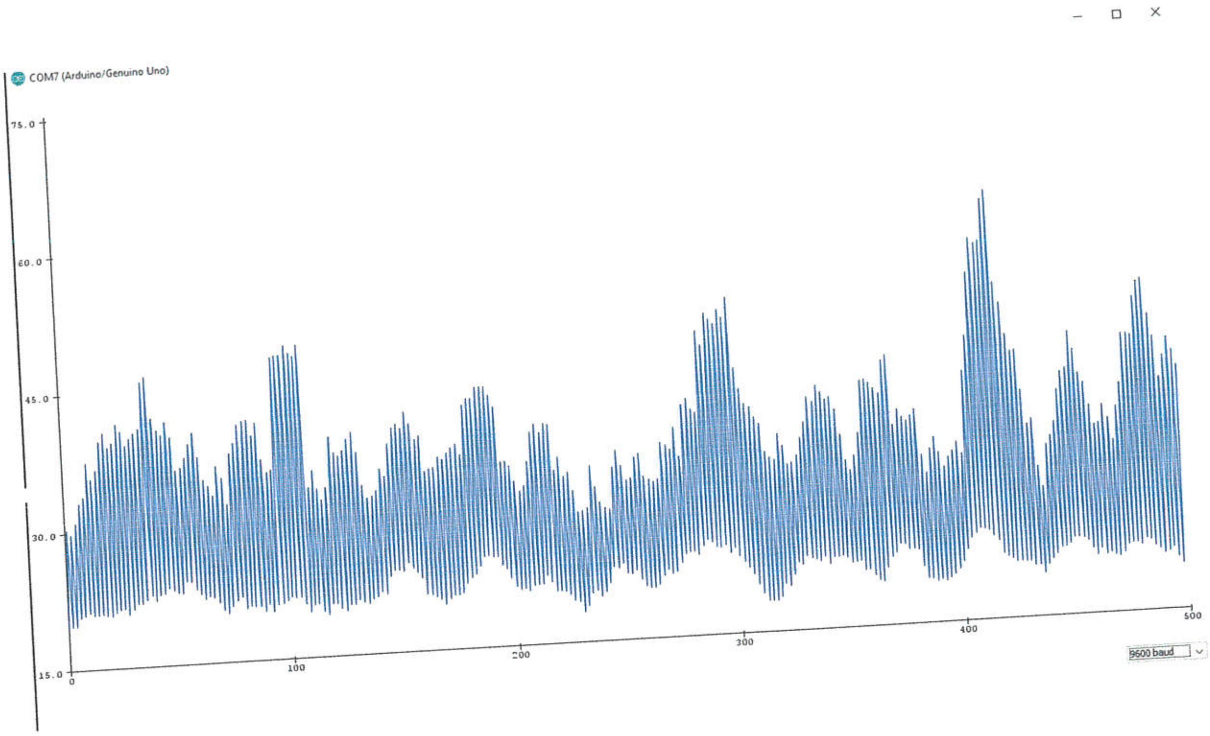


Fig 4.2: outdoor PM level chart

From the above plot, it can be observed that the outdoor plot of PM for the 500secondds duration was within 19$\frac{\mu g}{m^3}$ - 62$\frac{\mu g}{m^3}$ for PM10 and also it was within 17$\frac{\mu g}{m^3}$ - 23$\frac{\mu g}{m^3}$ for PM2.5.

- The PM operation was also tested in a dusty room, to observe the difference in the particulate matter nature due to the presence of dust in the atmosphere which was generated from sweeping. There was a sudden rise in the values of both PM10 and PM2.5 as a result of the large amount of dust particles suspended in the air.

