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Design of Aerial Probe for 3D Mapping of AQI Index of Carbon Monoxide Levels

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Abstract: With the onset of Industry 4.0, automation and its applications have led to an increase in the product development domain. Numerous products have been developed involving wireless connectivity, sensors and embedded systems that lead to easiness in data visualization and computation. The market of automation has just started to be penetrated by start-ups and various established multinational companies, leading to an increased focus on the future of integration of Artificial Intelligence with hardware and networking. With current focus on sustainable development and climate change, our idea was to develop a product which could help private as well as government agencies in mobile air pollution detection over large neighbourhoods and cities. The purpose of this paper is to define the design and development of a radio frequency remote controlled aerial probe which aims at providing real-time telemetry data to a wireless base station, along with the capabilities of 3D mapping the concentration of Carbon Monoxide (CO) particles in the atmosphere and the contaminants dependencies on air temperature and pressure. We also aim at testing the accuracy of the particulate contaminant sensor by comparing the collected data value with the given government database, in order to calculate the percent error.

Keywords* : *Aerial Probe Design, AQI Index, Climate Change, Embedded Systems, Wireless Sensor Integration

I. INTRODUCTION

Climate change can be described as changes in the earth's climate system, usually visualized as the rapid change in the earth's climate due to human activity. It is determined by varying patterns of temperature, wind, precipitation and even different seasons that we experience. For the past 5 years, climate change has been the center of attention for discussions during international summits and meets.

One parameter that majorly contributes to climate change is air pollution. Air pollution and climate change are very closely related to air pollutants contribute to climate change by directly affecting the amount of incoming sunlight. Some pollutants reflect this sunlight, while others absorb it resulting in heating or cooling of the earth's atmosphere [1]. Not only do these air contaminants affect us indirectly, but they also are a leading cause of death. According to the Institute of Advanced Sustainable Studies (IASS), approximately 7 million premature deaths annually are due to the effects of air pollution [1]. The most common air pollutants are particulate matter (PM 10 and PM 2.5), Ozone (O_3), Sulfur Dioxide (SO_2), and Carbon Monoxide (CO) [2].

From the information given above, we realized the importance of studying air pollution and identifying solutions in order to reduce emissions of these harmful gasses. This led us to create a product that would be able to identify specific areas where the concentration of such contaminants can cause health-related issues. In this study, using a self-made aerial probe that is attached to a drone, we will monitor the concentration of Carbon Monoxide particulates, which will be measured in ppm (parts per million). Additionally, real time 3D and 2D graphs would also be used in order to describe the dependency of contaminant concentration on air temperature and pressure. The monitoring of data would be done by a wireless base station.

The paper will be divided majorly into 7 sections: Literature Review, Problem formulation, Electrical Subsystem design Mechanical Subsystem design, Communication and Data Computation, Application of the product in various domains, and Results and Conclusion of the findings.

II. LITERATURE REVIEW

This section includes comprehensive reviews on existing technology in the field of air pollution monitoring system with IOT integration. With recent advent and growth of IOT systems, the focus has been on autonomous monitoring and data mining of air pollution contaminant levels. Research has been conducted to detect air pollution using machine learning models such as Random forest model, SVM model, decision tree model, gradient boosting model etc [3]. Product development has also been in growth over recent years and a major focus has been given to climate change. There has been more than adequate amount of research and development for air pollution systems using ATMEGA controllers, Raspberry pi, Node MCU etc. All these systems developed work on the principle of collecting AQI levels and displaying them to the user for processing and monitoring [4].

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Homi Bhabha Center for Science and Education has various scientific programs related to air pollution, where they collect data on air pollution levels using fixed monitoring systems. Additionally, the students collect data related to health status in the particular locality in order to correlate and draw conclusions between air pollution levels and health status [5].

The India Central Pollution Control Board is able to provide real time air pollution AQI levels of PM 2.5, PM 10, Carbon Monoxide, Carbon Dioxide, Ozone and Sulphur Dioxide using air contaminant detectors installed at controlled centres around a locality. The India Central Pollution Control Board is able to provide real time air pollution AQI levels of PM 2.5, PM 10, Carbon Monoxide, Ozone and Sulphur Dioxide using air contaminant detectors installed at controlled centres around a locality [6].

The aerial probe that we have designed brings the ability of air contaminants detection along with mobility, wireless technology and real-time data processing. The probe can easily be controlled using RF controllers, hence making the entire system mobile. Huge locality and neighborhoods can be swept in a matter of minutes to gather contaminant data, reducing the cost of installment of fixing monitoring systems and their maintenance.

III. PROBLEM FORMULATION

There are several drawbacks when it comes to conventional air pollution monitoring instruments. Some of these limitations include the large size, extreme weight and their cost related to fabrication and maintenance. These lead to sparse deployment of these monitoring stations. Another limitation is the location at which these systems are placed at. Air pollution in urban areas is highly correlated to human activities such as construction. Location dependencies such as traffic choke points, which have worse air quality, can also cause the effectiveness of these systems to reduce [1].

We will be tackling these problems by first making our entire system mobile. The probe would be mounted on a QAV-250 fabricated chassis and would be RF controlled.

This allows us to adjust the location of the monitoring system in order to obtain the true reading. This leads to elimination of dependencies, thus increasing the efficiency of the system.

IV. ELECTRICAL SUBSYSTEM DESIGN

This section describes the electrical design and power systems of the aerial probe along with sensor selection.

A. Sensor Trade and Selection

The probe will require two analog sensors: one for computation of air temperature and pressure and another for calculation of particulate concentration of Carbon Monoxide.

Table – I: Trade for Temperature and Air pressure sensor

Part Number	Operating Temperature (°C)	Voltage Supply (V)	Resolution (mV/C)	Precision
MCP9701	(-)40 - (+)80	3.1 - 5.5	19.5	±4°C
LM61CIM3	(-)30 -(+)100	2.7 - 10	10	±3°C
MPL3115A2	(-)40 - (+)85	1.95 - 3.6	10	±1°C

Table – II: Trade for CO contaminants Sensor

Part Number	Manufacturer	Operating Temperature (°C)	Voltage Supply (V)	Accuracy
SPS30	Sensirion	(-)10 - (+)60	4.5 - 5.5	0 to 100 µg/m³ ±10 µg/m³
MQ-07	Addrax	(−)10 - (+)65	5 ± 0.5	0 to 150 µg/m3 ±10 µg/m³

Table – III: Trade for Microcontroller

Microcontroller	Clock Speed (MHz)	Power Required	Boot Time	Flash Memory
Arduino Nano (ARM Processor)	64	3.3V - regulated, 6-20V unregulated external supply, 19 mA	2-3 seconds (with bootloader)	1Mb
Raspberry pi Zero (ARM Processor)	1000	3.3V	12-15 seconds	-

After studying the datasheets of several sensors, we decided to proceed with *NXP Semiconductor's MPL3115A2*. It is an I^2C precision temperature and pressure sensor with altimetry. The MPL3115A2 is a compact, piezoresistive, absolute pressure sensor with an I^2C digital interface. It also has a wide operating range of 20 kPa to 110 kPa, a range that covers all surface elevations on earth. The low power requirements of the MPL3115A2 sensor makes it especially attractive and allows us to design a low power consuming system. The sensor interfaces with our microcontroller through an I^2C serial interface. I^2C is a synchronous, multi-master, multi-slave, packet-switched, serial computer bus which is widely used for attaching lower-speed peripheral ICs to processors and microcontrollers in short-distance for intra-board communication.

For the calculation of particulate matter concentration of Carbon Monoxide, we have decided to go with the *Adraxx MQ-7 CO Carbon Monoxide gas sensor*. It is a simple-to-use Carbon Monoxide (CO) sensor, suitable for sensing CO concentrations in the air. The MQ-7 can detect CO-gas concentrations within the range of 20 to 2000ppm. This sensor has a high sensitivity and fast response time.

The sensor's output is an analog resistance. The analog output of the sensor is connected to the analog input pins of the Arduino in order to read the values using the *analogRead* function. The microcontroller choice for our probe is the Arduino nano.

It is selected because of the familiarity with the arduino IDE. It also has a lower boot time when compared to the raspberry pi, along with being cost effective and sufficient onboard FLASH to process cache data, which comprises mostly of the sensor data [7].

B. Electrical Power and PCB Design

The PCB file for the circuit was created in Autodesk Eagle and the circuit prototyping was completed on a perf board.
For the MPL3115A2, there were 4 connections to the microcontroller: *VCC, GND, SCL, SDA.* The VCC connection specifies the 5V input that needs to power the IC and GND species the ground connection. SCL and SDA stand for serial clock and serial data respectively. SDA and SCL belong to pins A4 and A5 on the Arduino Uno board. These pins are used during I²C communication protocols. SCL is the clock pin which indicates that the data transfer can occur between the master and slave, where the SDA pin is the data itself that is being transferred. The data can only be transferred if the SCL pin is low, as the SCL pin is an active low pin. SCL and SDA pins are pulled up by an external pull-up resistor [7].
The MQ-7 gas sensor only involved 3 connections: *VCC, GND, and A0.* Where VCC and GND were the power supply pins of the IC, A0 was the analog output of the sensor, which was connected to the analog input pin of the Arduino UNO.