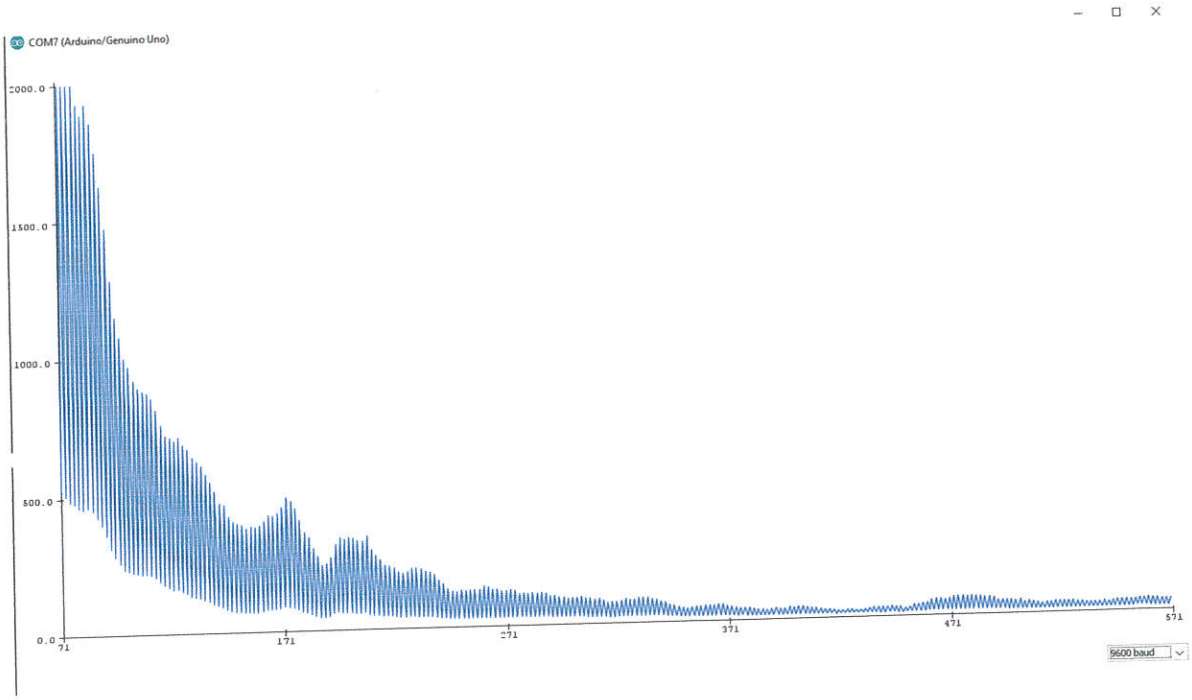
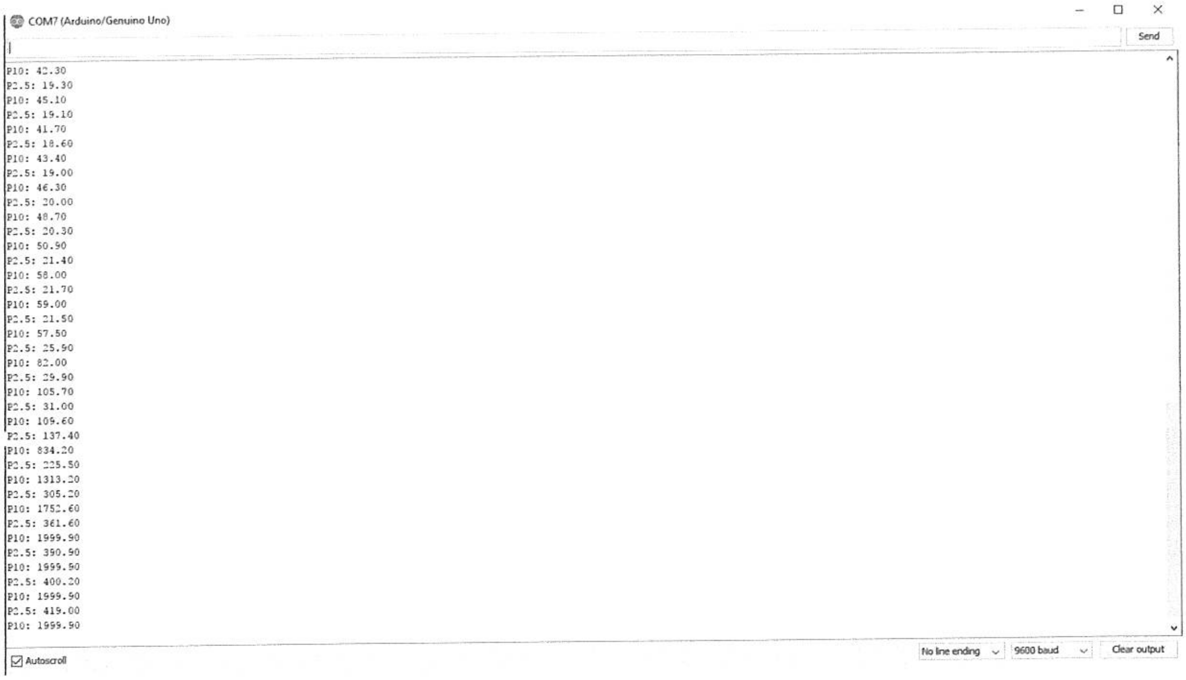