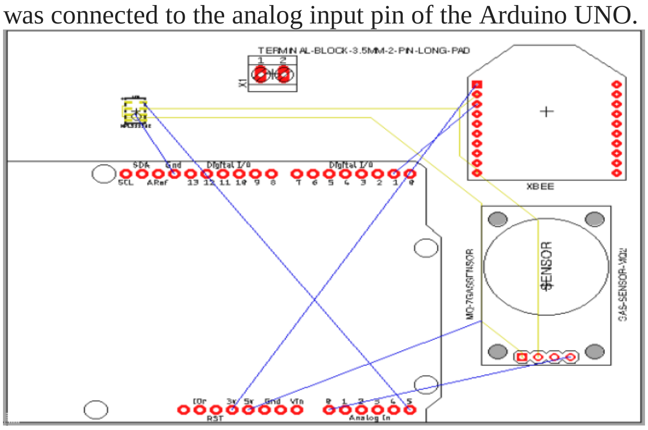

Fig. 1. PCB design board schematic of the prototype board using CADSOFT Eagle software

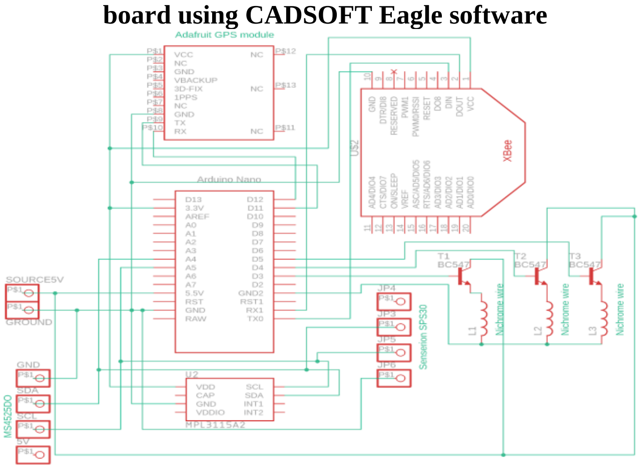

Fig. 2. PCB design schematic

C. Electronic Speed Controllers

Electronic Speed Controllers (ESC) speed controller that perform the basic job of operating the motor and changing the speed of the motor using PWM technology and providing +5V of power supply on which flight controller servos and other mounted electronics need to operate on.

An 1800 KV brushless motor that operates the drone system is a three phase motor. Each of the three wires on the brushless motor connect to the 3 wires on the ESC. On a multirotor, the black and red wires of ESC connect to the power distribution board and the other wire supplies the onboard (+5V), also known as the BEC. The functionality of the three phase motor is such that whenever the power to the brushless motor is provided, the current flowing through the wires energize the electromagnet inside the BLDC motor and pulls the rotor inside the BLDC towards it [8]. The wires are powered up in pairs so that the rotor is pulled towards the particular electromagnet, in a specific direction. Movement of the rotor is decided on how and in what particular order these pairs of wire are supplied voltage. The speed controller is responsible for this action. It also listens for the feedback from the rotor and hence it acts as an encoder machine and is able to decide the position of rotor, in order to decide which pair of wires are to be energized next.
The particular ESC we are using has the BLHeli firmware. BLHeli firmware is the most advanced firmware in the market which has faster throttle response, and the ability to change orientation of the elements like the traditional firmware [8]. BLHeli firmware operates on a higher efficiency scale with low speed motors or with small multirotor machines. BLHeli uses OneShot technology which is a synchronous connection which uses PWM and increases the update speed from 1Mhz to 8Mhz, providing us with increased stability and control over the multirotor machine.

D. Power Budgeting

Table – IV: Power requirements and calculations for probe

Component	Volage (V)	Current (mA)	Power (mW)	Power Consumption
Temperature Sensor MPL3115A2	1.95-3.6	10	33	33 mWh
Particulate Matter Sensor MQ-07	5	55	275	275 mWh
Arduino Nano	3.3	15	46.5	46.5 mWh
Xbee S2C Series	3.3	50	165	165 mWh
20mA Electronic Speed Controller	5	20	100	100 mWh
Flight Control Board (QAV-250)	11.1	-	-	-
Total Energy Required			***619.5 mWh***	

V. MECHANICAL SUBSYSTEM DESIGN

A. Design and Casing

This section describes the mechanical design and procedure of the aerial probe. The casing of the probe is 3D Printed from PLA (Polylactic Acid). Polylactic acid is a thermoplastic aliphatic polyester derived from renewable resources.

The design was modeled first using the software known as *SolidWorks*, which is a modelling computer-aided design and computer-aided engineering software published by Dassault Systèmes. Then the CAD file was converted to 3D Printer readable format by *Cura* which is an open-source 3D printer slicing application.

The casing is a 3 part assembly consisting of a base, a mounting platform, and the top cage. The base is printed with an infill density of 35% to support the other two sections of the assembly and hold them firmly while being attached to the drone from the bottom. The mounting stage has a 9V battery holder on the bottom. The battery would be used to power the microcontroller which is Arduino UNO. The printed circuit board (PCB) is to be mounted on the plane side using screws at the corner of the PCB. The dimensions of the PCB were 70mm * 90 mm making it a compact design. All joints were secured by M3 size screws.

The reason for choosing a tapered design was purely based on how it will be mounted on the drone and the size and design of the PCB. The PCB was made in a rectangular shape and had to include an Arduino UNO Board, hence the mounting section of the assembly was designed to support that with appropriate tolerances. Since the electronics required a 9V battery as the power source, a separate compartment holding a 9V battery was designed. The enclosure of the battery is a part of the mounting stage and is present at the bottom of it. The cage was initially thought of as a simple cuboid but was later chamfered from the top to reduce the material and weight. Since the probe is designed to monitor the concentration of Carbon Monoxide gas, several individual slots were made in the top cage to ensure airflow around the sensor.

The battery we will be using for our probe is a 11.1 Volt, 2200 mAh, lithium polymer battery. The total required power consumption is *619.5mWh* and the battery is supplying *11.1V* with *2200mAh*. The actual total required milliamp-hours is *55.8mAh*. Hence, the battery has sufficient amount of capability to power the probe system for a longer flight time. Since the probe is designed to monitor the concentration of Carbon Monoxide gas, several individual slots were made in the top cage to ensure airflow around the sensor.

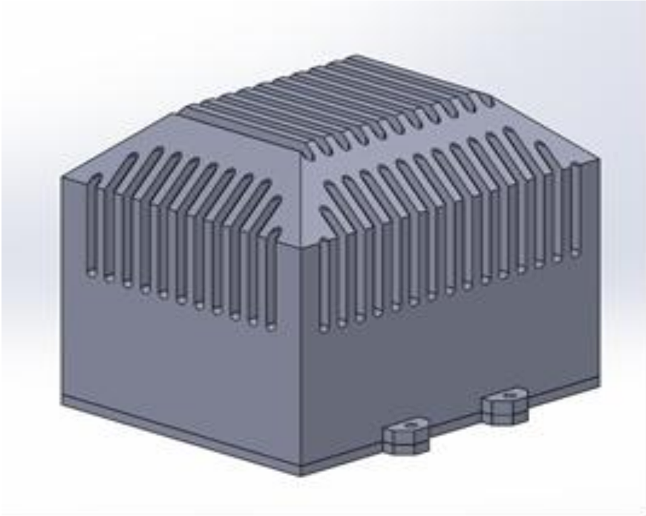

Fig. 3. Outside view of the Assembly rendered using SolidWorks

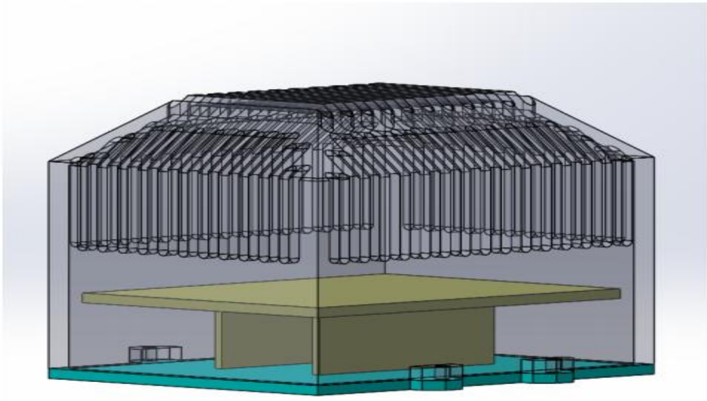

Fig. 4. See through view of the assembly along with highlighted parts: base plate, battery holder and tapered top

B. Finite Element Method Simulations

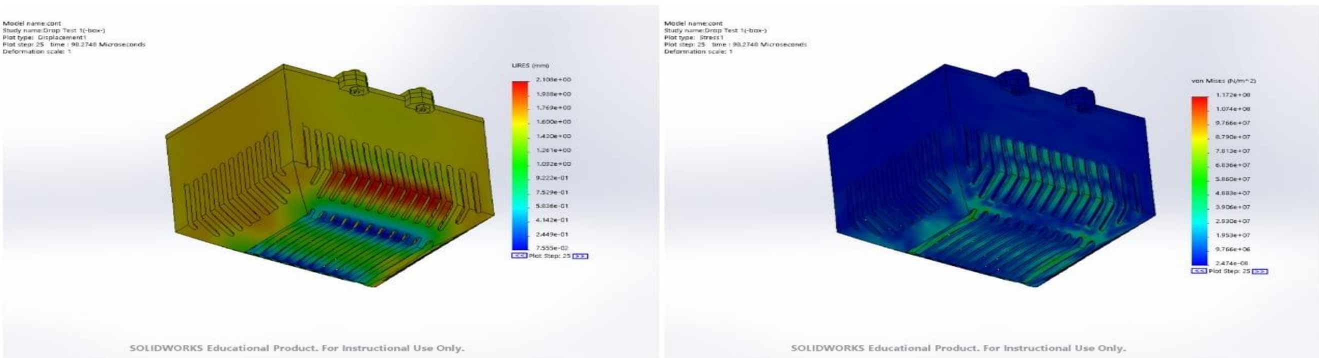

Fig. 5. SolidWorks simulation of Drop Test from a height of 25m showing the distribution of a) Deformation on the surface, b) Stress on the surface

For testing the structural integrity we did Drop test simulations and frequency simulations on Solidworks. The physical structure is made up of a plate, which is connected to the shell via nuts and bolts. A separate structure containing the battery holder and the printed circuit board mounting plate is placed inside the shell.