Fig 4.3: PM level chart in a dusty environment



```
P10: 42.30
P2.5: 19.30
P10: 45.10
P2.5: 19.10
P10: 41.70
P2.5: 18.60
P10: 43.40
P2.5: 19.00
P10: 46.30
P2.5: 20.00
P10: 48.70
P2.5: 20.30
P10: 50.90
P2.5: 21.40
P10: 58.00
P2.5: 21.70
P10: 59.00
P2.5: 21.50
P10: 57.50
P2.5: 25.90
P10: 82.00
P2.5: 29.90
P10: 105.70
P2.5: 31.00
P10: 109.60
P2.5: 137.40
P10: 834.20
P2.5: 225.50
P10: 1313.20
P2.5: 305.20
P10: 1752.60
P2.5: 361.60
P10: 1999.90
P2.5: 390.90
P10: 1999.90
P2.5: 400.20
P10: 1999.90
P2.5: 419.00
P10: 1999.90
```

Fig 4.4: PM level values in the dusty environment

The high values of the PM2.5 and PM10 reading from the sensor was displayed on both Arduino IDE Serial plotter and Serial Monitor and it can be deduced that sweeping is also a major cause of PM suspension into the atmosphere.

- MQ135 indoor test; the MQ135 operation was also tested in indoor air and the output was monitored with the Arduino IDE Serial plotter for 500second. The output of the Serial monitor showed low CO content in the atmosphere, making the indoor air of the location safe.

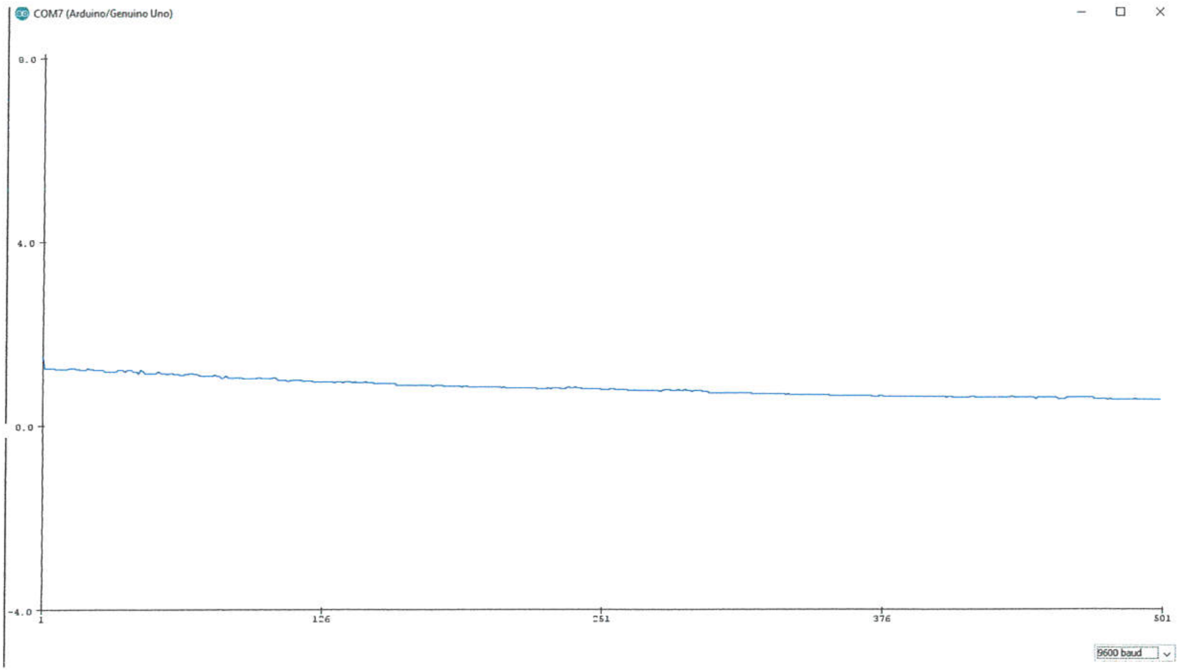


Fig 4.5: indoor CO chart

Another test was carried out on the MQ135 indoor test where pollutant level in the atmosphere was increased from combustion of some fuels (papers), the MQ135 output was observed on the Arduino IDE Serial plotter and it was observed that the level of CO in the atmosphere increased during the combustion and the value of CO exposure on the plot reduced in the surrounding after the process.

- MQ 135 outdoor air test; the same process was repeated for the outdoor air of the environment and it was likewise monitored with the Arduino IDE Serial plotter. The outdoor air was also safe; the plot showing that the overall output is less than the WHO limit for CO exposures.

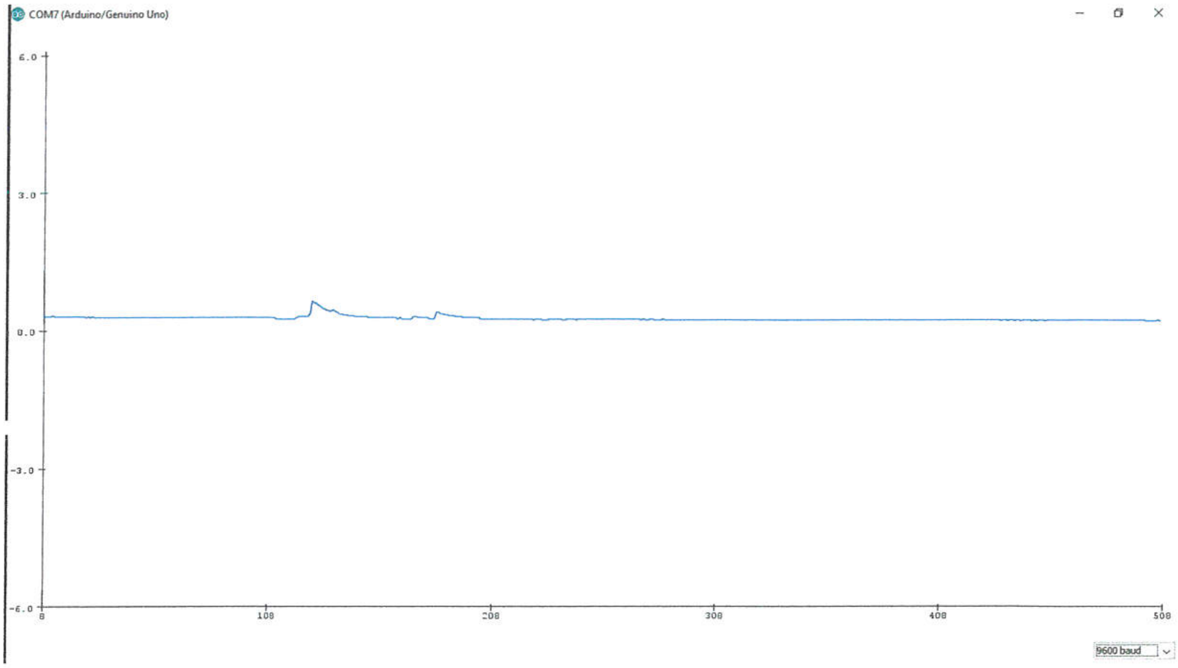


Fig 4.6: outdoor CO level chart

From the above tests, it can be observed that due to poor air flow indoor compared to outdoor, there are more pollutants in the indoor air compared to the outdoor air; this proves that moves of the suspended particles in indoor air remain in the household for longer period of time and in most cases takes longer time to spread and escape from the house depending on the type of ventilation in the house. Furthermore, it was also observed that the continuous air movement in the outdoor environment with low air pollution allows pollutants to spread easily making the pollutants level in the surrounding low compared to indoor space which is the retrospect in modern cities outdoor air due to high activities coupled with pollutant released.

CHAPTER FIVE

5.0 CONCLUSION

The low cost Particulate Matter and Carbon Monoxide Detector (PCD) was designed with NOVA PM Sensor SDS011, MQ135 as the CO sensor, 20 x 4 LCD as the display unit, buzzer as the alarm device all controlled by Arduino Uno R3 microcontroller which was programmed with the Arduino IDE; the device was tested under different conditions, the buzzer gives an alarm signal when the CO level is above 8ppm. Some observations were made while testing the device; pollutants concentration in the indoor air is higher than outdoor air of the environment due to poor aeration in the houses. Some common house chores such as sweeping tends to be a major source of PM in the house while cooking and gases from generating plants happens to be the major source of CO generation in the household. For all the above mentioned home practices and other practices contributing to pollutants release in the environment, it is advisable that certain preventive measures be conducted before carrying out the tasks; this will greatly reduce the health risks of those pollutants and as well as reduce the release of these harmful substances. In general, to mitigate the adverse effect of pollution in our country, the Government should enforce the pollution control policies and as well monitor the pollution exposure in our urban cities so as to reduce the impending catastrophe that is being caused in our communities especially Urban centers and also similar devices like this PCD should be made available in our communities.