Drop test simulation was done assuming a critical failure at a height of 25m, from the visuals some deformation around 2mm can be seen on the sharp edges (red) on the bottom.

Since the shell is made up of PLA with 25% infill the cracks, if produced will not be able to travel further. Also a graphic showing the Stress distribution on the surface is shown. From the graphic we can conclude that there is no major stress build up on the joints.

The frequency analysis shows the distribution of amplitude on the surface when the system is vibrated at various natural frequencies. The amplitudes of deformation are shown in the figures which are colour coded accordingly (these are exaggerations produced by the software itself).

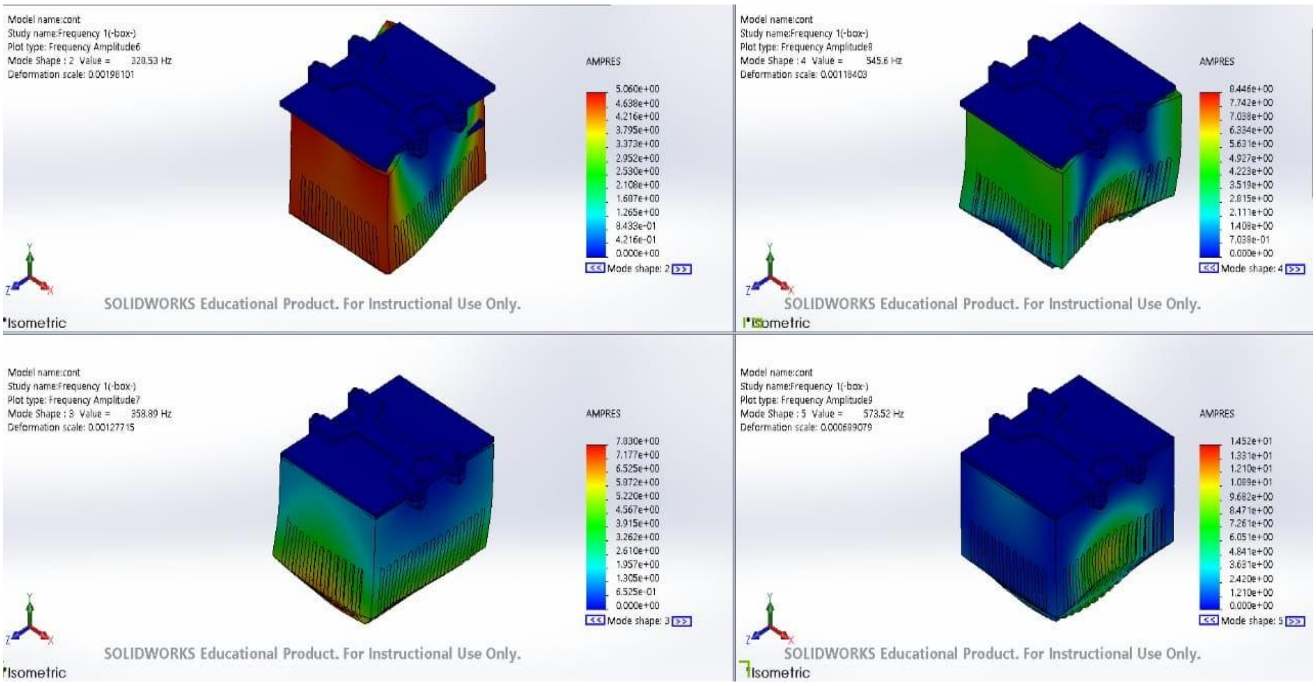

Fig. 6. SolidWorks Frequency simulation showing the amplitudes and deformation at the surface for different natural frequencies, a) for 328.53 Hz, b) 358.89 Hz, c)545.6 Hz, d) 573.52 Hz

VI. COMMUNICATION AND DATA COMPUTATION

This section describes the wireless communication process, antenna design, and the collection and processing of the data received from the aerial probe while it is deployed.

A. ZigBee Protocol and Networking

XBee devices communicate with each other, through wireless channels, sending and receiving data frames.. XBee devices cannot manipulate the sent or received data, however they can communicate with intelligent devices via the serial interface. The two types of data transfer that takes place for XBee devices to successfully communicate are [7]:

1. Wireless communication: This communication takes place between XBee modules. Modules that are supposed to work together need to be part of the same network and they must use the same radio frequency. All modules that meet these requirements can communicate wirelessly with each other.
2. Serial communication: This communication takes place between the XBee module and the intelligent device connected to it through the serial interface.