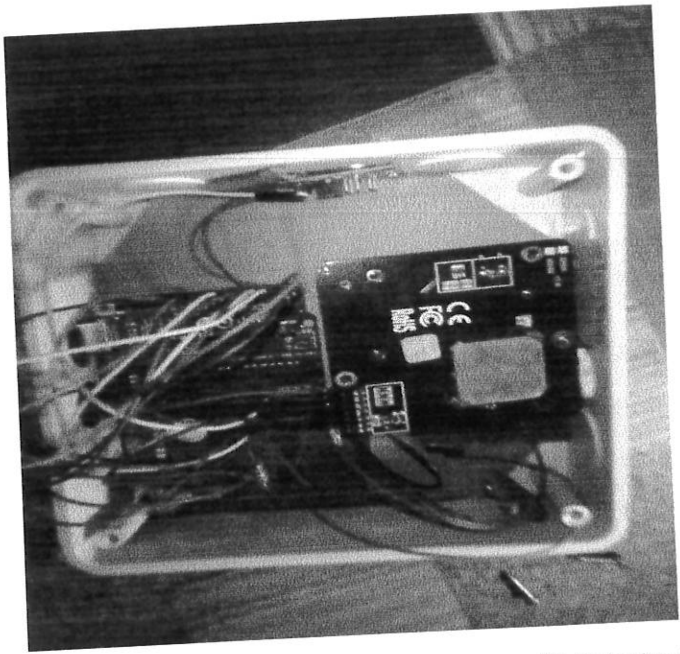


Fig 5.1 : Particulate Matter and Carbon Monoxide Detector (PCD) inner view

```
CO level:  0.88≡ppm
P2.5: 32.70 ug/m^3
P10: 61.60  ug/m^3
```

Fig 5.2: PCD showing the Display unit and sensor reading

5.1 Proposed Future works

- Improving the device by adding more sensors to it to widen its detection scope.
- Integration of Wi-Fi Modules (such as ESP8826) to enhance monitoring of the pollutant level in an environment via the internet.
- Use of wireless sensor modules with IOT (Internet of Things) and
- Addition of systems that will provide correction measures to the polluted environment.

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APPENDIX A: RZERO CODE

The original source code can be found in instructibles.com/pollutiondetector

```
#include<LiquidCrystal.h>

#include "MQ135.h"

LiquidCrystal lcd(12,11,5,4,3,2);

void setup() {

 // put your setup code here, to run once:

Serial.begin(9600);

lcd.begin(16,2);

float rzero;


}

void loop() {

 // put your main code here, to run repeatedly:

MQ135 gasSensor = MQ135(A0);

float rzero = gasSensor.getRZero();


Serial.println(rzero);

lcd.setCursor(5,0);

lcd.println("PPM");

lcd.setCursor(4,1);

lcd.println(rzero);

delay(1000);
```

APPENDIX B: PCD OPERATION CODES

The original source code can be found in github.com/sds011

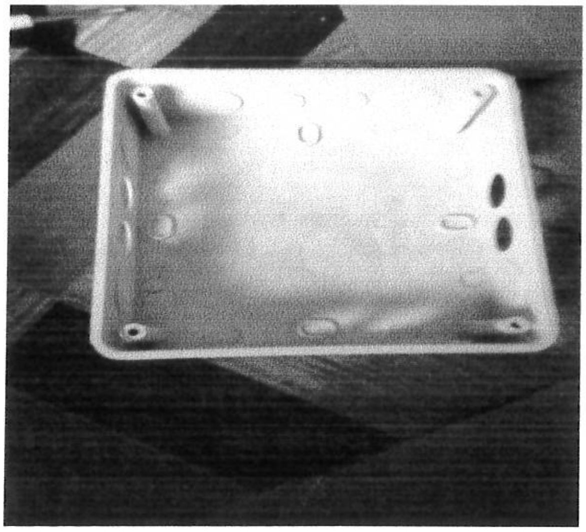
```
#include <SDS011.h>

#include <SoftwareSerial.h>

#include <MQ135.h>

#include <LiquidCrystal.h>

#define BUZZER 13

float p10,p25;

LiquidCrystal lcd( 12,11,5,4,3,2);

int air_quality;

int error;

SDS011 my_sds;

void setup() {

// put your setup code here, to run once:

Serial.begin(9600);

pinMode(13,OUTPUT);

lcd.begin(20, 4);

lcd.setCursor(0,0);
```

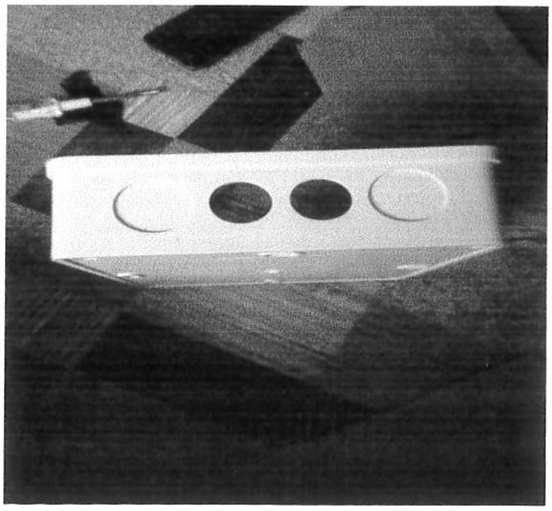
```
 lcd.println("pollution");
 lcd.setCursor(0,1);
 lcd.print("detector");
 delay (3000);
 lcd.clear();
 lcd.setCursor (0,2);
  lcd.print ("ABDULRAUF");
  lcd.setCursor(0,3);
  lcd.print ("AND JACOB");
  delay (5000);
  lcd.clear();
  lcd.setCursor (0,0);
lcd.println("MEE/13/1138");
 lcd.setCursor(0,1);
lcd.print("MEE/13/1151");
delay(5000);
lcd.clear();
```

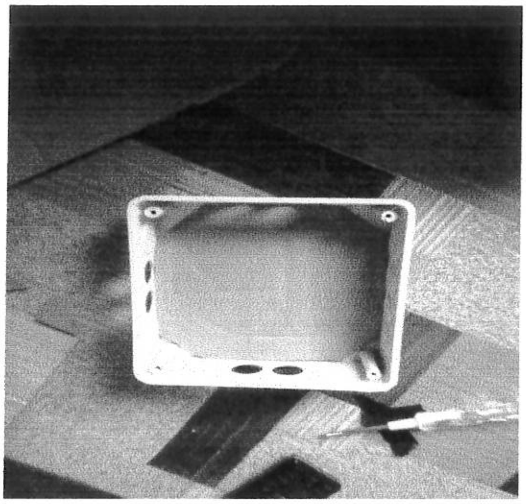
```
 lcd.print("DEVICE WARMING");

 delay(10000);

 lcd.clear();

 my_sds.begin(0,1);

 while (!Serial){

  ;

  }

}

void loop() {

  // put your main code here, to run repeatedly:

MQ135 gasSensor = MQ135(A0);

int air_quality = gasSensor.getPPM();

Serial.println(gasSensor.getPPM());

lcd.setCursor(0,1);

lcd.print("CO level(ppm):");

lcd.setCursor(8,1);

lcd.println(gasSensor.getPPM());
```