Many ZigBee / IEEE 802.15.4-based wireless data networks operate in the 2.4 GHz band, and hence often encounter interferences from the outside world. To avoid interference from WiFi networks, an IEEE 802.15.4 network can be configured to only use channels 15, 20, 25, and 26, avoiding frequencies used by the commonly used IEEE 802.11 channels 1, 6, and 11 [7].

The 2.4 GHz band provides coverage at a longer range, about 20–30 feet, but transmits data at slower speeds.

The frequency in the 5 GHz, in the 10–15 feet band, is lower since higher frequencies can not reach solid objects, including walls and floors, due to direct effect on skin depth. Higher frequencies, however, allow data to be transmitted more quickly than lower frequencies, so that the 5 GHz band allows you to upload and download files faster.

Xbee is much more reasonable; it has a much lower power consumption (25% of normal Wi-Fi), and likewise a lower data transfer rate of 250 kbps.However, the ability to create a mesh network of XBee devices ensures that every device can send and receive data by itself, serving as a node for the network [9]. In an application programming interface (API) mode, XBee radios can communicate, and in a basic serial pass-through mode. In API mode, digital or analog I / O pin statuses can be transmitted directly.

B. Loop Antenna

The probe is attached using sliders to an unmanned drone and hence requires a wireless solution to gather real-time data on the ground base-station. We used the *XBee module* at 2.4GHz as a transceiver for bi-directional data transfer where one acts as a router and other acts as coordinator.

The module was chosen solely on the basis of ease of use and general availability. Additionally, the transmission power of the module is 3.1mW (for low power application) and it accepts serial data at 9600 baud rate which acted as a perfect instrument for our probe.

A loop antenna is used along XBee to increase gain in the z-axis. It is a closed-loop of wire with a length equal to the wavelength of the RF spectrum used and helps in increasing the range of signal reception along with minimum interference due to human interaction.

Loop antenna is a simple conductor in a closed loop form. We are feeding the signal using a coaxial cable. The cable could be circular, rectangular shape or in any kind of closed loop shape. In a coaxial cable, one wire is connected to the inner conductor and another wire is connected to the outer conductor.

The loop antenna we are working on is a large loop antenna. A large loop antenna is an antenna where the length of the loop is approximately the size of the wavelength of radiation. In a large loop circular antenna the radiation pattern is as shown in the figure. Maximum gain is found in the direction of z axis or the vertical direction (line of sight). The radiation is perpendicular to the plane of the loop. It has a relatively higher radiation efficiency and radiation resistance when compared to the small loop antenna configuration. Large loops are often used for high frequency operation due to the property of higher radiation efficiency.

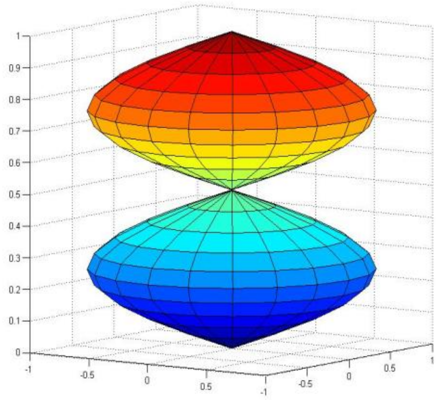

Fig. 7. Radiation pattern (dumbbell shaped) created by the loop antenna, with maximum gain in the Z- direction [10]

Fig. 8. Self- designed loop antenna made using coaxial cable. The antenna would be mounted on a steel frame at the ground station to increase range

VII. RESULT AND DISCUSSION

Our main objective for the research was to determine the accuracy of the probe designed and to establish a relationship of Carbon Monoxide contaminant concentration (in AQI levels) with respect to the local air temperature, pressure and altitude, which was derived using a real time MATLAB plot. The aerial probe was mounted on a QAV-250 chassis to collect data points regarding air pressure, temperature, altitude and Carbon Monoxide concentration in parts per million.

Fig. 9. 3D printed design of the aerial probe – external view. Switch attached on the side to power on the system

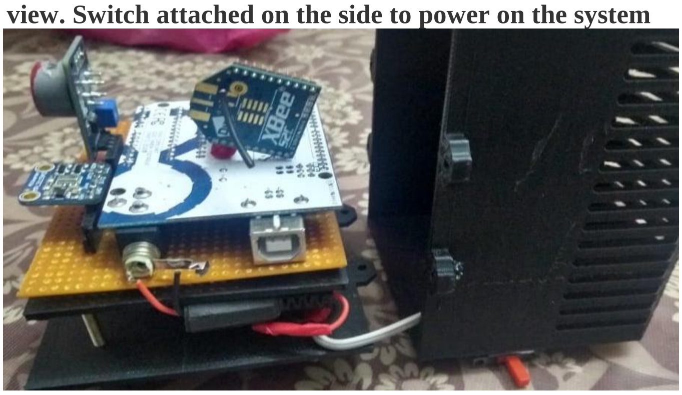

Fig. 10. Internal view of assembly, where the sensors and other electronics are mounted on a perfboard for prototyping purposes

The MATLAB plot shown below maps the collected data from the probe. The data points (coloured points) indicate air pressure (kPa) which varies from 65 kPa to 90 kPa. The total altitude the probe covered was around 70 meters with a variation of 5 ˚C in temperature. The AQI index of CO varied from a minimum of 42.1 to a maximum of 44.2. **According to the Government of India, air quality index website (airnow.gov), these levels of index lies in green zone indicating good air quality (in terms of carbon monoxide concentration only)** [11].