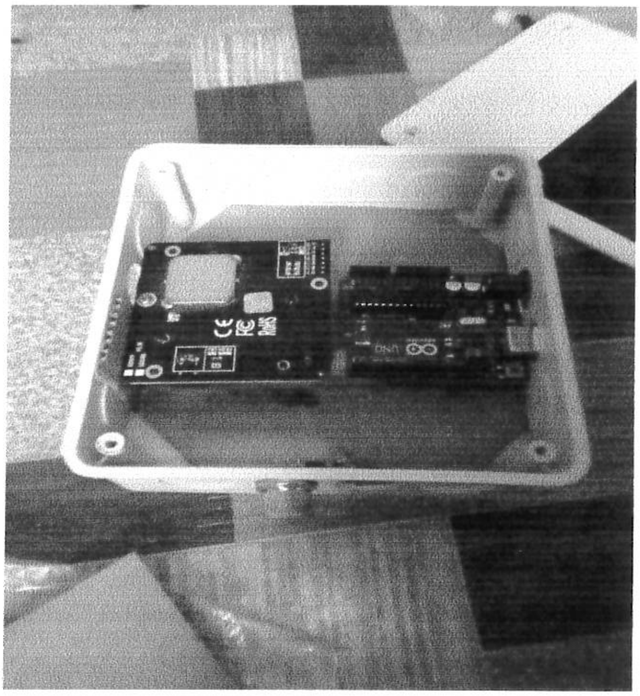
```
  delay(2000);

  error = my_sds.read(&p25,&p10);

  if(!error){

   Serial.println("P2.5(µg/m^3): " +String(p25));

   lcd.setCursor(0,2);

   Serial.println("P2.5(µg/m^3: " +String(p25));

   delay(2000);

   Serial.println("P10(µg/m^3: " +String(p10));

   lcd.setCursor(0,3);

   Serial.println("P10(µg/m^3: " +String(p10));

  }delay(2000);


if(air_quality >= 8){

 digitalWrite(13, HIGH);

 delay(3000);

  }

}
```

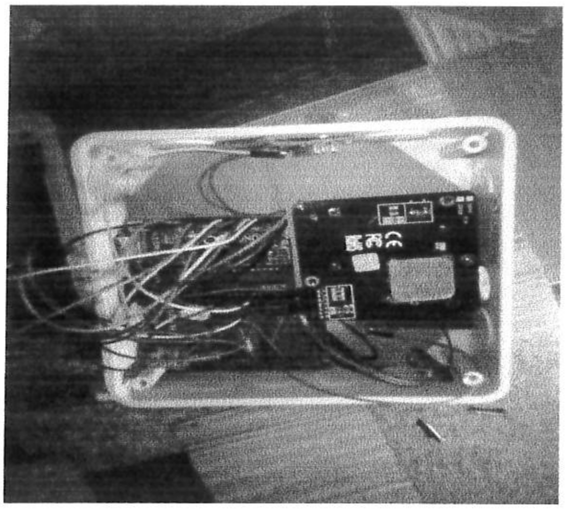
APPENDIX C: DEVICE PICTURES

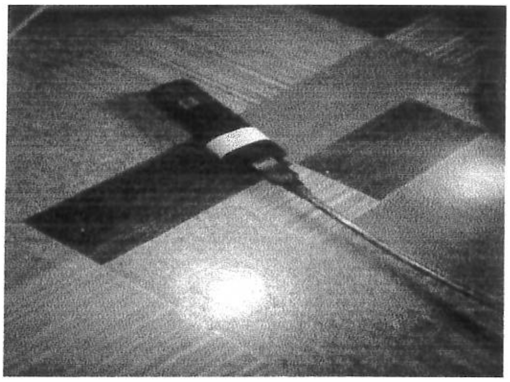


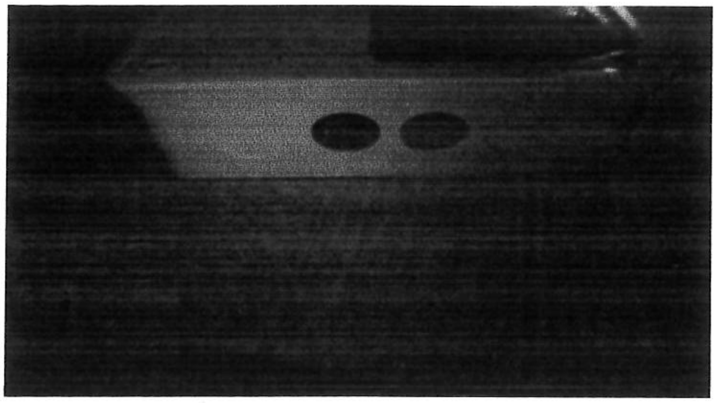


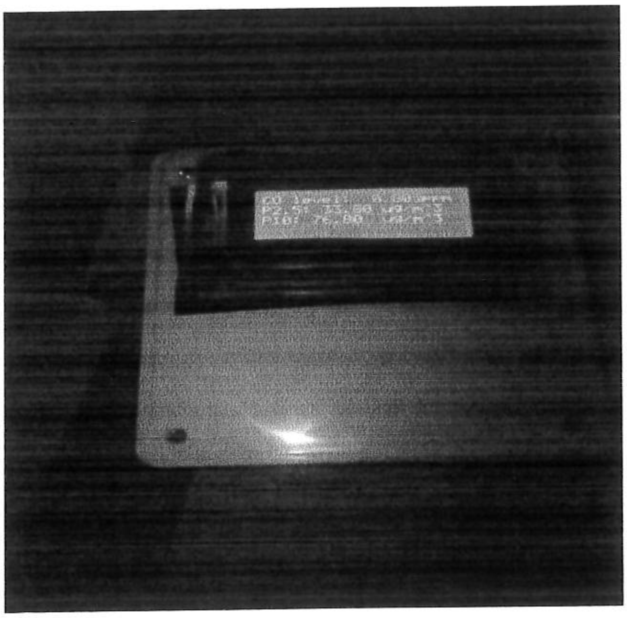











CO level:
P2.5:
P10:

APPENDIX D: BILL OF ENGINEERING MATERIALS

S/N	COMPONENTS	PRICE (#)	UNIT	TOTAL(#)
1	ARDUINO UNO R3	3,500	1	3,500
2	SDS011	8,000	1	8,000
3	MQ135	1,500	2	3,000
4	LCD 20X4	1,600	1	1,600
5	POTENTIOMETER	50	5	250
6	JUMPER CABLES	50	40	2,000
7	POWER SOURCE	2,000	1	2,000
8	VERO BOARD	400		400
9	SOLDERING LEAD	700	1	700
10	SOLDERING IRON	2,500	1	2,500
11	RESEISTORS	10	10	100
12	BREAD BOARD	400	2	800
13	GLUE	300	1	300
14	Tape	200	1	200
15	CASING	1000	1	1000
15	MISCHELLANEOUS	10,000		10,000
	TOTAL			36,350

APPENDIX D: LIST OF ABBREVIATIONS AND ACRONYMS

AASQA	Accredited Associations for Air Quality Monitoring
ABCD	Aerosol Black Carbon Detectors
AQM	air quality monitor
BAM	beta attenuation monitor
CO	carbon monoxide
CO_2	carbon dioxide
CSN	Community Sensor Network
EC	Electrochemical
EC	European Commission
EPD	Environmental protection Department of Hong Kong
EPA	environmental impact protection agency
GND	ground
HEI	Health Effect Institute
IAQMS	Indoor Air Quality Monitoring System
IAP	Indoor Air Pollution
IAQ	indoor air quality
IDE	Integrated Developers Environment
I^2C	inter-integrated circuit
KNN	K-nearest neighbor
LAX	Los Angeles International Airport
LCD	liquid crystal display
LDA	linear discrimination analysis
LED	light emitting diode

mAh	milli ampere hour
MEMS	Microelectromechanical systems
MEP	Ministry of Environmental Protection of the People's Republic of China
ML	Machine Learning
MLP	multilayer perceptron
MO	METAL 0XIDE
NDIR	NON DISPERSIVE INFRARED
NO_2	Nitrogen dioxide
OPCs	OPTICAL PARTICLEV COUNTERS
O_3	Ozone
Pb	LEAD
PCD	particulate matter and carbon monoxide detector
PM	particulate matter
PM2.5	particulate matter 2.5micrometers
PM10	particulate matter 10micrometers
PPB	parts per billion
PPM	parts per million
PNC	particle number concentration
PWM	Pulse width modulation
pg/m^3	picograms per cubic metre
RX	Receiver
SSN	Static Sensor Network
SO_2	Sulfur dioxide
SnO_2	Tin dioxide
TEOM	Tapered Element Oscillating Micro-Balance

TNGAPMS	The Next Generation Air Pollution Monitoring System
TX	Transmitter
UART	Universal asynchronous receiver/transmitter
UK	United Kingdom
UI	User Interface
US	United States of America
$\mu g/m^3$	micrograms per cubic metre
VCC	source
VOCs	VOLATILE ORGANIC COMPOUNDS
VSN	Vehicle Sensor Network
WSNs	Wireless Sensor Networks
ZnO_2	Zinc dioxide

APPENDIX E: INSTRUCTION MANUAL

- Connect the power source to the device via the Arduino power ports.
- The device will power on and display some initials.
- After about 20sconds, the device will start operating but the MQ135 sensor do take few minutes to stabilize.
- After few minutes of warming up, the device will display the sensor reading with MQ readings on top and pm readings below.
- When the level of CO is above 8μg/m^3 the buzzer will sound.