Additionally, in order to determine the precision of the probe, we tested the obtained values against the government generated data of the Central Pollution Control Board (CPCB). We then plotted an error graph with respect to the different times of the day when the probe was tested.

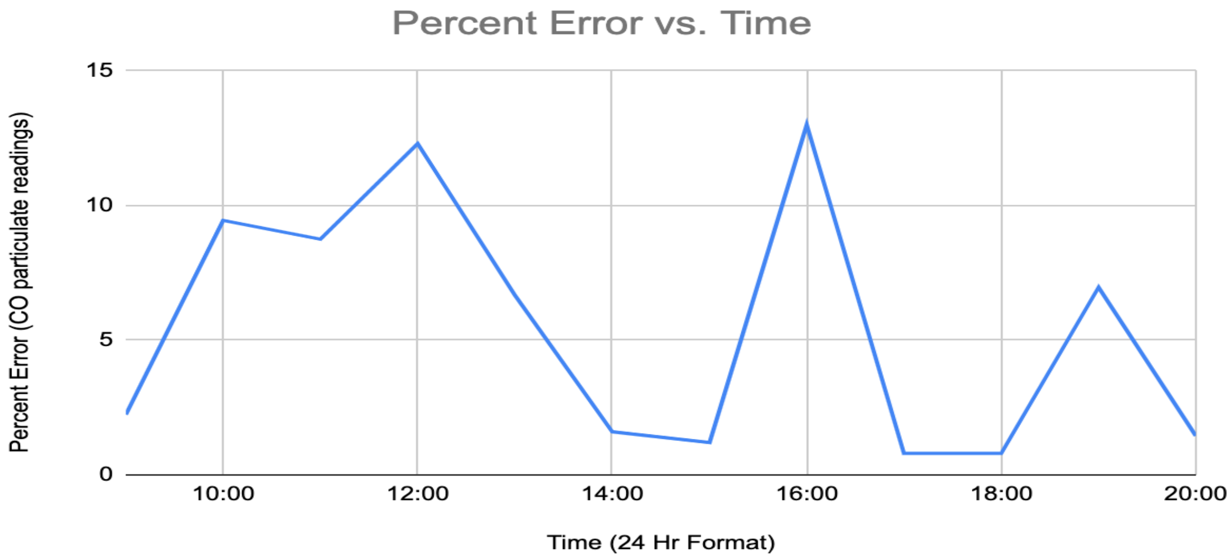

Fig. 11. Percent Error vs Time plot

Table – V : Carbon Monoxide Readings Comparisons (Central Pollution Control Board, October 13th, 2019) [6]

Carbon Monoxide Readings Comparisons (Central Pollution Control Board, October 13th, 2019)			
Time (24 Hour Format)	**CO Concentration (CPCB, Bawana , Delhi)**	**CO Concentration (From Aerial Probe)**	**Percent Error in Readings**
9:00	58	59.3	2.24
10:00	55	60.2	9.45
11:00	40	43.5	8.75
12:00	30	33.7	12.3
13:00	33	35.2	6.67
14:00	25	24.6	1.60
15:00	25	24.7	1.20
16:00	20	22.6	13
17:00	25	24.8	0.80
18:00	25	24.7	0.80
19:00	33	35.3	6.96
20:00	55	54.2	1.45

* Data from the Aerial probe collected every hour for 12 hours on October 13th, 2019.

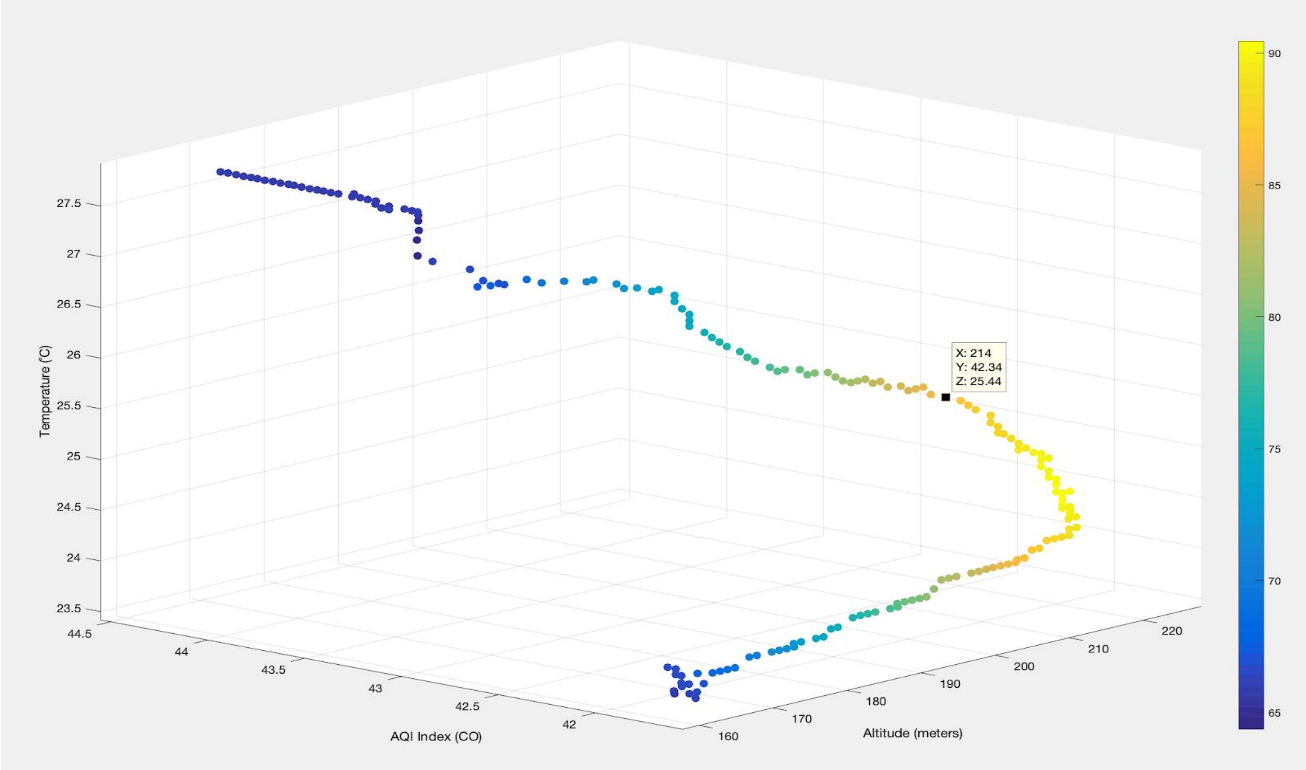

Fig. 12. 3D Plot rendered on MATLAB

VIII. APPLICATIONS OF THE DESIGN

The aerial probe designed is self-capable of data collection and computation and hence can be applied in different industries, with different sensors and actuators, to yield a wide variety of applications.

1. Agriculture Industry: Unmanned probes can be used for soil mapping, pest detection and crop prediction analysis using ML and AI algorithms. In addition, mounting it on fixed wing drones, plenty of data points can be collected to produce predictive models.
2. Calculation of pollution by vehicles can be done by studying pollution maps obtained using the probe. By studying the AQI indices of several major pollutants such as PM 2.5, PM 10 and CO, we can determine the efficiency of schemes such as odd-even which are implemented in the state of Delhi.
3. Aerial Probe can be used to determine the most habitable floor in a high rise building by calculating the average altitude having minimum concentration of air pollutants.
4. Energy Industry: Exploration of oil is currently a very hot topic in the oil and gas industry. New technologies are being introduced for exploration purposes. The aerial probe with the use of specific sensors and technology can be used for underground mapping of oil and its quantity. Similar functions can be performed on other non-renewable energy sources.

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The success and final outcome of this project required a lot of guidance and proper mentorship from a lot of people, and we are fortunate to receive all the help to help us complete the project. Hence, it is only befitting that we thank them all.

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Our next thanks go to our family and friends for always being there during the time of distress and for their untiring support. Lastly, we would like to thank God Almighty for ensuring that no unforeseen obstacles stayed for long during our course of work.

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AUTHORS PROFILE

Mr. Aditya Chaturvedi is a final year student, pursuing Electronics and Communication Engineering from Delhi Technological University, New Delhi, India. He has 3 years of experience in the field of Robotics, Automation, and product development. Along with numerous projects and achievements, he has interned at several Robotic start-ups, as a robotics and embedded engineer. In the summer of 2019, he successfully completed a 2 month internship at Schlumberger India, as an embedded hardware engineer. He aims to pursue his master's degree in the field of Electronics, with a specialization in either Robotics or VLSI design application in embedded systems.

Mr. Shaleen Jain is final year student, pursuing Electronics and Communication Engineering from Delhi Technological University, New Delhi India. He has 2 years in Control System and Instrumentation with expertise in the Oil and Gas Industry. He has successfully undergone internships at Qatargas Operating Company, Qatar and Schneider Electric and learnt about Instrumentation and Automation at an industrial scale. He wishes to apply the latest technologies towards the idea of sustainable development.

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